Total Cost Analysis in Logistics

- Practical Execution, Learning, and Teaching in Higher Education

Björn Oskarsson

Linköping Studies in Science and Technology
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in Higher Education*

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Abstract

Cost is considered a crucial factor in much decision-making in private and public organisations. Therefore, the ability to calculate total estimated costs for different alternatives is important. However, such total cost analysis is a challenging task. Providing students with the knowledge and skills needed for total cost analysis is therefore relevant in several disciplines within higher education.

Within logistics management, total cost analysis is for decades by several scholars regarded as a ‘cornerstone’, a fundamental part of the discipline. However, except for describing the basic steps and presumptions, the literature does not give much support concerning how to conduct such analyses, or which the difficulties associated with total cost analysis are. This blank space in literature is not limited to the logistics discipline, it stretches throughout many disciplines. Neither does literature cover how to teach to support students’ learning of total cost analysis.

Hence, to address the lack of research, the purpose of this thesis was formulated as follows:

To contribute to the understanding of conducting, learning, and teaching total cost analysis.

Three research questions were shaped to address each part of the purpose: conducting, learning and teaching.

RQ1 What challenges are connected to the process of conducting total cost analysis?

RQ2 What thresholds are there for learning how to conduct total cost analysis?

RQ3 How can total cost learning be supported by suitable educational methods?

The research questions are connected to each other in the sense that the challenges of conducting total cost analysis (RQ1) indicate within which areas total cost learning is difficult, and thereby where thresholds are to be investigated (RQ2). Further, knowledge about the learning thresholds is needed to discuss suitable educational activities (RQ3).

The research was conducted by a combination of literature reviews and multiple case studies at four Higher Education Institutions, where both teachers and students were approached. The findings for RQ1 were developed in an abductive procedure walking back and forth between literature and cases. A twelve-step process for total cost analysis was defined, and specific challenges associated for each of these steps. Regarding learning thresholds (RQ2), perceived difficulties with learning total cost analysis were identified in the case studies. These difficulties were then analysed against threshold characteristics available in literature. This resulted in the identification of four total cost learning thresholds. Literature on constructivist-based teaching was used to suggest teaching methods to support learning (RQ3). These types of activities proved to match the ones most appreciated by teachers and students in the studied cases.

The twelve-step process provides a more structured and holistic view of total cost analysis than previously available in the logistics literature. The description of challenges with conducting total cost analysis is novel, not only within logistics, but also generally, why this is a major contribution from this research. Aspects regarding teaching and learning connected to logistics, and to total cost analysis, are very sparsely addressed in literature, which makes the findings concerning learning thresholds and teaching methods valuable.

The findings are believed to be useful for different stakeholders. First and foremost, teachers can use the findings for designing programs, courses, and course modules which cover the important aspects of total cost analysis with help from educational activities supporting the students' learning. Second, for organisations where total cost analyses are conducted, the suggested process with its steps and associated challenges can be used to achieve better total cost analyses, and in turn more substantiated decisions. In the longer perspective, better education on total cost analysis at Higher Education Institutions will further strengthen the total cost competence in organisations, thereby improving the total cost-related decision making.

Total cost analysis is not unique for the logistics discipline. Although focus in the study has been on Higher Education Institutions providing logistics courses, the findings are to a high extent believed to be relevant also for other disciplines dealing with total cost analysis.

Sammanfattning

I såväl offentlig som privat verksamhet fattas många beslut till stor del baserat på en uppskattning av kostnaderna för de olika handlingsalternativ man väljer mellan. Att göra korrekta kostnadsuppskattningar är dock svårt. Det finns många svårigheter förknippade med så kallade totalkostnadsanalyser. Till exempel är det svårt att avgöra livslängden på olika investeringar, att förstå hur olika kostnadsposter principiellt påverkas om ett visst handlingsalternativ införs, eller att få tag i tillförlitliga indata till kostnadsberäkningarna. Otillräckliga kostnadskalkyler gör att beslut riskerar att tas på alltför lösa grunder.

Logistik, där beslut exempelvis handlar om hur man ska lägga upp distributionen av produkter till sina kunder, eller hur stort lager man ska ha av en viss produkt, är ett område där totalkostnadsanalys är centralt. Inom såväl logistik som andra områden saknas dock forskning om hur totalkostnadsanalys bör utföras, och vilka svårigheterna är med sådana analyser. Ett annat outforskat område är hur man ska utforma undervisning så att det stöttar studenters lärande av totalkostnadsanalys. För en universitetslärare som vill lära ut totalkostnadsanalys är det alltså oklart såväl vad som ska fokuseras innehållsmässigt, som hur undervisningen bör läggas upp.

Min forskning har bidragit till kunskap i dessa frågor, genom att grundligt gå igenom relevant litteratur och genom att samla in erfarenheter från lärare och studenter på fyra universitet där undervisning i totalkostnadsanalys ingår i logistikutbildningarna. En strukturerad process i tolv tydliga steg visar vad ett totalkostnadsprojekt innefattar, och till vart och ett av dessa steg lyfts ett antal utmaningar fram. Att vara medveten om och kunna hantera dessa utmaningar är viktigt för att kunna genomföra totalkostnadsanalyser som ger ett bra beslutsunderlag. Vidare har ett antal generella förmågor identifierats som viktiga för att man ska kunna lära sig totalkostnadsanalys. För att kunna förstå hur kostnaderna påverkas av olika handlingsalternativ krävs en bra insyn i den kontext, eller det system, som ska analyseras, liksom god kunskap inom det specifika ämnesområdet (logistik, vägunderhåll, vårdadministration etc.). Likaså måste man kunna anpassa beräkningsmodeller till den aktuella situationen för att kostnaderna ska bli rättvisa. Dessutom krävs ett kritiskt förhållningssätt för att ifrågasätta den data och information som samlas in som underlag för kostnadsanalysen. För att stötta lärandet av dessa förmågor, och av totalkostnadsanalys, rekommenderas undervisningsformer som engagerar och stimulerar studenterna genom att vara autentiska, dvs. så att studenterna upplever att undervisningen speglar det yrkesliv de utbildas för. Exempel på sådana undervisningsformer är praktikfall/case som bygger på verkliga erfarenheter, spel/simuleringar som illustrerar effekterna av olika beslut, och projektarbeten med företag/organisationer som uppdragsgivare.

Kunskap om totalkostnadsprocessen och dess utmaningar är användbara i alla sammanhang där totalkostnadsanalyser utförs. Genom att förhålla sig till dessa kan bättre kostnadsanalyser genomföras. Inom högre utbildning ger detta möjlighet till att bättre anpassa såväl innehåll i kurser och utbildningsprogram, som undervisningsformer, så att studenternas lärande gynnas. När studenterna kommer ut i arbetslivet kommer de att vara rustade för att genomföra bra totalkostnadsanalyser, vilket leder till att beslut kan tas på goda grunder.

Acknowledgements

Last night, I was on the threshold of hell. Today, I am within sight of my heaven.
(Brontë, 1847), *Wuthering Heights*.

When finally approaching the finishing line after quite a long time of work with a doctoral thesis, this quotation from Emily Brontë feels rather appropriate. However, despite the sacrifices needed from me and from my closest ones, all things considered I regard it a pleasant journey. Unlike most doctoral students, I have a tenure position at the university, not having to fear what will happen if I do not finish within the stipulated time. I have also had the opportunity to freely choose the topic of my thesis. That is, although I have spent about ten years on my PhD project, most of the time I have felt content and relaxed, knowing that I eventually will cross the finishing line.

Writing a doctoral thesis is truly an individual effort, but having said this, there are many people who have supported me along the road and deserve to be specifically acknowledged.

I would like to start with *my supervisors*: Maria, a colleague for over 25 years, who has supported and guided me from the start, through the licentiate thesis, and all the way to the finish line; and Jonas, who after long courtship joined in as a co-supervisor about two years ago, providing a solid ground concerning pedagogical issues. Your input has been invaluable to me, both concerning knowledge from your respective disciplines, and even more when it comes to the scientific discussions to raise the quality of the thesis.

Having worked on this project more or less on spare-time, in 2015 I was awarded a grant from *Jakobssonstiftelsen* which enabled me to work more concentrated on my research. Thank you!

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When working hard with something, it is crucial to leave the job behind and think of something else. *Karin*, thanks for supporting me, but also for requiring that I let go of work every now and then, and thanks to you, *family, and friends* for filling my life with cultural events, dinners, music, hiking, etc.

Finally, to everyone I forgot to mention but still deserve it – Thank you!

Returning to the issue of hard work, I would like to finish with another quotation, this time from the Swedish poet Bengt Cidden Andersson. As you never know what will happen next, you had better be prepared to be flexible:

*“Noone can say
we didn’t do good days of work.
God will reward us
with a trip to paradise.
If closed for the season
Öland Animal Park will do.”*

(Andersson, 1994), *Punken är död – leve tvåans buss*, my translation

Linköping, October 2019

Björn Oskarsson

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1 Introduction

The topic of this thesis stems from my long experience teaching logistics at university. Among the different topics covered in my teaching, total cost analysis has been present in various forms. I have also noticed that the seemingly easy task of comparing costs for different alternatives proves to be difficult for many students. Therefore, understanding how best to help the students overcome these difficulties is close to my heart.

To apply suitable educational activities to stimulate learning of essential knowledge, a teacher must know what the essential aspects are. How to teach is closely related to what to teach. Although total cost analysis is regarded important within the logistics discipline (as is elaborated on later in this chapter), in my role as a teacher I have found that beyond describing the basic steps and preconditions, the literature does not provide much support concerning how to conduct such analyses. In addition, the literature does not provide much guidance on how to teach total cost analysis. Hence, there is a lack of research concerning ‘what’ as well as ‘how’ related to teaching total cost analysis.

This research is positioned in the intersection between the discipline of logistics management and higher education. The aim with the thesis is to explore the challenges and difficulties associated with conducting, learning, and teaching total cost analysis, and thereby contribute to the understanding of these issues which ultimately can lead to better cost analyses and better decisions made. These issues will be further discussed and motivated in this introductory chapter, which starts with a brief description of logistics in section 1.1. Next, the importance of costs in decision-making is addressed in 1.2, followed by section 1.3, which specifically focuses on total cost analysis, including a historical overview. In 1.4, total cost education is in focus as relevant educational theories are presented and connected to total cost analysis. Based on the previous sections, the purpose and research questions are defined in 1.5. Finally, in section 1.6 an outline of the thesis is presented.

1.1 Logistics – a broad field with increasing complexity

Being quite a broad discipline rooted in areas such as industrial engineering, business administration, and operations research, logistics can be defined in different ways, see e.g. Mentzer et al. (2008). This thesis leans on one of the most frequently used definitions, provided by The Council of Supply Chain Professionals (CSCMP):

“Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements.”
(CSCMP, 2019)

In essence, this definition covers the planning and control of material flows to meet customer requirements in a cost-effective manner. This is a strategic area in the sense that good logistics management is a prerequisite for competitiveness in many industries and often high-level structural and strategic decisions lay the foundation for efficient and effective logistics.

Logistics is boundary-spanning, crossing traditional functional borders in organizations, and therefore associated with a certain degree of complexity, which has been growing over the years due to, for example, a greater emphasis on collaboration with supply chain partners (Esper et al., 2007; Frankel et al., 2008), globalization (Christopher, 2016; Coyle et al., 2017), sustainability (Singhry, 2015; Patel and Desai, 2018), and digitalisation (Singh Srai et al., 2017; Pirvulescu and Enevoldsen, 2019). This increasing complexity means that larger systems must be considered when modelling and analysing logistics. As CSCMP's definition indicates, an essential part of logistics decision-making relates to the trade-off between costs and service. Although costs are just one part of a larger picture, this thesis focuses on the costs as cost analysis in itself is a complex task.

1.2 Costs are crucial in much decision-making

Cost is an important aspect to consider not only in logistics, but also in decision making in all parts of society, for example, when a state sets the ambitions for social welfare, when a company selects a supplier for a certain product, or when a city considers whether to perform waste disposal activities themselves or to outsource to a private actor. To make as good decisions as possible, decision makers must be supported by thorough and adequate decision support. Focusing on the costs, the *total* cost associated with the alternatives at stake is to be estimated. Otherwise wrong conclusions might be drawn, When for example selecting a supplier, only considering the price paid to the supplier would probably be insufficient as other costs might differ between the potential suppliers, e.g. the cost for transports (if the suppliers are situated far from each other) or the cost for quality inspection (in case we do not trust their product quality to the same degree).

Basically, this is a very easy task. Find out which costs will be affected by the decision, calculate or estimate costs for the alternatives, and choose the alternative with lowest total cost (if we simplify the decision to be taken based on costs only). However, understanding and handling these trade-offs between costs is not easy, and there are also other aspects making the practical application of total cost analysis difficult even though the concept at first glance looks rather simple (LeKashman and Stolle, 1965). Some examples are presented below of shortcomings in total cost analyses.

- The cost budget for resurfacing a road bridge between Maine and New Hampshire, US, turned out to be wrong, mainly because the costs for the necessary arrangements to keep traffic running during the three-year project were significantly underestimated. After more detailed calculations, the budget was increased by \$17 million, approx. 50% above the initial budget. (McGuire, 2019)

- A European car manufacturer decided to switch supplier for seat covers from a European to a Brazilian firm. The decision, however, did not consider that no local company could provide the supplier with fabrics of sufficient quality for the seats. Therefore, the fabrics had to be shipped from Europe to Brazil, at a considerable cost and with unacceptable lead times. In the end, the car manufacturer returned to the old supplier. (Holweg et al., 2011)
- When switching to low cost country sourcing, goods are often ordered and delivered in larger quantities. This gives rise to increased costs for storing the goods; for high-value products, this cost can be substantial. Nevertheless, many companies tend to neglect these costs in their total cost analyses. What seems like a good outsourcing decision might in reality not give the predicted cost savings. (Kumar et al., 2010)
- In the early 1990s, there was a resistance to vaccinating against HIB (a certain kind of influenza) in some Swedish health care regions as this would lead to increased costs for the regions. However, taking a wider perspective, such a vaccination program would be cost effective, compared to the societal costs for a HIB epidemic. (Ramsberg and Ekelund, 2011)

These examples show that a total cost analysis might be insufficient because of a poor understanding of how decisions affect specific activities (the road bridge and seat cover examples), as an essential cost factor was disregarded (the low cost country sourcing example), or due to an overly narrow perspective (the vaccination example). In addition, all these examples illustrate a level of uncertainty involved when trying to predict future costs.

Some of these examples deal with large projects, and consequently large costs. However, even for decisions concerning smaller costs, over- or underestimations of costs can lead to poor decisions, which results in decreased profit or poor use of resources. Hence, more reliable total cost analysis is important to support decision-making in various situations.

1.3 Total cost analysis – an overview

Different strands of total cost analysis, henceforth referred to as TCA, have evolved within various disciplines. This development is briefly presented in section 1.3.1. Several authors emphasize the strong connection between TCA and systems thinking, which is the focus of 1.3.2. Finally, 1.3.3 addresses the lack of research regarding challenges with conducting TCA.

1.3.1 Historical overview

Scherer (2001) provides an early example of total cost considerations¹: an early 19th century publisher of sheet music compared two printing methods with respect to fixed and variable costs. Ford W. Harris, an American production engineer, was another pioneer regarding total costs. Harris invented the (for logisticians and operations analysts) well-known square-root or Wilson² formula used to calculate the optimal order quantity (e.g., in production). That is, the Wilson formula calculates the order quantity that corresponds to the lowest total cost for ordering and stock keeping. This formula is still frequently used, and Harris' (1913) description of the underlying cost considerations remains valid.

Logistics and marketing

Although Harris' formula certainly is relevant for logisticians, it was originally used within manufacturing. Logistics scholars often refer to a book from 1956 by Lewis, Culliton, and Steele³ as an important starting point for the total cost approach within logistics (Poist, 1974; Bowersox et al., 2013). In this book, the authors showed a case where high-priced air freights from an overall perspective rendered costs lower than cheaper freight alternatives because costs for inventory carrying and warehousing could be significantly decreased.⁴

Lewis et al. evaluated the alternatives for distribution of goods, a central issue within logistics. However, long before Lewis et al., marketing scholars had debated the role of total costs for distribution of goods. Greer (1931) stated that companies so far had been focusing production costs and concluded that the time had come to focus on distribution (in which he included sales, marketing, and delivery.⁵). He argued that distribution costs are more problematic than production costs because it is difficult to allocate parts of joint costs to specific products in a fair manner, a view shared by Greer's successors such as Walker (1946) and Sevin (1947). For some years, the same issues were discussed by

¹ According to Scherer, who has investigated previous economic literature, this is *the* earliest account of an examination of total costs.

² R. H. Wilson was an early adopter of this formula and used it frequently in his role as a consultant (Wikipedia, 2019).

³ Lewis, H, Culliton, J. and Steele, J. (1956): *The Role of Air Freight in Physical Distribution*, Harvard University Press.

⁴ Although in retrospect this book is regarded as an important milestone for TCA, at the time of its publication some readers were less enthusiastic. In a review of the book, Heye (1957) wrote that the report's value is 'very limited' and that it must be 'disappointing to the [...] organization who financed it'.

⁵ Walker (1946), commenting on the confused terminology in the marketing discipline's debate, stated that much of the costs dealt with rather should be labelled 'marketing costs'. However, the physical distribution is also part of these authors' discussions.

marketing scholars (AMA, 1957; Schaefer, 1958; Phillips, 1964); however, since these discussions, total cost issues do not seem to be debated within the marketing discipline.

However, in the 1960's, distribution cost is yet again addressed from a logistics perspective, when LeKashman and Stolle (1965), using industrial cases, clearly showed that considering total costs will lead to other conclusions than if each cost is viewed separately. LeKashman and Stolle introduced the customer service aspect into the cost model, since stock-outs, excess delivery times, and other service deficiencies will lead to lost sales. They stated that the effects of customer service should be considered part of the real cost of distribution, although this is hard to measure. Based on the dissertation by Lambert (1975) on a total cost approach to inventory decisions, Stock and Lambert (1982) presented a total cost model which stresses the important connection between customer service and logistics costs as changes in logistics systems affect costs as well as the level of customer service, which ultimately influences an organization's revenue. This shift of focus from total cost to total profit was argued for already by Poist (1974). The shift to a profit focus does not mean that TCA has decreased in importance. Rather, it puts logistics costs in a larger perspective, adding levels of complexity since costs in themselves are not enough to study.

Whether decisions concern operative matters (e.g., appropriate safety stock levels) or more strategic ones (e.g., where to establish a new distribution terminal), the different costs associated with the alternatives at hand must be evaluated. The importance of a total cost perspective is clearly stated by many logistics scholars, here illustrated with two examples:

"The total cost approach is one of the fundamental concepts underlying business logistics." (Poist, 1974), p. 14

"The total cost concept is the key to effectively managing logistics processes." (Grant et al., 2006), p. 11

Purchasing and outsourcing

In parallel to the development of total cost awareness within logistics, a similar development was seen within purchasing, to start with connected to outsourcing issues. While discussing make-or-buy decisions, Paton (1966) opposed the widespread impression that internal costs for making are easy to calculate and that costs for buying more or less are limited to the purchasing price. Although being rather price-focused, England (1967) addressed the need for the purchaser to estimate the supplier's costs (a difficult task according to England) to determine a reasonable purchasing price. Dale and Cunningham (1984) stressed the complexity of cost calculations in make-or-buy decisions, as well as the need to consider other factors together with costs. In the 1990s, the concept *Total Cost of Ownership (TCO)*, relying a great deal on Ellram's work, was established, see e.g. Ellram (1993) and Ellram and Maltz (1995). According to Johnsson

and Flynn (2015), TCO attempts to identify the actual cost for a supply decision alternative. For example, it is used for supplier selection and for outsourcing (make-or-buy) decisions by including all costs associated with the respective alternatives (i.e., in-house manufacturing and buying from an external source).

Another term also referring to the total costs related to purchasing is *Landed cost*, which according to Young et al. (2009) considers all costs incurred until the products are available to the consumer or end user. In comparison, TCO stretches further than Landed cost, since it encompasses all costs during the complete ownership of a product (which can extend long after the product is made available). Pumpe and Vallée (2017) argue that landed cost, being a bit less comprehensive, is easier to use than TCO, which primarily is used for capital expenditures, fixed assets, etc. with long life cycles. The issue of life cycles creates a bridge between TCO and the next sub-section.

Life Cycle Costing

Lichtenvort et al. (2008) state that *Life Cycle Costing, LCC*, gained real attention in the 1970s, although it was addressed as early as in the 1930s for public procurement in the US. Life cycle costs include:

“... all the anticipated costs associated with a project or a program throughout its life. They are the sum total of the direct, indirect, recurring, nonrecurring, and other related costs incurred, or estimated to be incurred, in design, research and development (R&D), investment, operations, maintenance, retirement, and other support over its life cycle (i.e. its anticipated useful life span).” (Farr, 2011) p. 1-2

According to Lichtenvort et al. (2008) and Korpi and Ala-Risku (2008), LCC and TCO are very similar as they both focus on life cycle costs. However, TCO is performed from an acquisition perspective, so the aspects considered in TCO are therefore often less comprehensive as in the LCC approach.

Lichtenvort et al. (2008) identify three LCC approaches: Conventional LCC, Environmental LCC, and Societal LCC. Conventional LCC includes the costs covered by the main producer or user in the product life cycle, with a focus on real and internal costs. Environmental LCC includes costs of other actors in the product life cycle and monetizes external aspects. Societal LCC includes all costs covered by anyone in society. Moving from conventional to environmental to societal LCC, one finds that the complexity increases because additional hard-to-monetize aspects are added. Typically, LCC considers future costs so the time-value of money must be accounted for, further adding complexity to the calculations (Korpi and Ala-Risku, 2008; Okano, 2001).

Cost estimation

When preparing large investments with a lifetime that extends long into the future (e.g., defence programs or infrastructure projects), estimating future costs is very difficult. Although this relates strongly to Life Cycle Costing, there is also a specific field called *Cost Estimation*. Mislick and Nussbaum (2015) define Cost Estimation as follows⁶:

“Cost estimating is the process of collecting and analysing historical data and applying quantitative models, techniques, tools, and databases in order to predict an estimate of the future costs of an item, product, program or task ... based on information available at the time” (p. 11, emphasis in original)

Due to the complexity of the cost estimation process, Hatamleh et al. (2018) stress that the belief in an *accurate* estimate is chimeric. Rather, as Mislick and Nussbaum (2015) state, the characteristics of a good cost estimate is that it is complete, reasonable, credible, and analytically defensible.

Various labelling of total cost analysis

As shown in the previous sections, TCA might have different labels, depending on, for example, in which discipline the issue is discussed. There are other examples than those described above such as *Cost of Poor Quality* (Mahmood et al., 2014) and *Total Cost of Care* (Green et al., 2017). The essence is the same, however, in all variants, i.e. to include all relevant costs in order to estimate *total* cost. However, the ambition level in ‘total’ can differ between different applications, as illustrated by the three LCC approaches described in the previous section. The ambition level is tightly connected to how the studied system is defined, which leads into systems thinking, the focus of the next section.

1.3.2 Systems thinking vs. total cost analysis

Systems thinking is by many regarded as a central foundation in logistics (Novack et al., 1993; Stock et al., 1998; Arlbjørn and Halldórsson, 2002). Several authors from different disciplines also highlight systems thinking in connection to TCA. However, before examining this connection, a brief introduction is given to what is meant by systems thinking.⁷

⁶ For this definition they refer to www.iceaaonline.com/?s=glossary.

⁷ Systems thinking is one of many ‘systems terms’ used in literature without clear distinctions between them, as elaborated by Lindskog (2012). Although the cited authors might have used various terms, I have chosen to consequently (except in quotations) use the term *systems thinking*, since my impression is that this term is most commonly used within the logistics discipline.

What systems thinking is

A system can be defined in several ways. Two examples are presented here:

"A system is a set of parts coordinated to accomplish a set of goals."
(Churchman, 1968) p. 29

"A system is a set of components and the relations between them."
(Arbner and Bjerke, 1994) p. 127 (translated from Swedish)

Embedded in both these definitions is the basic idea that any system can be divided into sub-systems that interact with each other. Another important cornerstone is that because of synergies (positive or negative), the total system's performance often differs from the sum of its sub-systems' performances, i.e., optimising each sub-system might lead to a sub-optimisation of the total system (Quade, 1985; Christopher, 1972). In an organisational setting, this can be exemplified by a purchasing situation. The purchasing department (one of the sub-systems) might minimize its cost for a certain product by choosing the supplier with the lowest price. However, this cost cutting might lead to increased costs for transportation, quality control, etc. (i.e., other sub-systems) and therefore not lead to the lowest total cost for the organisation (i.e., the total system). Therefore, it is crucial to define the system (i.e., to set the boundaries between what is included in the system and what is not), to make it represent reality in a good way (Ulrich, 1987).

Churchman (1968) as well as Miser and Quade (1988) argue that modelling the system is an urgent part of systems thinking to give structure to problems, to divide them into modules etc. In a logistics setting modelling might for example mean defining the system boundaries and describing system components, input and output. As models cannot fully reflect reality, it is crucial that selected models are adapted to the specific situation and that they highlight relevant aspects of reality in a good way (Miser and Quade, 1988).

Senge (2006) also discusses the whole and the parts. He stresses that a shift in thinking is required to see the whole instead of the parts (since the whole most often is not equal to the sum of the parts) and to understand how the parts influence each other within the whole.

Systems thinking in the total cost literature

Within the logistics discipline, Williamson et al. (1990) discuss the entrance of systems thinking into distribution:

"With the application of systems thinking came development of the total cost concept." (p. 65)

Another example is Abrahamsson and Aronsson (1999), who claim that understanding the system is crucial since the structure of the system in itself is the main cost driver. Using a case study on distribution structures, they developed a total cost model built on the idea of systems thinking theory. Waller et al. (2015) explain Walmart's business success with the combination of total cost analysis and system redesign. They state that:

"... systems thinking is at the core of the total cost concept of logistics."
(p. 303)

According to Lichtenvort et al. (2008), Life Cycle Costing (LCC) has its roots in systems thinking, which gives structure to the LCC calculations. They also argue that:

"...only the full system perspective gives a relevant total [cost] comparable to the total environmental impacts." (p. 10)

Nato (2007) claims that systems thinking is suitable for LCC because of the large amount of cost drivers and long-time perspectives. They, in line with other authors (Farr, 2011; IEC, 2017), also highlight the necessity of dividing complex systems into sub-systems.

TCA and systems thinking are combined also in other disciplines. For example, Fisher (1956) discusses weapon-systems in an early account of combining systems thinking and TCA and within healthcare Menezes and Chibana (2015) analyse total treatment costs from a systems thinking perspective.

1.3.3 The challenges with conducting total cost analysis are yet to be discovered

The increasing complexity and widened systems mentioned in section 1.1 add to the difficulties of total cost considerations within logistics. In an editorial in the Journal of Business Logistics, Waller and Fawcett (2012) conclude that despite the fact that total cost analysis for many years has been highlighted as a central aspect of logistics, research about the concept as such is scarce. They write that:

"Our fundamental concept, the total logistics cost concept, is ripe for theory development and testing." (p. 1)

Waller and Fawcett encourage researchers to conduct research on TCA and give a number of suggestions on what to focus. Some of the issues they mention relate to difficulties associated with conducting TCA (e.g., cost measurement and cost modelling, aspects also brought up in the examples in 1.2). Waller and Fawcett (2012) are not the only ones who mention difficulties associated with TCA. Other authors address problems such as defining the scope or system to consider in the analysis (Voorhees and Sharp, 1978; Cavinato, 1992) or predicting the cost effect of suggested actions (Poist, 1974). However, to the best of my knowledge, no one has taken a holistic view of the challenges associated with conducting total cost analysis, neither within logistics nor within other contexts.

The ability to perform TCA in a good way is desirable for organisations as well as society, since good TCA will enable better decisions and better use of resources. A first step towards this is to understand the challenges associated with TCA, because without understanding the challenges it will be impossible to avoid them. These challenges are not described in the literature, i.e., research on this issue is lacking. Therefore, identifying the challenges associated with conducting TCA is needed, a call to action that is in line with Waller and Fawcett's (2012) plea for more research.

1.4 Teaching and learning total cost analysis

One important vehicle for improving performance in organisations and society is the education of students at Higher Education Institutions (HEIs), as students will act as 'messengers of knowledge' when they enter the work force. Teaching this knowledge requires that appropriate aspects are included in the curricula, and that educational methods are used that support students' learning of these aspects.

Given that there are several challenges associated with conducting TCA, does this mean that it is also difficult to learn how to make such analyses? Over the years, I and my fellow teachers have witnessed that students seem to have difficulties learning how to perform TCA. In addition, faculty from other HEIs also agree that these difficulties exist. Therefore, a more precise understanding of these difficulties will help teachers select appropriate pedagogical methods for teaching TCA.

Since the logistics discipline regards TCA as important, it could be assumed that the issue is central in many logistics programs. However, according to Oskarsson (2014), research on logistics education does not provide evidence that this is the case. The literature on logistics education over the last 30 years only provides three articles that deal with TCA (Tyworth and Grenoble, 1991; Ashenbaum, 2008; Porporato, 2016). However, none of these articles focus on TCA per se as they use TCA only to illustrate other issues.

As there is a lack of literature concerning teaching and learning specifically addressing TCA, general theories on these areas are described in the following sections.

1.4.1 The interface between teaching and learning

Although teaching refers to teacher activities and learning to what the learner experiences, the two are closely related. In this section, this relationship is discussed based on theories concerning the pedagogical triangle, constructive alignment, and pedagogical content knowledge.

The pedagogical triangle

The pedagogical (or didactical) triangle is a commonly used model that shows how teaching, learning, and subject-matter are interrelated (Bertrand, 1994; Bränberg et al., 2013; Håkansson and Sundberg, 2012). Although some alternative denotations of the corners (angles) exist, the pedagogical triangle basically shows that the subject-matter (or knowledge) is connected to the teacher (who possesses knowledge) and the student/learner (who is supposed to learn) and that there is a direct relationship between teacher and student. To stress the interrelatedness between the three components, Bertrand and Houssaye (1999) use the term ‘pedagogical interactions’, as displayed in Figure 1.

Figure 1. The pedagogical triangle – inspired by Momanu (2012)

Constructive alignment

Based on the pedagogical triangle, Pettersen (2008) discusses some relational aspects that explain the important interplay between the actors and the content. In Figure 2, these relational aspects are included in the triangle model. The teacher applies certain strategies and methods to teach the subject in order to make the desired knowledge accessible for the students. The students apply working methods and use learning strategies to learn what they consider to be the important knowledge. Eventually, the teacher assesses to what extent students have gained the desired knowledge. Pettersen (2008) argues that teaching methods cannot be chosen independent from which learning strategies students apply. Teaching approaches and learning approaches affect one another. Likewise, how students are assessed affects what learning strategies students apply, why the forms of assessment should be mirrored in the teaching. What is embedded here is a kind of alignment between teaching, learning, and assessment.

Figure 2. *Pedagogical interactions, a relational model - inspired by Pettersen (2008)*

The close connection between teaching and learning is highlighted also by Biggs (2003). Introducing the term ‘constructive alignment’, he describes the importance of tightly connecting expected learning outcomes, educational activities, and assessment, as shown in Figure 3.

Figure 3. *Constructive alignment*

Biggs (2003) stresses that the expected learning outcomes should be carefully formulated, and that assessment and teaching should be based on the expected learning outcomes. He further claims that students are very sensitive to the type of assessments used. Students choose learning approaches that match how they will be assessed (i.e., the type of assessment). Therefore, the assessment should clearly ask students to demonstrate their understanding of the expected learning outcomes. This way, assessment directs the students into suitable learning approaches, which should guide the teachers to use corresponding teaching strategies.

Biggs’ and Pettersen’s models are rather similar although they have a slightly different focus. The ‘Expected learning outcomes’ in Biggs’ model is an articulation of ‘Knowledge’ in Pettersen’s model. Biggs has chosen to treat teaching and learning as an integrated element rather than as two separate ones. In addition, he considers pedagogical interactions to be central in the constructive alignment between the three elements in his model. Irrespective of these different labels, I regard Biggs (2003) and Pettersen (2008) to share the same principal ideas.

The intimate relationship between teaching and learning leads us to the next session, which deals with pedagogical content knowledge.

Pedagogical content knowledge

The concept of *pedagogical content knowledge*, PCK, was introduced by Shulman (1986), arguing that teachers not only need content-specific knowledge and general pedagogical knowledge, but also need a specific kind of content knowledge that enables explanation of the subject to others. In his subsequent work, Shulman (1987) specified several PCK components. Many authors – e.g., Fernandez-Balboa and Stiehl (1995) and Veal and MaKinster (1999) – have over the years discussed these components and suggested additional ones. The components listed below are selected to reflect the ones dominating the discussion in literature.

- *Content/subject-matter knowledge*: Since subject-matters are constantly evolving, teachers must keep up-to-date with the subject (Fernandez-Balboa and Stiehl, 1995). Shulman (1986) argues that a teacher must not only understand something as such, but also why this something is this way and why certain topics are central and others peripheral.
- *Knowledge about instructional strategies*: Included here are more directly instructional aspects as well as motivational activities and organization of learning activities (Fernandez-Balboa and Stiehl, 1995).
- *Knowledge about assessment*: This component includes according to Goodnough (2006) and Park and Oliver (2008) knowledge about which aspects of students' learning are important to assess, as well as which methods (instruments, activities etc.) are appropriate to use to assess the learning outcomes.
- *Curricular knowledge*: To relate the content of a given course to topics and issues handled in other courses, the teacher should have knowledge about preceding and following courses in the same subject area. (Shulman, 1986; Goodnough, 2006; Park and Oliver, 2008).
- *Knowledge about students' understanding*: Teaching should preferably be influenced by the student group. Among the aspects to consider are their study motivation and interest in the subject (Park and Oliver, 2008; Fernandez-Balboa and Stiehl, 1995), and their pre-knowledge about the subject (Goodnough, 2006; Fernandez-Balboa and Stiehl, 1995).
- *Knowledge about the learning context*: According to Shulman (1987) cultural, governance, and funding aspects influence class sizes, resources to use on instructional material, and the amount of time that can be spent on different educational activities.
- *Knowledge about one's teaching orientation and purposes*: Park and Oliver (2008) and Goodnough (2006) argue that the teachers' beliefs about their teaching purposes and goals guide their choice of instructional strategies and materials, thereby influencing their PCK.

Shulman (1986) argues that PCK exists at the intersection between content- and pedagogical knowledge. However, the last two components (*knowledge about the learning context* and *knowledge about one's teaching orientation and purposes*) contain aspects that do not belong to either of the two. Therefore, PCK could be seen as an extended intersection between content- and pedagogical knowledge, as illustrated in Figure 4.

Figure 4. Components of pedagogical content knowledge (Oskarsson, 2014), p. 27

Two of the PCK components: *knowledge about instructional strategies* and *knowledge about assessment*, strongly correlate to the ideas of constructive alignment presented in the previous section. They also relate to the issue of selecting appropriate educational approaches, which is discussed in a coming sub-section. Another crucial component is *knowledge about students' understanding*. Fernandez-Balboa and Stiehl (1995), Park and Oliver (2008), and Alonzo et al. (2012) all stress the importance of finding out what the students consider to be difficult, an issue that is closely related to threshold concepts which is addressed in the next sub-section.

Threshold concepts connected to total cost analysis

In my licentiate thesis (Oskarsson, 2014), I elaborated on threshold concepts in logistics education. A threshold can be described as something preventing a student from learning something; to cross such a threshold requires a kind of transformation in the student's thinking. Meyer and Land (2003), who introduced the term, describe the crossing of a threshold as something that:

"...can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding". (p. 1)

Identification of thresholds can be a key to understanding what students regard as troublesome and therefore pinpoints where to focus efforts to improve educational activities. Although it is not an easy task to identify and describe thresholds, a number of

characteristics have been suggested (Meyer and Land, 2003; Baillie et al., 2013), e.g. that they are⁸:

- *Transformative* – Crossing a threshold leads to a significant shift in how a subject matter is viewed.
- *Irreversible* – Once understood, the concept cannot become ‘not-understood’.
- *Troublesome* – Students often have difficulties in overcoming the thresholds, because they are difficult, challenging and sometimes counter-intuitive.

As total cost analysis is an important skill for logisticians, it is desired that students learn how to conduct TCA during their education. In order to be able to support students in their learning, teachers need to understand what is troublesome and what is to be considered thresholds for learning TCA. However, to the best of my knowledge, no research has investigated thresholds connected to neither TCA nor to logistics in general. Hence, this is an area where more knowledge is desired.

Activities supporting learning of total cost analysis

As described above, one part of PCK is knowledge about instructional strategies to motivate students and create realistic connections with their future work. Thus, teachers should select suitable educational activities that support the students’ learning. A general recommendation by e.g. Biggs (2003) is to use constructivist-based approaches, which encourage students to be active and engaged. These approaches are described with different labels in the literature, such as active learning (Bonwell and Eison, 1991), experiential learning (Kolb and Kolb, 2005), and authentic learning (Stein et al., 2004).⁹

To relate these PCK aspects to TCA, the teacher should have content knowledge (the challenges associated with conducting TCA) and know which the thresholds are (the major difficulties with learning TCA). Content- and threshold knowledge will help a teacher choose suitable teaching activities and assessment methods that support students’ learning of TCA. However, research in this area is scarce. Only a few articles concern the interface between TCA and education (see section 2.4.2 for details), and none of these focuses on teaching aspects. Clearly, more directed research is needed.

1.5 Purpose and research questions

As described in the previous sections, the ability to conduct total cost analysis is important to make good decisions. Conducting such analyses are associated with many challenges, but these challenges have not been clearly examined. Furthermore, students seem to have difficulties learning TCA. Again, studies have yet to identify the major difficulties or

⁸ Threshold concepts are more thoroughly addressed in section 5.1.

⁹ Constructivist-based approaches are more thoroughly addressed in section 5.2.

thresholds associated with learning TCA as well as which educational activities support the learning of TCA. Drawing on this discussion, the purpose of this thesis is:

To contribute to the understanding of conducting, learning, and teaching total cost analysis.

There are three activities in the purpose: conducting, learning, and teaching. Although there is a strong connection between these, specific research questions are formed for each one of them.

When conducting the steps or activities that belong to the process of total cost analysis, different challenges may be encountered. Awareness of these challenges is important for the ability to adequately conduct TCA, but existing research is limited concerning these challenges. The need for a more holistic approach to identify these challenges is therefore addressed in the first research question:

RQ1 What challenges are connected to the process of conducting total cost analysis?

Although many things can be difficult to learn, it is crucial to identify the most important ones, the thresholds that students must overcome. Knowing these thresholds is important when designing educational activities. As research has not explored thresholds associated with learning TCA, this issue is addressed in the second research question:

RQ2 What thresholds are there for learning how to conduct total cost analysis?

To support the learning of TCA, teachers should use appropriate educational methods – i.e., methods concerning teaching and assessment that stimulate students' learning. The literature has not investigated which educational methods are suitable for teaching TCA, why this is yet to be examined. However, because learning is affected by several aspects such as the students' characteristics and prior experiences, see e.g. Entwistle (2009), one should not expect to find specific methods that always are to be used. Rather, suitable methods on a more generic level can be suggested that presumably will support total cost learning.

RQ3 How can total cost learning be supported by appropriate educational methods?

The research questions are connected to each other as the challenges of conducting TCA (RQ1) indicate which areas of TCA are difficult for students to learn and thereby where thresholds need to be investigated (RQ2). Furthermore, identifying learning thresholds will help teachers design appropriate educational activities (RQ3).

Applying appropriate educational activities is supposed to support total cost learning. Overcoming the identified thresholds will enable handling the challenges in a good way,

which gives support to conducting the different steps in a total cost analysis process, as shown in Figure 5.

RQ1 Conducting		RQ2 Learning		RQ3 Teaching
Steps	Challenges	Difficulties	Thresholds	Educ. Methods
A	1	a	-	I
	2	b	*	II
B	3	-	-	III
	4	-	-	-
-	-	-	*	-
-	-	-	-	-

Figure 5. Connections between the research questions

1.6 Outline of the thesis

The thesis is structured as follows, see also Figure 6. Chapter 2 presents the research design, as well as the methods used for data collection and analysis. In chapter 3, the cases selected for the study are briefly presented. Chapters 4-6 are dedicated to the three research questions: collected data are presented, together with additional theoretical support, and each RQ is answered. In chapter 7, the study is analysed from a holistic perspective, focusing connections between the RQs. Chapter 8 summarizes the findings, discusses the quality of the study, and suggests ideas for future research. Finally, in the appendices, detailed information is provided about various aspects associated with the study. Here is for example each case study reported in detail.

Ch 1 – Introduction Background, purpose and research questions.	The basic frames for the study, and a presentation of the selected cases
Ch 2 – Research design Research design and methods used are described. Research quality is addressed.	
Ch 3 – Presentation of the studied cases Presentation of the selected cases.	
Ch 4 – Challenges with total cost analysis Description of the total cost analysis process. Presentation of the identified challenges.	Theoretical support and results for each RQ
Ch 5 – Difficulties and thresholds with learning total cost analysis Identified learning difficulties are presented and compared with thresholds characteristics	
Ch 6 – Methods for teaching total cost analysis Presentation of suitable educational methods identified in literature and case studies	
Ch 7 – Connections between challenges, thresholds and teaching methods Interrelations between the research questions are described.	The study is tied together
Ch 8 – Findings, reflections, and suggestions The contribution are presented, and the credibility of the study is discussed.	
Appendices Case descriptions. Details on data collection, analysis etc.	

Figure 6. Outline of the thesis

As the previous section reveals, descriptions of theory, method, data, and results to some extent are addressed throughout the thesis, as illustrated in Figure 7. For example, the chapters dedicated to the three research questions (Chapters 4-6) include theory, data, and results. Methods are mainly presented in Chapter 2, although some details are only available in the appendices, and a critical review of the methods are given in retrospect in Chapter 8 .

	Theory	Method	Data	Result
Ch 1	Total cost Pedag. concepts			
Ch 2	Research method	Pres. of design and methods		
Ch 3				
Ch 4	Total cost process		Challenges	RQ1
Ch 5	Threshold characteristics		Learning difficulties	RQ2
Ch 6	Constructivist teaching		Educational methods	RQ3
Ch 7				Holistic
Ch 8		Critical review		
Appendices		Details	Case study report	

Figure 7. Theory, methods, data, and results permeate the thesis

2 Research design

This chapter presents the research design and research methods used in the study based on support from theories.

The chapter starts with positioning the study in section 2.1, followed by recommendations concerning how to conduct case studies in 2.2. The overall design of the study is presented in 2.3, a description of how the literature studies were conducted is presented in 2.4, and the data collection procedures for the case studies are described in 2.5. In section 2.6, analysis procedures are described, and the measures taken for achieving a study of good quality are described in 2.7.

2.1 Point of departure

This thesis deals with understanding the challenges with conducting total cost analyses ‘out there’, in the ‘real world’. In addition, this thesis describes the problems associated with learning how to adequately conduct TCA and how to support this learning with appropriate educational methods. Since learning is a central aspect in the thesis, it seems appropriate to say something about my epistemological starting point – i.e., how I believe learning takes place.

2.1.1 Learning means constructing knowledge

Basically, I lean against constructivism, which states that:

“... ‘realities’ are not objectively ‘out there’ but ‘constructed’ by people as they attempt ‘to make sense’ of their surrounds”. (Pring, 2004) , p. 47

The basic idea in constructivism is that knowledge cannot be transmitted, but has to be re-created, actively constructed, by the individual learner, see e.g. Biggs (2003) and Karagiorgi and Symeou (2005). Furthermore, knowledge is successively built up by adding new knowledge to the one already possessed. As this concept is important for RQ2 (dealing with students’ learning), this understanding also has implications for my research design.

In my research process, I successively constructed my knowledge about these challenges by progressively improving my understanding, walking along the road. Certain aspects of existing theory were unavailable to me until I gained other insights from, for example, empirical findings and vice versa. This made it plausible, or rather necessary, for me to walk back and forth between theoretical and empirical material as well as between different strands of theory. This means I did not follow either a strict deductive approach (theoretical propositions are tested by empirical studies) or a strict inductive one (empirical findings are used to shape theory). Rather, I used a combination of these two

approaches – i.e., recurrently re-visiting theory as well as ‘the field’. This iterative procedure is called an abductive approach (Kovács and Spens, 2007; Gummesson, 2000).

2.1.2 Positioning the study

Here, the study is positioned based on the research questions and on my view on knowledge and learning.

An exploratory study...

As discussed in Chapter 1, my research describes an area not comprehensively described before. When knowledge about an area is limited, an exploratory research design is considered suitable (Ghauri and Grønhaug, 2005; Saunders et al., 2007). Cooper and Schindler (2003) describe the process as follows:

“Through exploration, researchers develop concepts more clearly, establish priorities ... and improve the final research design.” (p. 151)

This quotation indicates that an exploratory study is not to be seen as an ending point, but rather as a first step, triggering further research. Saunders et al. (2007) explain that rather than giving clear indisputable answers to the research questions, exploratory research provides an increased understanding, which is well in line with the goal of my research.

Although the literature provides some indications of the challenges associated with conducting TCA (RQ1), this subject has not been comprehensively studied, neither within logistics, nor in other fields. For the other research questions, the literature has addressed learning thresholds in general as well as educational activities that stimulate learning (see section 5.2 for a presentation). However, when it comes to the logistics field, literature that addresses learning thresholds and educational activities is scarce, something I examined thoroughly in my licentiate thesis (Oskarsson, 2014). General theories about educational activities as well as threshold theory, are therefore yet to apply on TCA, at least in the logistics field.

... conducted with a combined approach of literature and multiple case studies

As information about the unknown can be uncovered in different ways, a mixed method approach could give a richer understanding. Several approaches for exploratory research are suggested in the literature such as studies of literature and documents, case studies, and surveys (Saunders et al., 2007; Cooper and Schindler, 2003). According to my preliminary findings from literature, the challenges I have set out to study are not well described. I supposed that catching proposed challenges would require interaction with the respondents and therefore I chose the case study approach in combination with literature studies.

A single case can provide much interesting information as it goes deep into a case. However, in most situations, the use of multiple cases is encouraged as the cases either provide coinciding information, which strengthens the propositions produced during the study, or provide contrasting views, thereby enriching the broad knowledge of the aspect of study (this is further elaborated in section 2.2). In this research multiple case studies are performed in order to consider many empirical ‘voices’.

2.2 Using case study research for contributing to theory

Case study research has its advantages, but it is important to know when to use the method and what are its limitations. These considerations are addressed in this section together with advice on a how to perform a case study in a structured manner.

The case study method is recommended in different situations such as when the research aims to explore new fields and generate theory (Yin, 2018; Eisenhardt, 1989; Siggelkow, 2007). This situation corresponds to my research, which predominantly deals with generation of, or at least contribution to, theory. While theory can be viewed in many ways, I have chosen to use the term rather permissively, akin to what Pring (2004) refers to as a ‘body of knowledge’:

“... theories, propositions and explanations which have accumulated through enquiry, criticism, argument and counter-argument. They are what have survived testing and criticism.” (p. 80)

... and including ‘solid’ as well as ‘loose’ theories, using the terminology by Arlbjørn and Halldórsson (2002).

Eisenhardt and Graebner (2007) argue that theory developed from cases is interesting and testable. A central aspect of building theory from cases is that the cases are selected based on theoretical sampling (Eisenhardt, 1989). That is, cases are not randomly chosen, but are consciously selected because they are believed to replicate or extend the emerging theory. Thus, a case should be of a specific interest for the study:

“... precisely because it is very special in the sense of allowing one to gain certain insights.” (Siggelkow, 2007), p. 20.

Although single cases can provide valuable insights in certain situations, the use of multiple cases allows for stronger arguments in the construction of theory (Yin, 2018). The replication logic addressed above is then applied on the selection of cases, to make the set of cases contribute to theory in the best way. According to Eisenhardt and Graebner (2007):

“The theory is emergent in the sense that it is situated in and developed by recognizing patterns of relationships among constructs within and across cases and their underlying logical arguments.” (p. 25)

This indicates that theory is generated by induction, but the authors clearly explain that their standpoint is that induction and deduction is used in combination, because:

“The theory-building process occurs via recursive cycling among the case data, emerging theory, and later, extant literature.” (p. 25)

Similarly, Siggelkow (2007) advocates for first setting initial propositions and then refining these propositions successively by iteratively walking back and forth between data and theory.

Drawing on these insights from theory, I am now prepared to describe the design of my research, first from a general perspective (section 2.3) and then with specific attention to the review of literature (2.4), the case study data collection (2.5), and the analysis procedures (2.6).

2.3 Design of the study

To start with, section 2.3.1 describes the procedures for the selection of cases. Section 2.3.2 provides a principal description of the case study design, including the data sources used. Section 2.3.3 describes how the literature and cases interact to answer the research questions.

2.3.1 Selection of cases

In exploratory research, cases should provide rich information that helps the researcher build on the emerging theory. For such purposes, Eisenhardt (1989), Cohen et al. (2011), and others propose that cases are selected based on their possession of specific characteristics matching the purpose of the study. As Eisenhardt and Graebner (2007) express:

“Cases are selected because they are particularly suitable for illuminating and extending relationships and logic among constructs.” (p. 27)

In this section, the aspects considered when selecting cases in this study are presented, followed by a description of the selection process leading to the cases finally selected.

Defining where to look for cases

Cases should be chosen for their ability to provide rich information about the objects of study. Concerning the thresholds for learning TCA (RQ2) as well as educational methods supporting such learning (RQ3), teachers and students at Higher Education Institutions (HEI) where TCA is taught were supposed to be able to contribute significantly to such a study. The teachers are likely to have reflected on what is difficult to learn and how these learning thresholds can be overcome with help from suitable educational activities. The

students, in turn, may have valuable experiences on which activities that have supported their total cost learning, especially if they repeatedly have been confronted with TCA issues during their education.

When it comes to the challenges with conducting TCA (RQ1), one option would be to consult practitioners with experience in the field such as purchasers or strategic analysts in organisations. However, since my research is performed from an educational perspective, it seemed appropriate as a first step to turn to HEIs for this question too. To support and facilitate learning, the HEI teachers should understand what is difficult (challenging) in the material that is to be learned (total cost analysis). These teachers were therefore supposed to have reflected on these challenges, something I considered urgent as this is a relatively unexplored topic. Given that TCA is already integrated in the curriculum, there are also possibilities that the students can help identify the challenges.

Drawing from this, I chose to focus on HEIs when selecting cases. That is, all three research questions were covered with the same set of cases. More precisely, the cases were selected within the logistics field, since TCA is considered a central aspect within logistics and therefore commonly part of the curricula.

To summarize, cases were selected within Higher Education Institutions providing education within the logistics discipline.

Selection criteria

Given that HEIs providing logistics education are the target population for case selection, the selection of cases was based on the following criteria.

The kind of logistics education. TCA can be applied to operative as well as strategic issues within logistics, and it can be connected to different parts of the system such as supply, distribution, warehousing, and transportation. Furthermore, logistics as such is a rather broad field, and the label ‘logistics’ is not used in a uniform way. Educational programs in logistics may be oriented towards engineering, business administration, transportation, supply chain management, etc., see e.g. Niine and Koppel (2015). When selecting cases in this study, the program label as such was not crucial, but the intention and content of the program had to be in line with the definition of logistics management (CSCMP, 2019) presented in section 1.1.

Multiple occurrences of total cost analysis in the courses, which implies that the students take several logistics courses. The more logistics courses taken, the greater the probability that different challenges are encountered. If students work with TCA several times, they will probably experience a variety of teaching methods and learning activities, and there will be a progression in students’ learning, which increases the chance that they are able to reflect on their learning as well as on teaching methods and challenges associated with conducting TCA.

A group of teachers engaged in the total cost related teaching implies a higher probability that different aspects of the subject are addressed in the courses and that various educational activities are used. This also makes it more plausible the teachers have discussed total cost challenges. This is in line with Cohen et al. (2011) who argue that a researcher should try to find participants who are:

“‘knowledgeable people’, i.e. those who have in-depth knowledge about particular issues.” (p. 157)

An interest to participate from the teachers. Rodrigues et al. (2010), among others, conclude that the more genuinely interested the participants are, the more and better information they will probably be able to contribute. A genuine interest in the subject of the study also indicates that these people have been considering the issue to a high extent.

To summarise, the inclusion criteria for selecting cases were as follows:

- Logistics education within the logistics management field.
- Several logistics courses offered, where total cost analysis appears to be repeatedly addressed.
- A group of teachers involved in the teaching of total cost analysis.
- A genuine interest from the participating teachers.¹⁰

Selection procedure

As a first case, my own field of practice at Linköping University was chosen. An apparent advantage with this was that I was 100% sure that all inclusion criteria defined in the previous section were fulfilled and that I would have a very high access to the informants. Therefore, I considered the chances to be high for a strong development of the initial propositions already during the first case and thereby I could come to the subsequent cases with more worked-through propositions than otherwise possible. (The successive case study design is described in the following sub-sections). There are, however, some concerns with this choice, since it can be questioned whether I could remain objective when researching my own practice. I discuss how I handled this in section 2.7, and in 8.3 I retrospectively analyse the possible effects of this choice.

Method-wise, the Linköping case served as a pilot study, cf. Yin (2018) for testing the data collection instruments (see section 2.5 for information on data collection methods). Although the data collection worked out well, there was a risk that my close relationship to the respondents together with a high pre-understanding of the courses and educational activities used, made the data collection too easy, and that the same tools would not work quite as well at other HEIs.

¹⁰ The participating *students*’ interest was also regarded as important; however, this was considered when performing the case studies, not when *selecting* the cases.

To further validate the data collection method, I wanted to continue with cases rather similar to the first one and therefore looked for Swedish HEIs with a focus on engineering education. After checking program and course curricula on websites, I found two HEIs that matched the pre-conditions – Lund University and Chalmers University of Technology. I approached both through contact persons I already knew. Both responded positively, so I decided to include both.

Since the data collection tool worked out well in the new cases, I wanted to continue with cases that differed somewhat from the first two to open up for a broader range of opinions. I set out to include business schools (as the first three cases were within engineering education) outside of Sweden (preferably in the Nordic countries, for the sake of convenience). After checking program and course curricula, I found three suitable options. Although the first three cases had been rewarding, there was a slight tendency of a declining extra contribution from case to case. Therefore, I chose to contact only one of the business schools to start with. The choice could have been either one of them, but my choice was Hanken School of Economics in Helsinki, Finland, since one of the teachers there had shown great interest in my research. I thought this increased the chances of a positive response, which I also received.

The data collection worked out well also in this setting. However, the Hanken case contributed less than the previous cases. As Eisenhardt (1989) claims, when an additional case does not give any substantial contribution, theoretical saturation is reached. According to Eisenhardt, when approaching the saturation point, it is also a matter of researcher input (time and money) vs. expected additional contribution of a new case. Because every new case requires a certain amount of time for preparation, data collection, and analysis, I decided to draw the line, and not include more cases.

Hence, the cases selected were Linköping University, Lund University, Chalmers University of Technology, and Hanken School of Economics. A brief presentation of each case is given in Chapter 3, and more through descriptions are available in Appendix 9.

2.3.2 Design of the case studies

Eisenhardt (1989) as well as Yin (2018) recommend using multiple data collection methods (by Yin labelled ‘multiple sources of evidence’) so data can be triangulated in order to strengthen the results. Therefore, data were collected from different sources for each case, as visualised in Figure 8.

Figure 8. Data sources in the case studies

Documents used were of principally two kinds. First, program and course descriptions providing a preunderstanding about the curriculum, the focus of the courses, etc. Second, specific material from the different courses giving more details about how and to what extent TCA is addressed in lectures, exercises, etc.

The teachers' presupposed good knowledge on the objects of study was the main reason for choosing cases among HEIs. To stimulate a discussion among the teachers, focus groups were arranged (the focus group method is explained in section 2.5). The focus groups were complemented with individual interviews with some of the teachers to get deeper information concerning TCA related to their specific courses. The selection of participating teachers (and students) is discussed in 2.5.

Students also contributed to the study, especially those close to finishing their studies. The later in their studies, the more likely the students had encountered TCA several times and the more likely that they had reflected on the learning obstacles as well as the challenges with conducting TCA. Focus groups were arranged also for the student respondents.

Many *master's theses* within the logistics field are performed with an external organization as a sponsoring stakeholder – i.e., the thesis projects address real problems in organizations where students act as a kind of 'consultants'. Since the students work with real investigations, they also encounter real challenges. In those cases where the master's theses deal with TCA, one could expect to find indications of challenges.

The connections between the different data sources and the three research questions are presented in Table 1. Teachers and students were expected to contribute to all three. Documents were supposed to expose examples of supporting TLAs (RQ3). Finally, master's theses were only believed to address RQ1.

Table 1. Contribution of case study data sources to the research questions

Data sources	RQ1 TCA Challenges	RQ2 Thresholds	RQ3 Supporting TLAs
Teachers	x	x	x
Students	x	x	x
Documents	-	-	x
Master's theses	x	-	-

Further positioning of the study

Given that there are several cases with several data sources for each case, using Yin's terminology this study is characterized as an embedded multiple case study design (Yin, 2018), see Figure 9. The embeddedness means that there are several units of analysis in each case, here manifested by the different types of data sources in each case as well as several individual sources within each type.

Figure 9. Positioning of the case study

2.3.3 The interplay between literature and cases

While all the cases are used to answer all three research questions, different literature supports each one of them, see Figure 10. However, there is a difference concerning the role of the literature between RQ1 on the one hand, and RQ 2 and 3 on the other, as is discussed in the following.

Figure 10. How literature and cases are used to answer the research questions

RQ1 – Challenges with conducting total cost analysis

In RQ1, a literature review was made for the purpose of finding suggestions or indications on challenges with conducting total cost analysis. Therefore, the literature review is a

parallel source of information alongside the cases in an abductive procedure. Multiple strands of total cost literature were reviewed, and the findings were categorized as potential challenges. (The procedure for finding and selecting literature is presented in section 2.4.1). During the case studies, some of these potential challenges were confirmed and new potential challenges were identified. This way, the finally proposed challenges evolved in a ‘cross-source analysis’ of findings from literature and cases, see Figure 11. The analysis procedure is described in more detail in 2.6.1.

Figure 11. Cross-source analysis for RQ1 involving cases and literature

RQ2 and RQ3 – Identify and overcome thresholds for learning total cost analysis

Provided that there would be enough literature available addressing teaching and learning of TCA, a similar approach used for RQ1 could be used for RQ2 and RQ3 – i.e., forming tentative proposals from literature and successively developing them in an abductive manner. However, a literature review (see 2.4.2) revealed that this field is rarely addressed. Since the literature did not provide a starting point for these two research questions, an inductive procedure was applied with proposals generated from the cases and then compared to more general literature on teaching and learning. Since the cases were conducted successively, tentative proposals were built up over time. When all cases were conducted, a kind of cross-case analysis (see 2.6) was performed to decide the final proposals to be compared against literature, as shown in Figure 12.

Figure 12. Case findings analysed with literature for RQ2 and RQ3

Identification of thresholds

I divided the search for thresholds into two steps. First, identifying learning difficulties, and second, examining whether these difficulties qualify as being thresholds.

The first step is about identification of what is considered difficult when learning TCA. In other words, this step is about identifying what might be thresholds. The threshold literature (see section 5.1) gives some recommendations on how to identify potential thresholds. Therefore, this literature was used as support when forming the data collection procedures used in the case studies. The literature suggests that both students' and teachers' opinions should be considered (Entwistle, 2009; Smith, 2013; Heading and Loughlin, 2018). The use of multiple methods is suggested by e.g. Knight et al. (2014), and as a specific Entwistle (2009) and Knight et al. (2014) recommend concept maps. As described in 2.5, multiple methods were used to collect data (focus group sessions, interviews, and document studies). In addition, concept maps were used and both teachers' and students' perspectives were examined.

Hence, learning difficulties were identified in the case studies. However, because a concept is difficult to learn, does not necessarily mean it is a learning threshold. *The second step* investigated whether the identified difficulties qualify as threshold capabilities by relating them to the threshold characteristics defined by Meyer and Land (2003), as presented in 5.1. How this analysis was made is described in 2.6.2.

Identification of appropriate teaching methods

Essential features of constructivist teaching were identified with help from a literature review. (The literature search procedure is described in section 2.4.3, and the identified aspects are described in 6.1). Teaching methods used at the case universities were identified during interviews and focus group sessions, and the ones regarded by the teacher and student respondents to be most successful for stimulating learning of TCA were selected for analysis with respect to features of constructivist teaching. The analysis procedure is discussed in 2.6.3.

The next sections focus on the specific procedures applied to the literature reviews (section 2.4), the case study data collection (2.5), and the analysis (2.6).

2.4 How the literature reviews were conducted

This thesis reviews the literature in three specific areas. These review processes are described in this section, starting in 2.4.1 with the major literature review concerning challenges with conducting TCA. Section 2.4.2 describes the review concerning literature in the interface between total cost analysis and education, and section 2.4.3 presents the literature review of essential aspects of constructivist teaching.

2.4.1 Review of challenges with conducting total cost analysis

In an attempt to create a typology of literature reviews, Grant and Booth (2009) defined 14 types. Although there is a certain overlap between these types and the definitions of each type could be sharpened, their study clearly shows that there are many ways to perform literature reviews. The search for literature should be performed in a systematic manner so as to increase the probability that a majority of the relevant literature is found. Several authors recommend how to perform literature reviews systematically, e.g., (Kitchenham and Charters, 2007; Denyer and Tranfield, 2009; Seuring and Gold, 2012). Many guidelines for so-called ‘systematic reviews’ address rather precisely defined topics where the search terms can be clearly pinpointed. In exploratory research that intends to get a good overview of the literature, a ‘full-scale’ systematic review might be too time-consuming since the volume of matching literature often is very high (Kitchenham and Charters, 2007). In such cases, Kitchenham and Charters recommend a more limited approach, ‘systematic mapping’ (similar to what Denyer and Tranfield (2009) label a ‘scoping study’). Kitchenham and Charters (2007) point out certain parts of their systematic review guidelines as well suited for systematic mapping studies. Based on their recommendations, I have used advice from the systematic review literature in a selective manner to perform my literature review in a systematic way, while avoiding procedures that are too rigid and therefore not worthwhile given the exploratory direction of my research.

Of interest for my research was literature that either presented general information about TCA (historical development, analysis procedures, cost models used etc.) or suggestions about the challenges associated with conducting or learning TCA. Since I knew from pre-studies that challenges as such are not in focus in the literature, I assumed I would not find much specific literature about this. Therefore, I performed combined searches for general as well as challenge-specific literature.

The outcome of the review was useful both for the general description of TCA (presented in 1.3) as well as a for formulating propositions of challenges used in the subsequent

research phases. In these phases, the books were re-visited and analysed in the light of the emerging challenges. I describe how this analysis was performed in 2.3.3.

I used three main sources of information: logistics-related textbooks; scientific articles etc. identified with help from database searches; and complementary literature either identified through the literature found in the first two categories (so called backward snowball strategy, described below), recommended by colleagues, or previously known by me. How I used these different strategies for finding literature is described in the coming sub-sections.

Logistics textbooks

Since TCA is regarded as a central aspect within logistics (as discussed in Chapter 1), it seems plausible that this subject is covered in many logistics textbooks. As textbooks are used for educational purposes, one could also expect them to be written in a pedagogical way – i.e., clearly explaining and highlighting central aspects. If the authors regard some aspects of TCA to be challenging, one would expect these to be mentioned in the text. Therefore, I started the literature search by reviewing textbooks.

Selecting the books

I visited the websites from the major HE literature publishers to find the latest editions of books focusing on ‘logistics’ or ‘supply chain management’ (since ‘supply chain management’ is used in the title of many logistics textbooks) written in English or Swedish. The search included only textbooks published since 2010 to avoid outdated books. A few books were added that were previously known and easily available. In total, the review list included 29 books. Of these, 18 were readily available, either at our department or through Linköping University Library (hard copies or electronically). For the other 11, I contacted the publishers and asked for inspection copies. I received copies for eight of these, so in total 26 textbooks were reviewed. Appendix 4 lists all the textbooks reviewed.

Reviewing the books

A protocol was established to ensure the review of the books was done in a similar way. Relevant information from each book was noted under seven headings, of which some addressed preliminary challenges, which I established based on my pre-understanding of the subject. An example of a completed protocol is available in Appendix 5.

The book reviews were made in three steps:

1. The table of contents was checked to identify sections of certain interest
2. The complete book was scanned. Relevant parts were noted (brief content + pages). A double-check was made to make sure the sections noted from Step 1 were sufficiently covered.

3. For e-books, the search items ‘total cost’ and ‘trade-off’ were used to find possible information not found in Step 1 and 2. For paper books, the list of keywords (if available) was used for the same purpose.

To start, four of the books were reviewed by me and a colleague independently. One of these four was a book I co-wrote (Oskarsson et al., 2013), so including a second reader was an attempt to avoid a biased review. The other three books were randomly selected. When comparing our reviews of the books, the differences were only marginal. Because of this high inter-rater reliability, I felt confident in reviewing the rest of the books myself.

Database search

The search for and selection of literature to include in a literature review consists of several steps. Suitable keywords and search terms are selected and applied in relevant databases. Matching literature is screened and checked against inclusion and exclusion criteria. Since the search procedure strongly affects the outcome, it is crucial to report the procedure in sufficient detail so others can properly evaluate the effectiveness of the procedure (Tranfield et al., 2003; Kitchenham and Charters, 2007).

Search instrument

The search engine used, UniSearch (available via Linköping University Library), includes a large number of relevant databases (Academic Source Premier, Business Source Premier, Scopus, Web of Science, etc.), which were supposed to sufficiently cover the relevant literature.

Search terms

Keywords and search terms are not always obvious, but according to Denyer and Tranfield (2009), the efficiency of the search can be highly improved by being scrutinous in the definition of search terms. Kitchenham and Charters (2007) recommend to make a list of synonyms, abbreviations and alternative spellings and test these in the search. As Seuring and Gold (2012) point out, if the search result do not render a sufficient and manageable number of matches, the chosen search terms might have to be adjusted to expand or delimit the number of matching literature.

Relevant search terms were not obvious, since total cost analysis can be covered without this specific term being used. Within logistics, ‘total cost’ is used with different extensions – e.g., ‘total cost *analysis*’, ‘total cost *concept*’, ‘total cost *model*’, ‘total cost *calculation*’. Using ‘total cost’ only would render too many matches and therefore a number of searches were made using ‘total cost’ combined with different extensions.

However, terms other than ‘total cost + extension’ had to be used since other terminology is used in other research fields (and sometimes also within logistics). The other terms used was ‘Total Cost of Ownership’ (abbr. TCO, frequently used within purchasing and

outsourcing), ‘Landed cost’ (a purchasing term), ‘Life Cycle Cost’ (abbr. LCC, used in several fields, e.g. environmental engineering), ‘Total cost of care’, ‘Cost of poor quality’, and ‘Cost estimation’.

Search fields

To find a reasonable number of matches when searching with the selected phrases, some limitations had to be made concerning which search fields to use. This was decided separately for each search phrase. To start with, a search in the fields ‘Title OR Abstract’ was tested, but in several cases the search was narrowed to ‘Title’ to ensure a manageable number of matches.

Since the databases scanned by UniSearch not only contain academic journal articles, also books, conference papers etc. were found. To assure a certain level of quality, the ‘Peer reviewed only’ option was therefore used. For the sake of keeping the text easy to read, in the coming sections the term ‘articles’ is used as a general term although some of the matches might be books or other texts.

Procedure to select articles from the identified ones

Criteria for literature selection can be expressed as inclusion or exclusion criteria. There are different reasons for inclusion or exclusion. Clinton (2019), for example, set up three criteria in her meta-analysis on reading performance: First, content should be congruent with the purpose. Second, ‘confounding’ studies should be excluded to enhance comparability. Third, the methodological quality should be high. Criteria can also only be to include peer-reviewed academic papers (Jonsson and Tolstoy, 2013) or literature not published before a certain year (Colicchia and Strozzi, 2012). Scanning literature is preferably performed by first removing papers obviously irrelevant by viewing the title, second by viewing the abstracts, and third, by reading the remaining articles (Kitchenham and Charters, 2007).

The selection of articles was made in three steps:

1. By reading the titles, duplicate matches were eliminated (since an article can be included in more than one of the databases covered by UniSearch) as well as articles obviously irrelevant or written in languages other than English, German, Swedish, or other Scandinavian languages (the languages I understand).
2. Abstracts were read to check that the following inclusion criteria were fulfilled:
 - a. ‘Total cost’ does refer to monetary aspects
 - b. TCA is central enough (if treated too vaguely or peripherally, the article was excluded)
 - c. Electronically available (with the exception that if a non-available article was deemed to be highly rewarding, a paper copy was ordered)
3. By reading the article and checking that it fulfilled at least one of the following inclusion criteria:

- a. Describes or defines TCA
- b. Addresses how TCA is used in practice
- c. Describes difficulties/challenges connected to TCA
- d. Addresses educational/pedagogical aspects related to TCA

During the third step, all articles were entered into a spreadsheet database. Reasons for exclusion were documented for the excluded articles. For those included, information was entered regarding the major aspects of interest in the articles to facilitate further analysis. Examples are given in Appendix 3.

Search results

A detailed presentation of the number of matches and selected readings for all combinations of search phrases and search fields is provided in Appendix 3. A summary is shown in Table 2.

Table 2. Overview of the outcome of the database search

	Total matches	Remaining after first removal (step 1)	Remaining after reading abstracts (step 2)	Remaining after reading the articles (step 3)
No. of articles	749	480	156	97

Complementary literature

As a complement to database searches, a backward snowball strategy is recommended (Wohlin and Prikladniki, 2013; Clinton, 2019). This strategy requires researchers to read the literature searching for relevant references and track them down. Using this method, I discovered, read, and considered several additional articles. I also added literature already known to me, or recommended by colleagues, that did not show up in the database search. Reasons for this absence can be either that they did not match the search terms or that they were not included in the databases covered by UniSearch. In addition, I added a few textbooks from the purchasing field that were readily available. Since several academic articles address purchasing-related total cost issues, I assumed that such issues are also covered in purchasing textbooks.

These complementary literature review strategies resulted in another 46 sources, which were included and entered into the same database as the ones found in the database search.

Summary of the literature search

In this section, the total number of sources examined and selected are presented together with some statistics, since the included literature represents different kinds of sources, are spread out over a long period of time, and cover several disciplines.

Sources examined and selected

Summarising the outcome of the search procedures, 171 sources were found to be relevant to include for further study. Some more details are shown in Table 3.

Table 3. Overview of the outcome of the literature search

Examined sources	Total matches	Pot. relevant	Read	Selected
Logistics textbooks	41	41	28	28
Database search	749	480	156	97
Additional literature	52	52	52	46
Total	842	573	236	171

Source categories

Books (mainly logistics textbooks) and journal articles are the dominating sources. A few reports, dissertations, and standards were also deemed relevant. Despite the fact that ‘peer reviewed only’ was chosen in the database search, a few master’s theses slipped through the filter. In these cases, when this was discovered late in the process and these sources proved to be relevant, they were kept despite falling outside the initial criteria. A compilation of the selected literature divided by source category is shown in Table 4.

Table 4. Selected sources divided by source category

Source category	No. of Sources
Books	37
Journal articles	116
Other	18
Total	171

Disciplines

Many disciplines are represented in the selected literature. Because disciplinary categorisation is somewhat arbitrary, it is impossible to provide an exact number. In my somewhat subjective categorisation, there are 24 different categories. The most frequent are logistics and purchasing. In Table 5, some more information is given about this issue.

Table 5. Selected sources divided by discipline

Discipline	No. of Sources
Logistics	52
Purchasing (incl. outsourcing)	21
Manufacturing	16
Marketing	10
Healthcare	9
Environmental management	8
Civil engineering	10
Transportation	6
Other (16 diff. disciplines)	39
Total	171

Time of publication

The vast majority of the literature is from the last three decades, as displayed in Figure 13. Before this, total cost issues were sparsely covered, but some of the earlier literature is still relevant for describing the area,¹¹ an issue addressed in the historical overview in section 1.3.1.

Figure 13. Selected sources divided by time of publication

2.4.2 Review of the interface between total cost analysis and education

To check for relevant literature, I performed a database search using phrases that combined total cost-related words and pedagogically related words (as described in detail in Appendix 3). This search returned three potentially interesting articles, but these were ultimately excluded (two articles did not treat teaching/learning aspects and the third one did not focus on TCA).

Added to this, as part of my licentiate thesis (Oskarsson, 2014), I performed a literature review of the interface between logistics and education, which I later followed up to cover publications until 2016. Among the identified articles, only three dealt with TCA. However, all the articles described cases where TCA is applied, but teaching/learning issues related to TCA were not addressed.

To summarize, no literature was found in the interface between TCA and teaching/learning. Table 6 summarizes the search results and Appendix 3 describes more thoroughly the search phrases, inclusion criteria, etc.

¹¹ In part, the increased number of sources found can be explained by the fast-growing number of journals and publications in general during the last decades.

Table 6. Overview of the results of the search about total cost analysis vs education

Examined sources	Total matches	Pot. relevant	Remaining after reading abstract	Selected
Database search	210	138	3	0
Additional literature	3	3	3	0
Total	213	141	6	0

2.4.3 Review of essential aspects of constructivist teaching approaches

To identify essential aspects of constructivist teaching approaches, I started with sources I was already familiar with that deal with constructivist teaching and with literature recommended to me by colleagues. Using a backward snowball approach¹² (Wohlin and Prikladniki, 2013; Clinton, 2019), I added literature referred to in these sources that seemed relevant to my project. After a first scan, about one half of the sources were eliminated, as they did not address essential aspects of constructivist teaching. The remaining sources were entered into an Excel database used to store and structure relevant facts. From this analysis, essential constructivist teaching aspects were identified. These are described in Chapter 6. Table 7 summarizes the search results and Appendix 8 provides some additional information.

Table 7. Overview of the results of the search for constructivist teaching aspects

	Total considered	Pot. relevant	Selected after reading
No. of sources	81	41	40

2.5 Data collection from the cases

While the previous sections focus on the overall design of the study and the procedures for the literature review, this section specifically focuses on how the case data collection was conducted. Since each case consists of several sources of information, this section starts with an overview of the sequence for preparing and conducting the individual cases and ends with an overview of the data collection methods.

2.5.1 Design of the individual cases

Wilson (1997) argues that an appropriate sequencing of the activities is important to consider when using multiple data collection methods. The sequence principally followed in this study is shown in Figure 14. The figure provides an overview, why all details are not included. In practice, this planned sequence could not be followed completely in any of the cases. When necessary, certain adjustments were made in the sequence. For example, in Lund, the student focus group session was performed during a second visit with master's theses studied in-between the first and second meeting. The adjustments,

¹² The backward snowball approach is briefly presented in section 2.4.1.

however, did not disturb the essential aspects of the sequence, which is briefly commented on below.

Figure 14. Sequence of preparing and conducting an individual case

The contact person was important during the preparations. When I had explained my requests and wishes, the contact proposed appropriate participants, gave suggestions on suitable dates for my visits, and supported me with general documents on program and course curricula. The contact also informed the participants, so they were prepared when I approached them with invitations.¹³

The 'focus group manual' (explained below) refers to a document I prepared before each focus group. The general documents were used as an input for this.

The first part of the data collection was the teacher focus group. This was important because I wanted to conduct this group discussion before the interviews for two reasons. First, I wanted the participants to be as 'un-coloured' as possible during the group session. Second, interesting aspects mentioned during the focus group session could then be penetrated in detail during interviews with those teachers most concerned. I also wanted the teacher focus group to precede the student focus group, since I wanted the possibility to follow-up on specifics mentioned by the teachers and bring them with me to get the students' perspective on these issues. 'Course documents' refer to more specific material from the courses concerning educational activities connected to TCA.

I did not arrange separate sessions for the respective research questions. The questions are interrelated, and I believed it to be more fruitful to let the respondents move rather freely between these aspects.

¹³ In Linköping, no contact person was needed, since I had enough insight myself.

2.5.2 Focus groups

This section describes the focus group method and presents how I performed the focus group sessions. Also included is a presentation of concept maps, an instrument which I used during the focus group sessions.

The focus group method – a brief introduction

The focus group method is recommended by several authors (Cooper and Schindler, 2003; Rodrigues et al., 2010; Dahlin Ivanoff and Holmgren, 2017) for developing new knowledge, or refining and validating conceptual models – i.e., for exploratory research. A focus group consists of a group of people who discuss different aspects of a subject or a theme, with a moderator facilitating the discussion. Bryman and Bell (2011) argue that the focus group could be seen as a kind of group interview, and that the distinction between the two is somewhat unclear. On the other hand, other researchers, e.g. Dahlin Ivanoff and Holmgren (2017), state that what clearly distinguishes them is that in focus groups, the *interaction* between group members is central, where themes and subjects are viewed from different angles so a collective understanding can emerge. Bryman and Bell (2011) and Cyr (2014) agree, but they add that also the opinion of individuals can be of interest.

How the focus group sessions were conducted

Group composition

The participating teachers were expected to have a lot of subject matter knowledge. In groups consisting of experts, in this case teachers, relatively small groups are sufficient (Rodrigues et al., 2010; Bryman and Bell, 2011). Therefore, I planned for groups of 4-6 participants. Although I wanted all the teachers to have extensive experience teaching TCA, I also saw that a mixed group – older and younger and men and women – would facilitate catching different perspectives, something recommended by e.g. Wibeck et al. (2007). When it came to the students, I wanted them to be as late as possible in their studies to increase the probability of having approached total cost analysis several times and having encountered different pedagogical approaches. In addition, the student group was recruited with the ambition to obtain a mix of men and women and of students from different educational programs.

Except for Linköping, where I had direct access to potential respondents, I relied on the contact persons at each HEI to suggest respondents based on my requests. At each HEI, between four and six teacher respondents were suggested which I then invited. Except for Chalmers, where three of the participants cancelled on short notice, all invited teachers showed up to the sessions as planned. The student groups were more problematic. In Linköping, I asked two of my fellow teachers if any of their master's thesis students (whom they were supervising) would be interested. This resulted in six potential students;

they all agreed to participate. In Lund, a first attempt was made to engage students who were in the final part of their master's theses, but the response was very weak. A couple of months later, I was able to meet some students in direct connection to a start-up course for the master's thesis projects they were about to begin. At Chalmers, students following a course in the final parts of their program were approached, but despite encouragement from the responsible teacher, no students were willing to participate, so no student focus group was conducted at Chalmers. This happened also at Hanken. I did not have the chance to invite the Hanken students myself, but my contact sent out invitations to two groups of students. Only one student responded positively, but she had only taken one logistics course. Table 8 provides an overview of the focus group compositions. More details are provided in the case description in Appendix 9.

Table 8. Focus group participants, some basic information

			Linköping	Lund	Chalmers	Hanken
Teacher focus group sessions	Number of participants	Total	5	6	2	4
		Men	3	3	2	2
		Women	2	3	0	2
	Years of teaching experience	< 5	0	0	0	1
		5 – 10	1	2	0	0
		> 10	4	4	2	3
Student focus group sessions	Number of participants	Total	6	3		
		Men	3	1		
		Women	3	2		

Information to the participants

Participants should be well informed about the purpose of a study, how the session is to be performed, and how the results will be used (Bryman and Bell, 2011; Dahlin Ivanoff and Holmgren, 2017). A few weeks before their sessions, I sent an e-mail invitation to all participants, informing them about the purpose of the study, how I planned to conduct the focus groups, and how I intended to use the results. I also attached a one-sided poster presenting my research project. The poster and an example of an e-mail invitation are shown in Appendix 1. At the start of the focus group session, I repeated this information to the participants.

Preparation of the sessions

Several authors, e.g. Dahlin Ivanoff and Holmgren (2017) and Wibeck et al. (2007) recommend that researchers develop a plan or structure for the session as well as an interview guide to help the moderator make sure that certain topics and aspects are covered during the session. Before each session, I adapted the 'focus group manual' to the specific case. This manual served as a checklist while conducting the focus group sessions. The basis for the manual was my propositions (e.g., challenges with conducting TCA) as far as they had emerged (see section 2.3.3 for explanation of 'emerging propositions'). To this I added any relevant aspects I came across while going through the general documents (program and course curricula) for the specific case. To allow

plenty of time for discussions, two hours were planned for each session, a reasonable upper limit according to e.g. Wilson (1997) and Cooper and Schindler (2003). In practice, the sessions lasted between 50 and 120 minutes.

The session

A focus group discussion should be free and open-ended while maintaining a focus on the topic. Therefore, the moderator walks a tightrope, balancing between directing and not directing the conversation (Cohen et al., 2011; Wibeck et al., 2007). Too much structure might keep participants away from considering aspects they otherwise would have addressed, while too little framing on the other hand might result in ambiguity about what the moderator expects. As the moderator should encourage everybody to contribute, the moderator might need to hold back dominant participants and encourage the more silent ones.

My main intention was to encourage respondents to speak freely (which I clearly informed them about) in order to catch their spontaneous thoughts. However, I also had to make sure that the discussion kept on track and gently push them into areas where I wanted their opinions. Especially when working with groups of people who know each other well (as in my study), some issues might be taken for granted and therefore never mentioned in the discussions (Bryman and Bell, 2011).

In the first part of the session, I tried to stay in the background. During this part, I made a concept map for the total cost challenges that were addressed. A concept map (also called a cognitive map) is used to visualise how isolated concepts are connected. Eden et al. (1992) describe concept maps as graphs where short phrases are linked to represent how respondents think about certain things. By clustering related aspects, the map can be organised into a system of interrelated themes, why Hassmiller Lich et al. (2017) view concept mapping as a ‘systems thinking method’. Figure 15 shows a fictive example of a concept map for training.

Figure 15. Possible concept map of training (not exhaustive)

The use of concept maps is particularly useful for generating hypotheses and developing theory (Burke et al., 2005). Novak and Gowin (1985) believe concept maps highlight meaningful relationships between concepts and reveal new meanings. Ackermann et al.

(1992) describe this process as structuring, analysing, and making sense of accounts. When used in group settings, Trochim (1989) argues that concept maps are useful for developing a conceptual framework where the map displays all the group's ideas related to the chosen topic, shows how these are related, and might also show which of these are more relevant, important, or appropriate. When the discussion started to slow down, I showed the map to the participants to check if I had understood them correctly, which sometimes triggered further discussions. If necessary, I adjusted the map.

During the second part of the session, I took a slightly more directive role to encourage the participants to address issues not addressed during the first part of the session. However, I avoided suggesting prospective challenges. For example, I would ask questions (e.g., 'So you reach a result in the calculations, and then it is all set and done?') that would trigger discussions concerning uncertainties affecting the reliability in the result. The challenges discussed in this part of the session were also entered into the concept map, although with another colour to separate them from those spontaneously discussed. The concept maps are included in the case descriptions in Appendix 9. Except for the concept maps, I made only limited notes for moderation purposes, as all sessions were recorded.

Transcription and initial categorization

Recordings from focus groups and interviews were transcribed, although not literally as e.g. Dahlin Ivanoff and Holmgren (2017) advocate. Several authors (Bryman and Bell, 2011; David and Sutton, 2011; Merriam and Tisdell, 2016) stress that transcription is very time-consuming. Therefore, I chose to transcribe selectively, as proposed by Ochs (1979):

"One of the important functions of a transcript is that it should not have too much information. A transcript that is too detailed is difficult to follow and assess. A more useful transcript is a selective one." (p. 44)

However, Ochs (1979) stresses that the researcher should purposefully select what is included in the transcription and be explicit with how this is done. In my case, I included those parts that correlated to any of the research questions – i.e., challenges with conducting TCA (RQ1) and aspects related to learning (RQ2) and teaching (RQ3) TCA. From the reviewed documents, I selected information on the same premises as for the oral sessions and henceforth the document information is included in what I label 'transcripts'. Next, following recommendations from Merriam and Tisdell (2016) and Dahlin Ivanoff and Holmgren (2017), I went through the transcripts and divided the content into suitable categories. As highlighted by e.g. Braun and Clarke (2006), the crucial thing when considering if a specific content is worth categorising is whether it captures something important related to the research questions. As described in section 2.3.3, the tentative categories for RQ1 developed from literature and antecedent cases guided the categorization of every new case.

With Hanken as an exception, focus groups and interviews were conducted in Swedish. Hence, the transcriptions from Lund, Chalmers, and Linköping are translated to English.

2.5.3 Interviews

Interviews were performed one-on-one with teachers about their specific thoughts and experiences about TCA. Respondents were chosen either because they were suggested by the contact persons, the focus group session revealed that an interview would be rewarding, or as the teachers themselves expressed a wish for a deeper discussion.

As recommended by Bryman and Bell (2011), all interviews were semi-structured to ensure certain issues were addressed, but open enough to allow for unforeseen topics to be queried if needed. I did not really prepare ‘questions’ (as is often done in semi-structured interviews). Instead, I was guided by the ‘manual’ used in the focus group session and the relevant aspects that had turned up during the focus group. Sometimes, I also had the opportunity to review course-specific documents (e.g., lecture slides) before the interview, which triggered aspects I would like to cover during the interview. All the interview respondents also took part in the focus group sessions, with the exception of one Linköping and one Chalmers teacher.

The interviews lasted between 25 and 60 minutes and they were recorded, except for one occasion when I had not noticed that my recording device’s battery had died. At that occasion, I took careful notes and documented the interview as soon as possible after the session. Table 9 lists the number of interviews for each case.

Table 9. Interviews performed at the four HEI cases

	Linköping	Lund	Chalmers	Hanken
Number of interviews	2	3	1	4

2.5.4 Observations

Although no observations were planned, there were opportunities to observe. According to Eisenhardt (1989), adding new data collection methods is allowed in exploratory research as long as this can be defended.

In Lund, I was invited to visit a supervision session in a course related to a teaching case the students were working with. TCA was one of the aspects covered, so this seemed to fit well in the research. As I wanted to keep a low profile and not interfere, I did not ask for permission to record the session. I took some notes though and discussed the session with the teacher immediately after the session. Soon afterwards, I documented my observations and sent to the teacher for review.

2.5.5 Document studies

The *general documents* were examined to obtain a good overview of the logistics-related programs and courses at the respective HEIs. I also searched for indications of specific courses where TCA was addressed.

In the *specific course documents*, I specifically looked for how TCA is addressed in the courses, i.e. I looked for examples of educational activities.

Master's theses at the four HEIs were scanned to see whether and how TCA was explicitly performed and/or discussed. The number of master's theses within logistics differ between the cases, as well as the frequency of TCA appearance in them. To reach a comparable number of theses addressing TCA from the different cases, different amounts of theses had to be scanned. In three of the cases, a fairly equal number of relevant theses was identified. At Hanken, only a few theses turned out to be written within logistics and even fewer addressed TCA. After consulting the Hanken teachers, I considered it not to be fruitful to spend too much time on this activity and therefore I only examined a limited number. Table 10 shows the number of theses examined and found relevant in the different cases.

Table 10. Master's theses examined in the four cases

	Linköping	Lund	Chalmers	Hanken
No. scanned	54	115	161	30
No. addressing total cost analysis	16	9	11	0

The selected master's theses were reviewed more carefully to determine which total cost challenges they addressed. This determination was based either on the authors' explicit discussions or on implied evidence for total cost challenges. As an example of the latter, it might be obvious that all desired data were not available and that this caused problems even though the authors did not discuss this as problematic or challenging. The challenges found were entered in a spreadsheet database, similar to the one for challenges identified in the literature as described in section 2.4.1.

2.5.6 Documentation and credibility check

An e-mail request for some complementary information was sent to all participating teachers. Some teachers responsible for relevant courses but not having participated in focus groups or interviews were also contacted by e-mail requesting specific information about their courses. These e-mail requests are in Appendix 2.

The collected material was documented in case descriptions for each case (see Appendix 9). These descriptions were sent to the respective contact persons so they could provide their opinions on the accuracy of the reports. The individual respondents are kept anonymous in the report as I did not find it purposeful to display their names.

2.5.7 Overview of the data collection in the case studies

Some sources of information could not be used in line with the intentions, as two of the student focus groups had to be cancelled and master’s theses were relevant in only three cases. On the other hand, observation was added in one of the cases. In Figure 16, a compilation of the data collection used in the respective cases is shown.

Figure 16. Sources of information in the respective cases

The findings from the case studies are presented in Chapters 4, 5, and 6, which are dedicated to the analysis and results of the respective research questions.

2.6 Analysis

As described in section 2.3.3, a great deal of the analysis in this study is intertwined with the data collection, which is in line with the recommendations concerning exploratory research by Eisenhardt (1989). Although analysis to some extent has been treated in the previous sections focused on analysis in general, this section specifically focuses on the different analyses performed.

2.6.1 Research question 1 – Challenges of conducting total cost analysis

The proposed challenges were developed with help from literature and cases in an abductive procedure. Following Eisenhardt (1989), I used literature to construct propositions concerning TCA challenges. As a first draft, I set out with a very limited number of tentative challenges, which were based on my pre-assumptions and informal discussions with colleagues. Next, I reviewed the selected total cost literature looking for challenges connected to conducting TCA that were explicitly (although not necessarily labelled as challenges) or implicitly addressed. All relevant sources were entered into an Excel database. I then followed Finfgeld-Connett’s (2014) recommendations for content

analysis by labelling columns after tentative challenges and for each source adding information corresponding to the respective challenges (where applicable)¹⁴.

According to Braun and Clarke (2006), researchers should start with pre-defined categories when the review and coding are made with a specific research question as a base. However, Finfgeld-Connett (2014) stresses that such an initial categorization must be alterable. Accordingly, the pre-defined categories were gradually adjusted as the deep reading of the literature continued. New challenges were added, some challenges were split up in a finer granulation, while others were more precisely defined. The result of this stage was an initial set of challenges used as a basis when entering the case studies.

Having these propositions in mind when entering the first case, I could specifically look for aspects relating to these challenges, but I was also open to new input. By performing the cases successively, learnings were brought from earlier cases to later. The model was changed by adding, changing, renaming, or removing challenges after input from each case and after revisiting the literature. This iterative approach resulted in the model being developed from case to case, as illustrated in Figure 17. This means that the challenges were successively developed over time using an abductive approach during the research process that included elements of analysis, an approach in line with Eisenhardt (1989), who writes that multiple sources of evidence should be used to build ‘construct measures’ that define the constructs and distinguish them from other constructs. These measures are then used to test how well the constructs fit the data for each case. If necessary, constructs are modified (or even rejected), which triggers new definitions, tests, etc. in an iterative process. The central idea is, according to Eisenhardt (1989) that:

“... researchers constantly compare theory and data – iterating toward a theory which closely fits the data.” (p. 541)

Figure 17. The iterative procedure in RQ1 – going between literature and cases

As a final step, with the final set of challenges at hand, I performed a cross-source analysis by revisiting both literature and cases to assure that all relevant information regarding each challenge was captured. Braun and Clarke (2006) advocate such a revisiting to check that there is a good match between the defined categories and the entire data set and also as input for clear definitions and labels of the categories. This compilation provided me

¹⁴ Appendix 6 provides an example of how this database was created.

with the material necessary to prepare the final descriptions of each challenge, which are presented in Chapter 4.

2.6.2 Research question 2 – Thresholds for learning total cost analysis

For each case, I gathered teachers' and students' opinions about difficulties with learning TCA.¹⁵ By bringing the suggested difficulties from all respondents in all four cases together, all difficulties brought up were viewed holistically. Single opinions, being rather vaguely described by individual respondents, were disregarded. However, most were considered relevant and mentioned by more than one respondent. These were grouped into four learning difficulties to be analysed with the help from literature.

Characteristics for learning thresholds are well described in the literature (see section 5.1). Each learning difficulty that was identified during the case studies was compared with the threshold learning characteristics to evaluate whether they qualified as a threshold for learning TCA.

2.6.3 Research question 3 – Teaching methods supporting total cost learning

Unlike the threshold characteristics (discussed in 2.6.2), the characteristics of constructivist teaching are not clear-cut in the literature. Therefore, I performed a content analysis of articles and books to search for characteristics. The sources found in the literature search (described in section 2.4.3) were entered in an Excel database. Screening each source, I found characteristics of constructivist teaching and documented these in the database, either under an already defined heading or under a new one (if the characteristic differed too much from the already existing ones). When the literature screening was completed, I reviewed all characteristics, looking for similarities and differences. This resulted in some changes in headings, where some were grouped together, and others split up. This process identified several essential features of constructivist teaching.

In a similar manner as described in section 2.6.2, teachers' and students' views were gathered concerning educational activities supporting learning of TCA. As similar educational activities were brought forward from case to case, selecting between these did not become an issue.

The respondents' opinions concerning advantages and essential aspects of these methods were compiled and compared with the features derived from theory to find out if there was a match between constructivist-based approaches considered good in general and the educational activities actually being used according to teachers and students. Such a

¹⁵ It should be noted that student respondents were present in just two of the four cases.

match strengthens the probability that the activities regarded positive by the respondents really contribute to the students' learning of TCA. However, this study did not examine the students' actual learning.

2.6.4 A note on within-case and cross-case analysis

In literature on multiple case studies, it is stressed that *within-case* as well as *cross-case* analysis should be performed, see e.g. Merriam and Tisdell (2016) and Yin (2018). Concerning the within-case analysis, (i.e., the analysis of each individual case), Merriam and Tisdell (2016) conclude the following:

"Data have usually been derived from interviews, field observations, and documents. In addition to a tremendous amount of data, this range of data sources may present disparate, incompatible, even apparently contradictory information. The case study researcher can be seriously challenged in trying to make sense out of the data." (p. 233)

In cross-case analysis, the same type of challenges occurs (disparate, incompatible, and contradictory information), but on another level. The quotation above indicates that within-case analysis (and analogously also cross-case analysis) compares data to find similarities and differences between data sources or between cases. An underlying ambition is to position cases or individual data sources against each other in a comparative manner. This comparison could be used to enable grading of the cases, as mentioned by David and Sutton (2011).

In this study, with its exploratory focus, comparative evaluation has not been regarded to be of major importance. Therefore, in the previous sections, procedures for within-case and cross-case analysis are not presented as clearly as literature suggests. Undoubtedly, some comparisons have been made, for example, to find potential contradictory statements from students and teachers from the case universities. However, focus has been on discovering, for example, potential challenges with conducting TCA. A potential challenge mentioned by several respondents in several cases might increase the probability that this aspect is important enough to be included in the challenges finally proposed. However, a potential challenge mentioned by just a single respondent might be of high value because of its embedded appropriateness. Therefore, analyses within and between cases were not in focus. For RQ1, the challenges rather evolved in a cross-source analysis where the content analysis of literature was expanded to also include the cases, as described in 2.6.1. For RQ2 and RQ3, a kind of cross-case analysis was made to select which learning difficulties and educational activities to compare against theory. However, this was not made with the ambition to compare the cases by pointing out similarities and differences between them.

The final section of this chapter addresses the study's trustworthiness.

2.7 Building trustworthiness into the study

Quite a high number of different aspects of quality suitable for qualitative research is mentioned in the literature, see e.g. Bryman and Bell (2011), Yin (2018), or Cohen et al. (2011). I have chosen to use the term *trustworthiness*, elaborated upon by e.g. Halldórsson and Aastrup (2003) and Bryman and Bell (2011), which includes four aspects that will be discussed in the coming sub-sections: *credibility*, *transferability*, *dependability*, and *confirmability*.¹⁶ In this section I will focus on what measures I took to build trustworthiness into the study. In Chapter 8, I evaluate the resulting trustworthiness in retrospect.

2.7.1 Credibility

A general characteristic of qualitative research is that it is close to impossible to make exact representations of reality. The researcher has to interpret reality to gain understanding and to make sense out of the collected data (Merriam and Tisdell, 2016; Ghauri and Grønhaug, 2005). However, research respondents base their experiences on their interpretations of reality. The researcher then becomes an interpreter of interpretations, a phenomenon Halldórsson and Aastrup (2003) discuss. Because interpretations may obscure the representation of reality, the researcher should strive to make the representation as credible as possible. To ensure the credibility of these representations, respondents should have the chance to comment on the researcher's interpretations, see e.g. Halldórsson and Aastrup (2003) and Yin (2018).

Credibility checks in my research

According to the discussion above, all research is in some way afflicted with interpretation. All data in this research have one way or another been interpreted by me. This is also the case for focus groups, interviews, and the literature.

The books, articles, and master's theses I have read are to some extent results of interpretations made by their authors, and it is possible I might have misunderstood the authors' intent to some degree. However, the use of literature, with its embedded interpretations, is a standard source of information in research and not unique to this study. It would be unreasonable to check with every author concerning my interpretation of their texts. However, I used multiple literature sources, which in turn contributes to increased credibility.

Sometimes I was unsure about the meaning of certain statements made in the focus groups and interviews. To limit these ambiguities, during the sessions I directly asked for clarification when the respondents' statements were unclear to me. As these sessions were

¹⁶ These authors have borrowed the categorization from Guba & Lincoln (1989): *Fourth Generation Evaluation*, Sage Publications.

recorded, I did not risk losing important aspects because of not taking notes. However, my interpretation of statements could still deviate from the respondents' intentions. Therefore, the case descriptions for each studied case were given to the respective contact persons for validation, further increasing credibility.¹⁷ This led to only a few minor modifications in the descriptions.

The use of multiple sources in each case also limits the risk of incorrect interpretations. For example, the students' and teachers' opinions often confirmed each other, something that increased the credibility.

2.7.2 Transferability

When qualitative research is concerned, generalizability in a traditional sense, meaning that a result is valid and true in other contexts, is most often not applicable. However, results from specific cases can to some extent be transferrable to other cases.

Transferability describes the usefulness of the results in other contexts. In contrast to positivistic research, where the researcher is supposed to convince the reader that the research is 'generalizable' to other contexts, the 'burden of proof' here rests on the receiver (Larsson, 2005). This, however, requires that the researcher gives the receiver the possibility to evaluate the findings. For example, Merriam and Tisdell (2016) and Bryman and Bell (2011) recommend researchers to include so called 'thick descriptions' describing the context well enough to make it possible for readers to make their own evaluations of the transferability to their specific contexts.

Indeed, I used thick descriptions of the context – i.e., each of the four studied cases is presented in detail (see appendix 9).

2.7.3 Dependability

Traditional positivistic research requires that a study should be designed and reported so it can be replicated. However, research that relies on case studies cannot be replicated as it is impossible to recreate the same settings. Merriam and Tisdell (2016) argue that in qualitative case studies the exact method should be gradually developed during the study; this means any attempt to repeat such a study will and should not give the same result. However, what is important is to provide the ability for another researcher to conduct a new case study in as similar fashion as possible in order to test the findings presented in the research. Merriam and Tisdell (2016) and Bryman and Bell (2011) propose that this

¹⁷ Of course, the contact persons' views of reality might differ from the respondents' views. This means that another layer of interpretation arises. However, the contact persons are supposed to have a better general picture of their contexts than I have, so I believe this kind of check should increase the credibility of the study. The alternative to ask every respondent for feedback was dropped because individual statements were anonymized in the case reports.

is achieved by carefully documenting the case study procedures. Yin (2018) agrees to this and proposes that the process steps are made as operational as possible. He recommends that a ‘chain of evidence’ is established throughout the research, making it possible for an external observer to:

“... follow the derivation of any evidence from initial research questions to ultimate case study findings” (p. 134)

Yin states that the chain of evidence requires the following. *First*, the final reporting of the study itself refers to relevant parts of the ‘case study database’ (i.e. different information collected, such as field notes, documents, narratives etc.). *Second*, the case study database contains all necessary evidence, including procedures for how these were retrieved. *Third*, these procedures are in line with what was stipulated in the ‘case study protocol’, i.e. the plans and tools that guide the collection and analysis of data.

I have tried to live up to this by providing a thorough description of the research procedures, for example, by reporting exclusion criteria for literature I did not find relevant, keeping track of all literature by using a protocol with certain categories, and clearly explaining the procedures I have used for case selection, data collection, and analysis.

2.7.4 Confirmability

The possibility to confirm the researcher’s conclusions is partly addressed by the dependability criterion, but confirmability also refers to the researcher’s objectivity (Halldórsson and Aastrup, 2003). Bryman and Bell (2011) mention personal values and theoretical standpoints as examples of aspects that might (but should not) colour an investigation. Cohen et al. (2011) notes that researcher bias can be in the form of ‘illusory confirmation’ – the tendency of finding relationships even if they do not exist. Illusory confirmation could be the case if the researcher is unable to take an objective stance, but lets the desired outcome affect what is discovered. In the following, some comments are made regarding the confirmability in this thesis.

Illusory confirmation - finding what you would like to find

As Yin (2018) stresses, the researcher may see explanations and patterns even where evidence is weak. One measure that can be taken to avoid this is to document each case carefully before starting the analysis. Since it would be disappointing for me not to find many suggestions on challenges, learning obstacles, etc., I can see the risk of seeing more in the data than there really is. To limit this risk, I took some concrete preventive actions, as described in the following.

In the first part of the literature study (logistics textbooks), a colleague and I both read a few books and compared our findings concerning how TCA was covered in general and

in particular concerning which challenges were mentioned. As there was a high inter-reliability between our findings, this gave me comfort I was not ‘overestimating’ the challenges.

When conducting the first focus group session, another colleague took notes of the discussion. After having listened to my recording and made a first ‘selective transcription’ (i.e., having chosen the parts of the discussion I considered to be of interest for further analysis), we compared our respective documentations. My colleague’s notes (containing the parts considered most essential while taking notes) and my semi-analysed documents proved to be in good harmony with each other.

After having documented and analysed all case studies and performed within-case as well as cross-case analyses, a few colleagues compared my proposed findings with the case documentations.

With the abductive approach I have followed, analysis has been an integrated part of the research process. This means that to a certain degree analysis was performed successively. As just mentioned, I made some analysis already in my first write-up of the cases, so I did not follow the recommendation made by Yin (2018) to document the cases carefully before the analysis. However, during the final phases of analysis, I revisited all case descriptions to further strengthen the analysis. This is in line with Merriam (1998), who is in favour for successive analysis, and stresses the relationship between analysis and data collection:

“[It] is not to say that the analysis is finished when all the data have been collected. Quite the opposite. Analysis becomes more intensive as the study progresses, and once all the data are in.” (p. 155)

About researching one’s own practice

One of the cases selected for this research is the specific division at Linköping University, where I work. That is, I have strong personal relations with the respondents. Furthermore, I am familiar with the courses that are provided and have been actively engaged in several of them. As the former Director of Studies for the division (i.e., responsible for course content as well as pedagogical issues), I am well aware of how TCA has been discussed among my colleagues over the years.

A high level of pre-understanding has advantages as it makes it possible to gain access to more information than would otherwise have been possible (Siggelkow, 2007). On the other hand, as e.g. Merriam and Tisdell (2016) discusses, familiarity with a case presents a risk for bias.

One of my main concerns in the research was how to deal with this risk of my own bias, which could result in leading my colleagues in a certain direction. To counteract this, during the preparation of the case study I did not discuss with them the preliminary

challenges, learning obstacles, etc. Of course, they were long aware of my research topic, and some of them showed high interest in it, but I kept my thoughts to myself until the interviews and focus group sessions were performed and documented. During the sessions, I let the respondents speak rather freely to catch aspects they spontaneously came up with. I worked in this manner for all the cases, but I was extra careful during the data collection in Linköping.

Moreover, I am the co-author of a logistics textbook¹⁸ that discusses TCA. Obviously, this textbook reflects my pre-understanding of the subject. Therefore, my use of this textbook as a source of evidence when constructing the challenges might compromise my objectivity. However, using this book as one input among many, I do not consider this a significant problem. In my view, it would have been more questionable to leave out a book clearly addressing the research questions just because I am the co-author. To avoid possible over-estimation of this book's contribution, this was one of the books selected for double reading (as described in a previous sub-section).

¹⁸ Oskarsson et al (2013), *Modern logistik*, Liber

3 Presentation of the studied cases

In this chapter, the four studied cases are briefly presented. A more thorough case description, including the outcome of the data collection is provided in Appendix 9.

3.1 Linköping University

Linköping University, based in Linköping, Sweden, has approximately 27 000 students, divided into four faculties, and four campuses. Logistics is almost exclusively part of study programs at the Faculty of Science and Engineering, where two departments offer logistics courses at Campus Valla (in Linköping) and Campus Norrköping. The case studied in this research is the logistics education at Campus Valla, provided by the Department of Management and Engineering, mainly by the Division of Logistics and Quality Management.

Programs and courses

Logistics education is mainly provided to students from two five-year engineering programs. During the two final years (master's level), the students can choose to specialize in Logistics Management. Approx. 50-70 students follow these so called 'master profiles' each year. The master profiles account for 66-90 ECTS¹⁹ credits (it differs between the two programs). 30 of these are devoted to a master's thesis project, and the remaining are for courses. There are 14 logistics-related courses available, three of them mandatory and the others elective.

Total cost analysis in the courses

In four of the courses, TCA is explicitly addressed, and in many of the others more implicitly. There are specific exercises and teaching cases devoted to TCA, where the issue is addressed with calculations as well as qualitative discussions. In other educational activities, total cost calculations are performed in connection to different logistics decision situations.

3.2 Lund University

Lund University, based in Lund, Sweden, has approximately 29 000 students, divided into eight faculties, and three campuses. Logistics is almost exclusively part of educational programs at the Faculty of Engineering, mainly at Campus Lund, which is in focus in this research. The logistics courses are provided by the Packaging Logistics

¹⁹ ECTS - European Credit Transfer System - is a European standard for calculating course work. 60 ECTS equal one year of full-time studies.

Division (part of the Department of Design Sciences), and the Engineering Logistics Division (part of the Department of Industrial Management and Logistics).

Programs and courses

Logistics education is mainly provided to students following a two-year, 120 ECTS credit, master's program in Logistics and Supply Chain Management and to students from two five-year engineering programs, where 120 credit specializations within Logistics / Supply Chain Management can be selected. The same courses (more or less) are included for all these student groups. 30 credits are devoted to a master's thesis project, and 90 to courses. There are 17 logistics-related courses available. At the MSc program, eight courses are mandatory, and another four must be selected to reach the 120 credits. For the students following specializations, there are no mandatory courses at all, it is up to the students to pick a suitable combination of twelve courses. Each year, about 60 students follow the MSc program or the specializations.

Total cost analysis in the courses

In two of the courses, TCA is explicitly addressed, with specific exercises and teaching cases devoted to TCA. In other courses it is implicitly covered. Total cost calculations are regarded as important, but more stress is generally put on the principal understanding of trade-offs between costs, and between costs and other aspects.

3.3 Chalmers University of Technology

Chalmers University of Technology, based in Gothenburg, Sweden, has approximately 10 000 full-time students. The university has two campuses and 13 departments, of which the Department of Technology Management and Economics is the main provider of courses within logistics. Within this department, two divisions are responsible for different courses: The Division of Supply and Operations Management, and the Division of Service Management and Logistics.

Programs and courses

Logistics education is mainly provided to students following a two-year, 120 ECTS credit master's program in Supply Chain Management. Compared to the Lund and Linköping cases, this program has a broader content, as it covers more than the logistics aspects of supply chain management. In total, 28 courses are available, of which 17 are categorized as logistics-related. There is, however, a logistics core in the program, since all eight mandatory courses are logistics-related. Each year, about 60 students follow the MSc program.

Total cost analysis in the courses

TCA is explicitly addressed in three of the courses and covered in exercises and teaching cases. Typically, these courses discuss qualitative issues concerning cost trade-offs, cost effects, etc., and to a lesser extent calculations are performed.

3.4 Hanken School of Economics

Hanken School of Economics operates at two locations in Finland, Helsinki and Vaasa, and has in total about 2 500 students. Logistics-related courses are offered to students in Helsinki at bachelor's and master's level. Courses within logistics are provided by the Supply Chain Management and Social Responsibility fraction of the Department of Marketing.

Programs and courses

Logistics education is provided to students following a three-year, 180 ECTS credit bachelor's program in Economics, and a two-year, 120 ECTS credit master's program in Economics. In the BSc program, one logistics course is mandatory and four logistic courses are electives taught by Hanken faculty, but other courses are provided by another HEI that collaborates with Hanken.

Students following the MSc program can specialize in different majors or tracks, among them Supply Chain Management and Social Responsibility, and Humanitarian Logistics. The same courses are included in both these tracks, but with a difference concerning which ones are mandatory. Four courses (summing up to 30 ECTS credits) and a 30-credit master's thesis project are mandatory. The remaining 60 credits are selected among courses within and outside the logistics field. 12 courses are available in the logistics and supply chain management field. Compared to the other cases, Hanken offer courses related to logistics, rather than courses specifically focusing logistics. Each year, about 20-25 students follow the MSc major/track.

Total cost analysis in the courses

TCA is not a central part of any of the courses. However, total cost issues are present in many of courses, mainly through qualitative reasoning, while cost calculations receive little attention.

3.5 A comparative overview of the cases

In Table 11 below, some aspects of the four cases are presented to give on overview of the similarities and differences between them.

Table 11. Facts about the four HEI cases

	Linköping	Lund	Chalmers	Hanken
Country	Sweden	Sweden	Sweden	Finland
Student group	Engineering	Engineering	Engineering	Business
Level of logistics studies	MSc	MSc	MSc	MSc (+BSc)
No. of MSc level students	50-70	60	60	20-25
No. of MSc logistics courses	14	17	17	12

4 Challenges with Total Cost Analysis

In this chapter, focus is on the first research question: *What challenges are connected to the process of conducting total cost analysis?* The set of challenges presented in this chapter was developed with help from literature and case studies, and the procedure for determining these challenges is described in section 2.3.3.

To start with, based on literature the steps in the total cost process are described in section 4.1. In the subsequent sections the challenges with conducting total cost analysis are presented. In section 4.2, using both literature and empirical material, the steps are more carefully described, and the challenges connected to each step are presented. Finally, the interrelations between the challenges are discussed in section 4.3.

4.1 The process of conducting total cost analysis

A TCA project can be viewed as a process covering a number of activities or steps. Although many authors cover specific parts of TCA, only a few describe a more holistic view of the steps included in a TCA process. The most thorough process descriptions come from the Life Cycle Costing field, and are given by Nato (2007), Mislick and Nussbaum (2015) and IEC (2017). Within the logistics discipline, Bowersox et al. (2013) and Oskarsson et al. (2013) provide the process descriptions with best coverage. In the case of Bowersox et al, the suggested process covers logistics development projects in general, rather than specifically designed for TCA, but the authors use cost analysis for some examples. During the reading of the literature, five major process stages emerged as a suitable division for a rough process description: *Setting the scope*; *Cost modelling*; *Calculations*; *Critical review*; and *Presentation*.

Although the authors do not agree on the process and do not share terminology, the literature reveals similarities. Table 12 lists the authors' process content under these five stages. Drawing on this information, twelve process steps were defined and sorted under each of the five process stages. These are presented in the following sections²⁰.

²⁰ The authors' different terminology is preserved in the table. However, the steps presented in the subsequent text are labelled by me, why there are some deviations in labelling between the text and the table.

Table 12. Process stages in total cost analysis, source by source

Source	Setting the scope	Cost modelling	Calculations	Critical review	Presentation
Bowersox et al. (2013)	Understand current processes System boundaries Define alternatives	Measurements Identify data sources Analysis techniques	Collect data Validate data	Sensitivity analysis	Managerial report Qualitative rationale Quantitatively justified
IEC (2017)	Boundaries of analysis Define alternatives Define time horizon	Define cost factors How to collect data How to calculate	Collect data Cost allocation	Identify uncertainties Sensitivity analysis	
Mislick & Nussbaum (2015)	Defining the system Estimate the relative importance of costs	Select cost estimation approach Identify data sources	Collect data Process data to be comparable	Identify uncertainties Sensitivity analysis	Complete Understandable
Monczka et al. (2010)	Map current process	Define cost factors How to measure	Collect data Calculate costs		
Nato (2007)	System boundaries Define time horizon	Define cost factors Define input data	Collect data Calculate costs	Sensitivity analysis	Report + oral pres. Range of probable outcomes
Oskarsson et al. (2013)	Define alternatives System boundaries	Define cost factors Define input data How to calculate	Collect data Calculate costs	Identify uncertainties Sensitivity analysis	
Perng et al. (2012)	Define alternatives Project the future Simplifications	Define cost factors Define input data How to calculate	Collect data		
Sakao and Lindahl (2015)	Define alternatives System boundaries		Collect data Calculate costs	Sensitivity analysis	
White et al. (1993)	Define time horizon	Define cost factors How to calculate	Allocation of costs to the alternatives		

4.1.1 Setting the scope

All the authors highlight the need for scoping the study from the start to set the scene for the more detailed planning that will follow. Bowersox et al. (2013) states that:

“... system design and planning provides the foundation for the overall analysis. A thorough and well-documented problem definition and plan are essential to all that follows.” (p. 312)

Most of the authors stress the need for *defining the alternatives to be compared*. If not given from the start, it must be made clear which alternatives to evaluate. In some cases, the alternatives come rather naturally, but in other occasions it is a task that must be done in the scoping stage.

Defining the system (i.e. to decide which parts to include in the investigation), is another thing stressed by most authors. This includes e.g. to identify which activities need to be analysed for their cost effects.

In some cases, the quality of the analysis will depend on which time perspective is applied, e.g. expected lifetime of certain investments. *Making time considerations* is therefore an important step, to clarify if and how the time perspective is to be handled.

The last step concerns putting the costs into a larger context. Sometimes, cost may be the only factor that guides a decision, but often other aspects are important too. *Identifying other aspects of importance* for the decision to be made is therefore important, including

how crucial the costs are, relative to the other aspects. As Mislick and Nussbaum (2015) propose, the higher relevance of the costs, the more thorough must the subsequent steps be planned and executed.

4.1.2 Cost modelling

Cost modelling refers to the more detailed planning activities that take part when the scope of the study is set. This area is discussed by most authors. Although Bowersox et al. (2013) do not explicitly focus on cost analysis, transferred to a cost context their aspects correspond well to the other authors'.

Although some cost categories are frequently relevant, for every new study it must be decided which cost categories that are to be considered for each specific case. Therefore, *selecting cost categories* to include is the first step in this stage.

The next issue deals with *selecting calculation models* – i.e. planning how to calculate the selected costs. There are often alternative models, formulas etc. available, and it is important to understand which one best represents reality in a specific situation.

Performing calculations, data are required. Although formulas and models principally define which input data are required, there are still some issues that must be handled, such as the amount of data needed to get a good enough basis for the analysis. Hence, *defining required input data* is considered a step of its own.

4.1.3 Calculations

Although cost calculation could be regarded as necessary by implication, all but one author explicitly address this area.

Retrieving input data needed for the calculations is the first, and often rather time-consuming, step. Sometimes, data are readily available, but at other occasions, data collection can require quite an effort.

Once data are gathered, it should not be taken for granted that calculations can start right away. *Processing input data* is for different reasons often necessary, since the retrieved data might not be in a form directly usable in the calculation models. For example, Mislick and Nussbaum (2015) stress that data often must be normalised, i.e. adjusted to a comparable format. IEC (2017) and White et al. (1993) discuss cost allocation, i.e. that retrieved costs might be bundled and therefore have to be allocated to the specific products, projects etc. in a fair manner.

4.1.4 Critical review

As the previous steps require making many assumptions, cost calculations will not provide unquestionable results. A certain level of uncertainty will always be embedded, and six of the nine authors address the need for critically reviewing the results.

While numerous uncertain factors might be embedded in a TCA, a few authors point out the importance of finding which factors are the most uncertain. *Identifying the uncertainties*, including their relative importance, is the first step in the critical review.

The next step deals with *analysing the effect of uncertainties*, i.e. to analyse how big impact the uncertain factors have on the result. This is made by some kind of sensitivity or uncertainty analysis.

4.1.5 Presentation

After performing a TCA, the results should be presented to the decision makers and other potential stakeholders. Only three of the authors discuss the presentation of the TCA as a specific step in the process. However, both Perng et al. (2012) and IEC (2017) address the importance of having the target audience in mind during the process by using, for example, analytical and communicative techniques that make the information accessible to the audience. Because TCA is difficult to understand for the uninitiated and often produces a great deal of information, the audience's understanding of the analysis will be influenced by how this information is communicated as well as by what information is included. Hence, *selecting content and presentation format* is defined as a step in the presentation stage of the total cost process.

4.1.6 A compilation of the steps

Having briefly presented the steps associated with the different stages in a total cost investigation, a compilation is presented in Figure 18.

STAGE	STEP
Setting the scope	1. Defining alternatives to compare
	2. Defining the system
	3. Making time considerations
	4. Identifying other aspects of importance
Cost modelling	5. Selecting cost categories to include
	6. Selecting calculation methods
	7. Defining required input data
Calculations	8. Retrieving input data
	9. Processing input data
Critical review	10. Identifying uncertainties
	11. Analysing the effect of uncertainties
Presentation	12. Selecting content and presentation format

Figure 18. Steps in the total cost analysis process

Now, the stage is set for diving deeper into the steps presented above and for discussing the challenges associated with each of these steps.

4.2 The challenges, defined and discussed

In the previous section, twelve steps associated with total cost analysis were introduced. Each of these steps will now be discussed in separate sections, and challenges connected to these steps are presented using findings from the literature and the cases. It should be noted that all challenges described are not present in all practical situations. Rather, they should be viewed as *potential* challenges that might be present in the respective steps.

4.2.1 Step 1 - Defining alternatives to compare

Most authors discuss TCA assuming that there are given alternatives to compare. How these alternatives have been defined is not addressed: it is a non-issue for these authors. Truly, the alternatives to consider are sometimes rather obvious or provided to the cost investigator by someone else. However, the situation can also be more complicated, and the issue of defining these alternatives can therefore be part of the total cost investigation. Although many authors disregard this issue, some address it. Bowersox et al. (2013) as well as Oskarsson et al. (2013) present step-wise approaches for logistics investigations, including but not limited to TCA. These authors include the definition of alternatives as an important early step in the process. In addition, IEC (2017) and Bacchetti et al. (2018)

point out the need for specifying the alternatives, something that can be difficult, especially for novice investigators according to the teachers from Case Linköping and Case Chalmers.

In some situations, the alternatives must be created, since ready alternatives do not exist. If for example a company would like to reconfigure its distribution system, different options for how to configure the distribution must be developed, something that requires a good knowledge about distribution systems. As inspiration for defining alternatives, Bowersox et al. (2013) and Oskarsson et al. (2013) suggest literature and competitive industry practices. Benchmarking and best practice studies are also suggested by Abrahamsson and Aronsson (1999). Even though e.g. a distribution system cannot be copied from one company to another, valuable experiences can be gained from studying similar projects in similar settings.

At other occasions, there are numerous potential alternatives to choose from. When selecting a supplier for a commodity, there might be hundreds of companies around the world ready to deliver. Some kind of pre-selection has to be done to reduce the number for the final comparison. This might be done on certain aspects that are regarded important (such aspects are further discussed in 4.2.4) such as lead time or quality certification. A more thorough procedure might also be required. Within supplier selection, Dayama and Jidugu (2009) recommend cross-functional cooperation for identifying the alternatives, to ensure that all essential aspects are regarded.

How many alternatives to compare depends on for example the number of existing alternatives, how much available time there is for the analysis, and how important the decision is. Bowersox et al. (2013) argue that the less frequently the existing solution is challenged the more options should be considered. They stress that the alternatives should “*challenge existing practices, but they must also be practical*” (p. 317) and they also raise a warning that too many options can result in very time-consuming evaluation, an opinion shared also by e.g. Saccani et al. (2017).

Green et al. (2017) stress that to estimate the true savings, the alternatives considered must be compared to the present state, where no interventions are made, i.e. costs for the ‘do nothing’ alternative must also be calculated. This aspect was also expressed by the Hanken teachers.

Based on the discussions above, the following challenges are connected to defining alternatives to compare.

- *To define potential alternatives*
- *To decide how many alternatives to include*
- *To select the ones to include from the potential alternatives*

4.2.2 Step 2 - Defining the system

Defining the system includes not only deciding what to include in the investigation but also from which perspective to view the system.

The system boundaries are important

More than 70 years ago, Walker (1946) noted that companies calculating marketing costs did not consider the costs of other actors in the supply chain. The fact that decisions within a firm might affect the costs of other firms is confirmed by e.g. Kosior and Strong (2006), who state that “*total cost analysis is a concept without clear boundaries*” (p. 354). The scope and size of the total costs included depend on the size of the studied system, so how the system boundaries are defined will affect the total cost calculations, as indicated by e.g. Anderson and Taylor (1977) and Larson (1992). A Hanken teacher gave an example of a U.S. company that outsourced some operations to Mexico to cut costs. The company, however, failed to consider that the inventory would be affected. In fact, the increased unpredictability in supply forced them to put up a big safety stock. In the end, it turned out that the total costs rose after the outsourcing, partly because the company did not understand what to include in the system when estimating the costs.

A good understanding of the processes is important

According to both teachers and students at the case universities, effectively drawing system boundaries is difficult. Waller and Fawcett (2012) note that the investigator needs a good understanding of the processes. In line with this, discussing distribution structures, Abrahamsson and Aronsson (1999) argue that an understanding of the system is necessary in order to identify which parts of the supply chain to include in the system. They, as well as Ellram and Maltz (1997) suggest performing a flow analysis that includes all activities and the links between them to help understand the system and the associated costs and to ultimately set the system boundaries. Such an analysis was also recommended by the teachers at all four case universities; however, a teacher from Lund stated that a flow analysis might be difficult, especially when the scope covers more than one company in the supply chain. Ellram and Maltz (1995) describe a case of a potential outsourcing of manufacturing to a supplier. They argue that input from the potential suppliers is needed to understand the processes: “*Suppliers should be involved in any in-depth TCO [total cost of ownership] analysis relating to outsourcing*” (p. 64). In situations where the decision concerns whether to replace an existing solution, a thorough mapping of the current state is also needed, as discussed in section 4.2.1.

Where to set the boundaries – what should be included?

White et al. (1993) report that there is a tendency to “*draw narrow boundaries around costs, savings, and revenues ... thereby omit or underestimate the potential returns*” (p. 248). Actually, the ‘returns’ could be overestimated as well, even though this is not

discussed by White et al. Since the system boundaries could be set differently, it is important to be explicit about the implications of the chosen system. Examining a selection of production equipment, Bacchetti et al. (2018) for example, clearly state that certain parts of the manufacturing activities were excluded from their analysis, as these parts did not affect (and were not affected by) what was focused in the study.

When viewing the world with a systems approach, every chosen system is part of a larger system. Churchman (1968) concludes that sub-optimization therefore is inevitable. According to him, a solution for a given system is doomed to be insufficient, since from a wider perspective even more aspects would play a part. One teacher asked whether system boundaries could be an issue at all, considering the word ‘total’ in total cost analysis: *“In ‘totality’ I think I would consider everything. I don’t think you can set boundaries then.”* (Hanken teacher 1). Although too small systems should be avoided to limit sub-optimization, too large systems would in practice be too hard to handle (which this particular teacher also admits). As everything cannot be included, Bowersox et al. (2013) stress the need for defining constraints and limitations that fit the problem.

Worth noting is that although it is objectively preferable to have a wide system (since this will reduce sub-optimizations), some stakeholders might not appreciate such a holistic view because cost savings might not benefit them. Alam et al. (2017) as well as Linköping teachers note that minimizing total system cost might be insufficient, if the chosen solution fails to ensure that each stakeholder makes a profit. Different actors may look at the system from different perspectives, which leads into the next section.

System viewed from different perspectives

Closely related to the issue of setting system boundaries, is the matter of which perspective to take when viewing the system. Teachers from all four case universities raise this as an important issue. Similarly, Asiedu and Gu (1998) conclude that the life cycle cost of a product consists of the costs for the manufacturer, user, and society, and that these different actors are interested in different parts of the total cost. Hence, what is included in the total cost might depend on the perspective taken. In the context of inventory management, Wu (2005) and Chopra and Meindl (2016) point out that the conclusions will differ if costs are viewed from the independent actors in a supply chain, or from a joint perspective. Cavinato (1992) gives an illuminating example concerning system boundaries as well as the perspective of viewing the system. Discussing the cost for buying a certain product, he provides five examples on how the ‘goal function’ affects how to define and view the system.

- Lowest price paid to the supplier
- Lowest landed cost, i.e. incl. all costs until the product has ‘landed’ at the company
- Lowest total cost for the buying firm
- Lowest total cost for the final firm in the supply chain
- Highest total value to the ultimate customer of the final firm

When discussing pollution prevention projects, White et al. (1993) conclude that effects on public health or ecology might cause considerable cost effects on a societal level, although from a company perspective these will not be seen in the calculations. Depending on whose perspective is taken, system boundaries may be different, and so will the design of the total cost analysis.

The following challenges are derived from the discussion above.

- *To understand and describe the system (flows, processes etc.) sufficiently*
- *To set the system boundaries*
- *To understand which system perspective(s) that are most important to consider*

4.2.3 Step 3 - Making time considerations

Different types of time considerations are addressed in the literature, highlighting the need for awareness of how the time perspective affects the total cost analysis.

Costs are not always stable over time

We live in a dynamic world. What we see today might look different next year. Only looking at the present costs or the expected costs for the next year, without considering how these will change in the future might result in an insufficient analysis (Weingarten, 1992; Sanders, 2017). Paton (1966) gives an early example where outsourcing of manufacturing in the short run might lead to unused facilities and increased associated costs. In the longer run however, the facilities might be sold or used internally, i.e. depending on the time perspective, the cost picture will look different. Since Paton's work, several authors have addressed the need for a long-term perspective on costs. For example, Wildern and Isaacs (1998) deal with pollution prevention projects, Kumar and Kopitzke (2008) discuss the costs of outsourcing, and Harrison et al. (2015) examine supplier selection.

How far into the future should we look?

Because cost affecting parameters might change over time, Poist (1974) and Dayama and Jidugu (2009) point out that the time-perspective chosen can affect decisions. Hence, determining a time horizon to consider is crucial albeit difficult. When, for example, investing in production equipment specifically aimed for manufacturing a newly developed product, it is difficult to tell how long the product will be produced before replaced by the next product generation. Both Asiedu and Gu (1998) and Xie et al. (2018) state that the longer into the future you look, the more uncertain are the figures.

Investment costs

Many changes are associated with some sort of investment or one-off cost. When, for example, considering a change from manual order picking to an automated picking solution, a considerable investment in warehousing equipment is required. Adding to this, the ‘change-over’ from one state to another can also be seen as an investment, since it requires management capacity, training of personnel etc. as mentioned by teachers in Case Linköping as well as in literature (Agarwal, 2008; Eggimann et al., 2016). An example of this is searching for new suppliers and building relations with them (Moeller, 2002). Investment costs are present in many situations, such as weapon-system projects (Fisher, 1956), pollution prevention initiatives (White et al., 1993), space missions (Remer et al., 1992), and set-up time reduction in manufacturing (Nye et al., 2001).

Hence, investment costs might be predominantly visible (e.g., costs for buying warehousing equipment) or invisible (e.g., time spent by management), but nevertheless relevant to include in a TCA. Since the expected lifetime might differ between investment alternatives, the investment cost should be spread out to enable a comparison of, for example, yearly costs. However, the longer the new system is supposed to be up-and-running, the less influential the investment will be on the total cost.

If a decision to change is already taken (e.g., concerning the automation of order picking in the warehouse), it could be argued that no matter which equipment supplier is chosen, the costs for the change-over (training, management etc.) will not differ between the alternatives. This might be true, but certainly not always. One specific type of equipment might require longer time to assemble and get running than another type. Another factor to consider is whether the alternatives have the same expected lifetime. The investment should be spread out over the expected lifetime; with a shorter lifetime, each year will carry a larger part of the investment cost.

Hence, challenges related to time consideration are as follows:

- *To define the time period which the analysis should cover*
- *To define the expected lifetime of the different alternatives*

4.2.4 Step 4 - Identifying other aspects of importance

Although the cost in many situations is an important factor when making decisions, it is not necessarily the only one. There is a strong agreement between teachers and students at the four universities that other factors must be considered along with the costs. This view is also highlighted by several authors, explicitly in principal discussions as well as implicitly in cases described where TCA is performed.

It could be argued that TCA could be conducted in isolation, and the TCA results later to be considered by decision-makers together with other aspects. If so, these other decision

factors should not be given attention during the TCA process. However, it is not that easy to separate the costs from other aspects. One reason for considering other aspects when planning a TCA is that cost data is sometimes collected together with other data relevant for the decision. The cost analyst should then be aware of this when planning the cost data collection. Another reason is that other aspects might set the frames for the cost analysis, so they should be considered at an early stage. For example, if a delivery service is of major importance, alternative service levels must be determined to enable the calculation of the costs needed to achieve these service levels.

Potential aspects to consider

Although there might be several factors that are affected by the choice of alternative, all these are not necessarily taken into account when making the decision. Decision-makers may for some reason choose to consider some specific aspects. Which aspects to consider in addition to costs might differ from case to case. The following sub-sections focus on those aspects most commonly discussed by the case respondents and in the reviewed literature.

Profit and revenue

An early example is provided by Walker (1946), who elaborates rather thoroughly on total marketing costs, but at the same time stresses that the lowest cost might not lead to the highest profit. Similarly, Poist (1974), in a critical examination of the total cost concept, states that its biggest shortcoming is that this concept *“does not explicitly consider the impact of alternative service levels upon sales demand”* (p. 16). He concludes that sales revenues together with costs would form a better decision model, a ‘total profit model’. A similar standpoint was raised by students and teachers in Lund and Linköping. The Linköping teachers suggested that it would be more appropriate to talk about ‘Total Value Analysis’, including costs, revenues, and future competitiveness. The interplay between costs and revenues might be rather complex, as illustrated by the following research case from an e-commerce company in the fashion business:

“The big revenue comes from customers who return a lot. If you only consider the costs, the return costs for these customers are very, very high ... What happened was that when they made it hard to return, these customers stopped buying. Then you lose in profitability. And it’s hard to understand this, that’s clear, ... that the profitable customers are the ones with many returns.” (Lund teacher 2)

Discussing make-or-buy decisions, Dale and Cunningham (1984) argue that for such strategic matters *“cost should not be the main decision-making criterion”* (p. 45). Cavinato (1992) stretches the discussion even further, as he suggests that from a supply chain perspective, focus should not be on maximizing a specific company’s profit, but rather on maximizing the end customer’s perceived value. This focus on customer value is shared also by e.g. Lambert and Burduglo (2000).

Clearly, revenues are tightly connected to the service offered to the customers, which is specifically addressed in the next sub-section.

Customer service

It is fair to say that the trade-off between service and costs is a central issue in logistics. This has been argued by many leading scholars over the years, e.g. Poist (1974), Novack et al. (1992), and Esper et al. (2007). Similarly, the respondents at all four case universities highlighted customer service as an important factor to consider. In addition, CSCMP's definition of logistics management, among other things includes the phrases "*efficient, effective ...flow*" and "*meet customers' requirements*" (CSCMP, 2019). Discussing a case concerning distribution alternatives, Shutes (1960) concludes that if the delivery time to the customer could be decreased from seven to three days, the costs would rise, but as the customers would be willing to pay more, it would still be profitable. Short delivery time, or lead time, is an example of a service aspect that some customers will appreciate. Other examples of service factors are timely deliveries, high stock availability, and a generous policy for product returns.

Lambert (1975) stresses the crucial interface between logistics and marketing. Logistics activities contribute to creating customer service (in Lambert's discussion represented by availability), which directly connects to the 'place' component in the 'marketing mix model' (also known as the 'four p model')²¹, and influences the 'price' component in the same model. Lambert mainly discusses the service-logistics interface connected to inventory carrying, a rather common topic treated by e.g. Voorhees and Sharp (1978), Goyal (1987), and Rushton et al. (2017).

As stock availability is tightly connected to the safety stock level, the connection between inventory carrying costs and customer service is rather straight-forward. However, the service-cost interface is relevant more generally, and Lambert's work is used as a general model in textbooks by e.g. Lumsden (2012) and Coyle et al. (2017). Examples of other such interfaces are given by Holweg et al. (2011) concerning global sourcing, and Kim (2014) evaluating packaging systems. The latter explicitly states that "*Logistics activities do not just generate cost, they also generate revenue through the provision of availability*" (p. 30).

It is rather common (Lambert, 1975; Coyle et al., 2017; Rushton et al., 2017) to use the term 'cost of lost sales' as a label of service deficiency, although it is hard to quantify the real cost of poor customer service. Considine et al. (2006) discuss how missed or erroneous deliveries cause costs. They label these costs 'quality costs', which can serve as a bridge to the next category of aspects to consider.

²¹ The four p's are *product, place, price, and promotion*. For details about the model, see e.g. Kotler (2002).

Product and service quality

Kenderdine and Larson (1988) discuss different kinds of quality costs resulting in a total quality cost model. Leaning towards this, Larson (1992) shows that product quality has a clear impact on total logistics costs. Although the cost effect of quality is not always easy to quantify, some authors, such as Larson (1992), Helu et al. (2012), and Nakandala et al. (2016) assign costs to the levels of quality. In the studied cases, only the Chalmers teachers emphasised the importance of quality.

The cost-quality interface is discussed in, for example, manufacturing (Helu et al., 2012), transportation (Nakandala et al., 2016), and purchasing (Sanders, 2017). A specific aspect of quality can be seen in healthcare, where high quality in the processes leads to better patient care and a better quality of life for the patients (and therefore higher end customer value). Quality in healthcare connected to total costs for the care is discussed by e.g. Romeyke and Stummer (2012), Olsson (2016), and Turchetti et al. (2017).

Environmental effects

All respondent groups at the four universities highlighted environmental sustainability as an aspect relevant to consider in many situations. The overlap between economic and environmental considerations is highlighted by e.g. Björklund (2018). Waller et al. (2015) claim that although there might be trade-offs between costs and environmental sustainability, the two often go hand in hand. They argue that ‘systems thinking’ is at the core of the logistics total cost concept, as well as of sustainability initiatives.

Environmental sustainability aspects have become increasingly important. As a consequence, the trade-off between costs and environmental impact has risen in importance. With respect to logistics, emissions related to transportation are the most discussed issue, see e.g. Manners-Bell (2017) or Jonsson and Mattsson (2016). However, other aspects are also discussed, such as packaging (Grant et al., 2017), noise from transports (DeCorla-Souza et al., 1997), and exploitation of nature for building roads, warehouses etc. (Jonsson and Mattsson, 2016).

Looking outside the logistics domain, the aspects considered in combination with total costs include energy consumption in manufacturing (Helu et al., 2012; Schönsleben, 2016), pollution prevention projects (White et al., 1993; Wildern and Isaacs, 1998), and design for disassembly (Wang and Gupta, 2011).

Social effects

Another aspect of sustainability concerns social effects, which was brought up by teachers at Hanken and Lund as well as Linköping and Lund students. Pollution prevention projects may lead to a strengthened corporate image, as well as better employee relations (Wildern and Isaacs, 1998), which can serve as examples of social benefits that are hard to measure. In addition, such benefits often show up after a considerable time, adding to

the complexity (see discussions on time considerations in section 4.2.3). DeCorla-Souza et al. (1997), providing another example of social benefits, refer to how a public transportation system may contribute to community pride, and give socially and economically disadvantaged citizens better access to public life. The Hanken teachers suggest that social effects, such as working conditions, should be considered when evaluating suppliers from developing countries. In addition, referring to the social effects of healthcare, Olsson (2016) and Turchetti et al. (2017) address how better outcome of treatment leads to a better quality of life for the patients.

Risks

Different kinds of risk are at stake in many situations, and these must somehow be considered when making decisions. Bowersox et al. (2013) state that suppliers and/or production facilities in foreign countries may seem a cheap alternative at a first glance, but in the long run they can turn out to be costly due to risk of disruptions in supply caused by for example natural disasters. Kumar and Kopitzke (2008), Young et al. (2009), and Holweg et al. (2011) also discuss the risks associated with choosing suppliers from low cost countries, due to political instability and loss of intellectual property. Similarly, Lund students and Hanken teachers mentioned the relevance of considering risks together with a TCA.

Examples from other contexts are given by Romeyke and Stummer (2012) dealing with risks of poor outcome of medical treatment as something to be evaluated together with costs, and Meyer-Aurich et al. (2016) incorporating risk models and costs when evaluating different alternatives for cereal irrigation.

Strategic considerations

As a general recommendation, Ellram and Maltz (1995), Nato (2009), and the Linköping students recommend aligning the TCA with strategic goals and issues. One way to ensure such an alignment is to employ strategic considerations. In her master's thesis on warehouse layout, Sjöberg (2017) appeals to the importance of a solution that considers future expansion of the business. Sandung (2017), discussing electricity distribution systems, points out that a factor to consider together with costs is the flexibility for future upgrading of the system.

The relative importance of costs

Yet another reason for considering other factors when planning the TCA is that it is interesting to know if the costs are supposed to be an important decision factor or not. The more important the costs are regarded, the more careful should the TCA be. One student argued that: *"You often reach a cost figure and then run a discussion about other aspects. But it could be the other way around, that other aspects are the important ones, and then you say that costs might be discussed."* (Linköping student 1). If other decision factors are more dominant than costs, more general cost estimations might be sufficient.

For example, Grant et al. (2017) argue that quantified costs can draw managers' attention away from more qualitative sustainability aspects.

Hence, to evaluate the relative importance of costs compared to other aspects is an important but difficult task. Decision-makers can sometimes give an indication of this, but it might also be that the cost analyst does not get any guidance. According to Mislick and Nussbaum (2015) it might in such cases be wise not to spend too much time in making a very thorough cost analysis, striving for great detail in the result. The decision-maker might be satisfied with a rough estimate, or: *"...tell you that they need a tighter range of costs, and that you will then need to seek additional data or another methodological approach to support the refinement of your estimate"* (p. 2).

The following challenges relate to identifying other aspects to consider alongside the costs:

- *To identify aspects that may be important*
- *To get to know decision-makers' priorities*

Having gone through the challenges connected to the steps concerning setting the scope for the investigation, the coming sections are connected to the stage of modelling the TCA, i.e. Steps 5-7.

4.2.5 Step 5 - Selecting cost categories to include

When performing a total cost analysis, a cost model should be created, that includes relevant cost factors to compare. The literature frequently describes total cost models. I have here chosen to use 'model' as an umbrella term for compilations of cost factors to be included in a TCA. These models are sometimes presented as graphical illustrations that show principal interrelations between costs (Lambert, 1975; Jonsson and Mattsson, 2016; Schönsleben, 2016), sometimes in form of charts showing how different cost factors depend on e.g. the order quantity (Wisner et al., 2017; Murphy and Knemeyer, 2018), or the number of warehouses (Abrahamsson, 1993; Christopher, 2016). Most often, however, the suggested cost factors are presented in text or tables. These total cost models either suggest relevant cost factors for certain purposes (e.g., in textbooks or descriptive research articles) or present which cost factors have been considered in a certain situation (e.g., in case studies where TCA is applied).

Set vs tailored models

The total cost models investigated cover many disciplines and situations. Some examples are transportation (Lumsden, 2012), inventory management (Bowersox et al., 2013), distribution (Christopher, 2016), purchasing (Jonsson and Flynn, 2015), life cycle costing (Mangan and Lalwani, 2016), and quality (Goetsch and Davis, 2010).

It is not self-evident which cost factors to include in the ‘total cost’. This inconsistency is demonstrated by the fact that six logistics textbooks identify a variety of cost factors to be included in cost models, labelled ‘logistics cost’ or ‘total logistics cost’, see Table 13. Notably, Coyle et al. (2017) present three models all labelled ‘logistics cost’ in three different sections of their book (each one in different contexts, however with clear explanations). What makes this even more complicated is that a specific cost might be positioned under different headings. For example, the cost for transport administration might be placed under ‘transportation cost’ or ‘administration cost’. There is no correct answer; it is rather a matter of preference. However, this means that ‘transportation cost’ in one analysis might not be fully comparable to ‘transportation cost’ in another.

Table 13. Cost factors associated to ‘total logistics cost’ in logistics textbooks

Source	Transportation	Warehousing	Inventory	Administration	Change-over	Lost sales	Capacity-related	Information	Packaging	Customer service	Miscellaneous
Coyle et al. (2017)	x	x	x			x			x		
Coyle et al. (2017)	x	x	x	x		x			x		
Coyle et al. (2017)	x	x	x	x	x						
Gleissner and Femerling (2013)	x	x	x	x				x			
Jonsson and Mattsson (2016)	x	x	x	x	x	x	x		x		
Mangan and Lalwani (2016)	x	x	x	x						x	
Oskarsson et al. (2013)	x	x	x	x							x
Rushton et al. (2017)	x	x	x	x							

From this compilation it is clear that some cost factors (transportation, warehousing, inventory, and administration) are regarded as central within logistics since they are included by all (or almost all) the authors. When it comes to the other cost factors, the authors have made different choices. For example, Jonsson and Mattsson (2016) include many factors, while Oskarsson et al. (2013) introduce the factor ‘miscellaneous’, which implicitly includes all the factors mentioned by the other authors.

As described above, several total cost models are found in the literature. Although these models serve as good starting points, in most cases the models need to be adapted to the specific situation, a view stressed by teachers and students at all four universities as well as in the literature. As early as the 1960s, LeKashman and Stolle (1965) made clear that the total cost approach “*works out differently in every practical application*” (p. 44), a statement later confirmed by several authors, (Davis, 1991; Ellram, 1995; Abrahamsson and Aronsson, 1999; Kosior and Strong, 2006). More precisely, the adaptation is about which cost factors to include in the model: “*Relevant costs within each category, and even cost categories, will vary for each analysis*” (Ellram and Maltz, 1995), p. 64.

What guides the selection of cost categories?

Bowersox et al. (2013) conclude that everything cannot be included in a TCA. Of course, in some situations all the relevant costs *can* be considered, but often this would be impossible, or at least unwise. As Needy et al. (1998) put it, a cost model attempting to include all relevant cost factors “*would be prohibitive both in the ability to collect such data and in the proper usage of such data in decision making*” (p. 120). Waller and Fawcett (2012) point out that logistics research has not comprehensively addressed what cost factors to select for analysis. Although this seems to be true on a principal level, in many *applications* of TCA the relevance of different cost factors is explicitly discussed within the logistics discipline, see e.g. Considine et al. (2006), Ho (2007), Shapiro and Wagner (2009), as well as in other contexts, such as Environmental engineering (Wildern and Isaacs, 1998), Space engineering (Remer et al., 1992), Staff management (Weingarten, 1992), and Manufacturing (Nye et al., 2001).

Some authors, however, discuss the issue on a more principal level. Perng et al. (2012) as well as Oskarsson et al. (2013) suggest ‘selection of cost parameters’ as an essential step in a TCA process. Cole and Grossman (2002) argue that traditional cost models concerning environmental protection do not take enough factors into account, so adaptation is needed as “*the real world is ... more complicated than most existing theories suppose*” (p. 224). Ellram (1995) identifies many factors (e.g., type of purchase or the specific item bought) that affect which costs are relevant when making purchasing decisions. In the report *Code of practice for life cycle costing*, Nato (2009) recommends constructing a ‘cost breakdown structure’ (a total cost model) to ensure that all relevant costs related to the system of interest are considered. According to Ferrin and Plank (2002), many organizations are unsure how to effectively identify the critical cost drivers for estimating total cost of ownership. Case studies have shown that practitioners “*include or disregard elements of total cost as they see fit it*” (Kumar and Kopitzke, 2008), p. 121. Both Ellram and Siferd (1993) and the Hanken teachers note that such a personal preference approach could overlook important cost elements, due to a lack of understanding which the key cost elements are. Similarly, Sandberg and Abrahamsson (2019) argue that a limited understanding of the processes prevents many retail companies from considering important logistical cost components.

In many cases a large number of cost factors are more or less affected - as an extreme example, Olsson (2016) reports on a case from the healthcare sector where more than 600 cost items were identified. Therefore, some kind of pre-selection must be done. Since cost calculations can be difficult, Holweg et al. (2011) suggest starting with a more limited analysis. Their suggestion is supported by one of the students: “*It might be more costly to investigate this cost, than the ‘revenue’ this work will lead to.*” (Linköping, student 1). In addition, IEC (2017) concludes that: “*... it may be beneficial to exclude some elements from the analysis in order to simplify or reduce the cost of the analysis*” (p. 18). Drawing on this, Oskarsson et al. (2013) recommend the following sequence: first, identify all cost factors that will change; and second, estimate which ones will be more heavily affected

and select these for more detailed examination. This sequence is in line with Fisher (1956), who stresses the need to emphasise *“those components that are relatively most important and that are particularly sensitive to changes”* (p. 566), and Ellram (1993), who recommends focusing on the most significant cost components. To identify the most significant components, Saccani et al. (2017) suggest conducting a pilot study to assess the relevance of the tentative cost items. In addition, in their master’s thesis Bäckström and Magnuson (2015) advocate including *“only costs that are manageable to identify and calculate”* (p. 57).

Touching upon the challenge of how to calculate specific costs (which is discussed in the next section), the difficulty of calculating or estimating costs may result in a decision *not* to include them in the model. Examples of such problematic costs are opportunity costs (Waller and Fawcett, 2012), the costs of idle capacity (Schaefer, 1958), and discontinuous costs (Waller and Fawcett, 2012).

Drawing on these discussions, the following challenges are defined.

- *To construct a total cost model, or adjust a set model to suit the situation at hand*
- *To identify all cost categories that will be affected*
- *To select the most crucial cost categories to include*

4.2.6 Step 6 - Selecting calculation methods

When performing total cost analysis, calculations are central. Identifying the proper equations, formulas, or calculation methods is therefore crucial. Fisher (1956) argues that it is more important to find proper calculation methods than to strive for exact correctness when estimating each included value: *“Prime emphasis should probably be placed on consistency in costing method rather than on accuracy of cost estimations in an absolute sense”* (p. 568). Sometimes, calculating a certain cost can be rather straight forward. For example, given a certain unit price and a yearly demand, the yearly material cost is easily calculated. Literature presents formulas for the calculation of some costs, such as inventory carrying. However, in other situations, it is unclear what the proper cost model or equation should look like. Kosior and Strong (2006) state that *“results will not be realized if the mathematical functions ... are not properly formulated”* (p. 350), followed up by claiming that *“the critical step in extending cost models to mathematical programming is in developing costs that vary as functions”* (p. 353).

Set formulas may be available, but are they valid?

Since the calculations should be adopted to the specific situation, it is not possible to stipulate exactly how to calculate all relevant costs. In many cases, a good understanding of the system that is to be analysed is therefore needed to understand which activities will

be affected and in turn how these will affect costs. Some costs, however, are recurrently calculated in similar manners, and are therefore described in textbooks. Within logistics, the costs associated to carrying inventory is such an example, where all the examined textbooks provide the reader with the components needed to calculate this cost (albeit, in different detail).

Although generally applicable formulas are uncommon, the literature provides a lot of detailed descriptions on calculation methods and formulas for specific applications. For example, Abrahamsson and Aronsson (1999) propose a method for calculating cost effects when reducing the number of warehouses in a distribution structure, Kumar and Kopitzke (2008) describe formulas used for evaluating the total cost of outsourcing manufacturing operations to low cost countries, Cui et al. (2017) develop a context-specific cost model for comparing different alternatives for operation and maintenance of data centres, and Bacchetti et al. (2018) present detailed equations for analysing investments in an aluminium melting process.

To develop functions that properly reflect real cost behaviour, knowledge about how these costs behave is necessary, an issue mentioned by Hanken teachers as well as Cowell (1988), which in turn requires an understanding of the system, as previously discussed in section 4.2.2. As an example, considering inventory carrying cost is illustrative. In the basic formulas displayed in most logistics textbooks, inventory carrying cost is calculated based on an assumption of a smooth outflow of products from the stock. But what if this assumption does not correspond to reality in a specific setting? Can the formula still be used, can it be modified, or does it have to be replaced? Morrison et al. (1997) give an example from healthcare, where the traditional view was that certain factors affected the treatment cost in a linear way, leading to a rather simple cost function. Closer examination, however, showed that this relationship is non-linear, which presents problems when creating a representative cost function. Another example of the complexity of creating cost functions is given by Larson (1992), who notes that a certain cost might have several interacting cost drivers, such as the number of orders as well as the number of units. The Linköping teachers made similar observation. On the same issue, Waller and Fawcett (2012) present an illuminating discussion about transportation costs, which clearly shows the problematic issue of finding simple models for cost calculation:

“Transportation costs increase the unit cost when order quantities involve LTL [Less than truckload] shipments. However, when they get to the point where they involve TL [Truckload] shipments, then they become an ordering cost. This is not too complex for a single item, but when a truck is carrying multiple SKUs [Stock-keeping unit], it is very complex. Suppose a retailer replenishes a set of stores from a given distribution center. Assume each store gets a TL per day. Sometimes the TL is not full but it is going every day regardless. In that case, the transportation cost cannot be assigned to a particular SKU because no particular SKU is causing the transportation cost. In effect, the daily truck to the store from

the DC [Distribution centre] is essentially a store operations cost. Such a scenario can get even more complicated. For example, suppose that at some point additional SKUs are added to the store such that one truck is not enough. In that case, applying the total cost concept would require the cost to be assigned to the incremental increase in the assortment - it should affect the assortment decision.” (p. 2)

Crocker et al. (2012) give yet another example: a product’s storage cost is commonly falsely assumed to be proportional to its value in stock. Connecting this example to Fisher’s statement above, no matter how much effort is given to assigning correct stock values to the products, the storage costs cannot be correctly calculated if the calculation formula is based on incorrect assumptions.

Some things are hard or impossible to monetize

Although the ambition with TCA is to assign figures to all factors considered relevant for the analysis, in practice this can be a difficult task. Examples of this are costs of poor service (Davis, 1991; Schönsleben, 2016; Coyle et al., 2017), environmental effects (Sanders, 2017; Grant et al., 2017), opportunity costs (Waller and Fawcett, 2012), quality costs (Sörqvist, 1998; Nakandala et al., 2016; Olayinka, 2015), and revenues (White et al., 1993; DeCorla-Souza et al., 1997).

When costs are hard to quantify, they are according to Wildern and Isaacs (1998) often excluded from the analysis, even though they might be significant to the decision. One answer to such problematic situations is to handle these non-monetizable aspects separately, alongside the cost analysis, as discussed in section 4.2.4, resulting in a trade-off between, for example, total costs and CO emissions or between total costs and customer service levels. Sometimes, these other aspects are quantifiable (although not in monetary terms), but as already Schaefer (1958) observed, there are situations where qualitative aspects cannot be measured. In such cases, these aspects are to be considered in other ways as a foundation for making decisions.

Hence, although the step addressed in this section is labelled ‘Selecting calculation methods’, *calculation* is not always possible. *Estimations* might be used instead of calculations, for instance when data are scarce or when future events are uncertain. Such estimations can be based on knowledge and experience of experts or on similarities with previous projects (Więcek et al., 2019). The ability to make good estimations and assumptions increases with experience, but even for experienced investigators, new situations will pose problems. To avoid making such assumptions out of the blue, using external sources of information might be helpful, a strategy suggested by Bacchetti et al. (2018). In their investigation in the healthcare field, Turchetti et al. (2017) used available national statistics to estimate costs for laboratory tests, specialist clinical consultations, and care providers’ expenditures on food and transport. Saccani et al. (2017) used publicly available information on the internet to estimate purchasing price of consumer goods.

When investigating total costs associated with the construction of road bridges, Corotis et al. (2012) used some figures from similar investigations to determine the costs of traffic delays associated with construction work.

Challenges connected to the selection of calculations methods are summarised below.

- *To construct or select calculation methods, and adapt these to the situation at hand*
- *To understand the relations between changing conditions and cost behaviour*
- To select reliable cost estimations methods when calculation is not possible

4.2.7 Step 7 - Defining required input data

Lambert and Mentzer (1980) state that “*If cost tradeoffs are at the heart of the logistics concept, then adequate cost information is at the heart of cost tradeoffs*” (p. 18). Kosior and Strong (2006) agree: “*Acquiring correct and reliable data is crucial to the successful practical application*” (p. 350). Therefore, determining which data are required is crucial and tightly connected to how the costs are to be calculated. However, according to e.g. Moeller (2002), defining which data are needed is not always an easy task. If a certain model or formula is considered suitable for the cost calculation, the parameters included in this formula will guide which data are needed. In other circumstances, there might not be any suitable models available, which makes it even harder to identify the most important inputs. Sörqvist (1998) argues that often data are used just because the data are easily retrievable, irrespective of the data’s relevance.

Proper time horizon for input data

Estimations of future costs are often based on historical data, at least to some extent. A question then arises about which time horizon to use for the historical data (Bowersox et al., 2013). Using only individual values or data from the most recent past might hide variations or trends while using relatively old data might not capture relevant trends. There is no easy way to select the time horizon, but the problem has similarities with forecasting, where different methods are used to make predictions based on historical data.²² When, for example, predicting future demand for a certain product, trends as well as seasonal or cyclic variations might be informative. To capture trends, the exponential smoothing method is often a good choice. This method emphasises more recent data – i.e., the older the data are, the less impact the data will have on the prediction. In such cases, a relatively short time horizon might be sufficient (Davis et al., 2003). If there are seasonal variations, at least two years of data must be collected to catch possible seasonal

²² For readers interested in forecasting methods, see e.g. Jonsson (2008).

trends. With cyclic variation not related to seasons, the length of the cycles must be identified before determining the proper time horizon for historical data. Although forecasting methods in most cases are not directly applicable to total cost estimations, these methods can be used to help define a time horizon for input data in TCA.

How much and how detailed data are needed?

The time horizon chosen partly depends on how much data are assumed necessary. Because retrieving data might be difficult, it is important to decide what data are needed and what level of detail these data should represent. Several of the teachers from the case universities regard this as an important issue. One of them argued:

“Where should we have detailed data? We might not be able to have it everywhere, because then we would never reach an end. ... It is kind of a trade-off analysis. Look at the whole package, view the complete system and then see where the trade-offs are important, and which data is needed there in order to reach some result.” (Lund teacher 3)

A Chalmers teacher also highlighted the format of the data:

“You shouldn’t think that just because you say that you would like data about something from a company, they will be able to get it for you. This data is not always available, at least not in the format you would like it to be.” (Chalmers teacher 1)

Specifying the desired data format increases the probability of obtaining useful data. If asking for transportation cost but not clearly stating that the cost per product and delivery is desired, the received data will most probably be at a more aggregated level.

The challenges discussed above are summarized as follows.

- *To define which time period data should cover*
- *To define the desired format of data and level of detail*

4.2.8 Step 8 - Retrieving input data

IEC (2017) states that it is important to consider how to collect cost data, the effort this will require, and the expected quality of data. In their study on costs for cancer care, Mariotto et al. (2011) report that their estimated costs are higher than in previous studies. They suggest that this is due to their more careful searches for where to get the most accurate data, which resulted in a more realistic cost estimation. Required data can be obtained from various sources, such as interviews, observations, and stored data in IT systems. Nato (2009) suggests that when preparing a cost analysis, analysts should consider all credible data sources. Bacchetti et al. (2018) argue that the retrieval of data

should involve several people: *“Collecting [cost] data in a company is a cross-functional and complex process, as it usually involves know-how of different corporate departments”* (p. 12).

The university teachers and several authors bear witness to the many problems with retrieving the desired data in real settings. One teacher expressed that even if analysts clearly define what they want to know, they should not assume the data they desire is readily accessible: *“Whatever you want to analyse, and what you have data for are to very different things”* (Hanken, teacher 2).

Required data are not available

A major problem highlighted in literature is that the required data are not available (Poist, 1974; Cavinato, 1992; Kosior and Strong, 2006; Coyle et al., 2017). Ellram and Siferd (1993) and Wouters et al. (2004) regard this as a major obstacle for proper TCA. The reasons for lack of data could be external – e.g., cost-related information about potential suppliers is not good enough (Holweg et al., 2011) – but even more important are the internal factors. Although the IT systems in most organizations store masses amount of information, the match with desired data is often insufficient.

Sometimes data are accessible, but not in a form that suits the intended calculations. Cavinato (1992) reports that traditional budget-based accounting systems cannot provide information that follows the ‘horizontal flow of materials’, which is important in logistics settings. Waller and Fawcett (2012), for example, conclude that transportation costs cannot be assigned to a particular stock-keeping unit. Costs for every incoming transport might then be available, but these costs are not easily separated to the different packages and products in each transport. This critique applies to quality-related costs stored in existing IT systems, according to Sörqvist (1998) and Mahmood et al. (2014).

In situations where desired data are not available and it is impossible or not worthwhile to try and catch the necessary information, two strategies can be used. One option is to withdraw the cost from the calculations. Withdrawing cost factors will result in a ‘less total’ total cost analysis. This might be justified if the analysis is about the difference between alternatives (while the total cost as such is not that crucial) and if the cost factor is believed to be of minor importance (i.e., either relatively small compared to other cost factors or expected not to differ much between the alternatives). The other option is to make estimations and assumptions to make further analyses possible; this is briefly discussed in section 4.2.6.

Restricted access

An issue raised by the teachers at Lund, Chalmers, and Hanken, is that data may be available, but the access to data restricted to the investigator. This problem is probably more common for external investigators, such as consultants or students - an example

from a master's thesis project is provided by Harrysson and Landin (2015). However, also within an organization there might be unwillingness to reveal information to people from other departments.

Data are available, but time-consuming to retrieve

The data collection could be time-consuming, especially when dealing with complicated systems, and/or when the ambition with the investigation is high: *"In terms of time, effort, and resources consumed, collection of data is a major part of the life cycle costing effort."* Nato (2009), p. 11. For example, Remer et al. (1992) describe the difficulties collecting data about a space mission that took about one year to complete and required numerous consultations with a number of respondents.

Hence, even when data principally is available, the effort to retrieve it might be too high, as e.g. Sörqvist (1998) and Wouters et al. (2004) indicate. As mentioned previously, Ellram (1993) and others stress the need to find out which costs are significant enough to justify the work needed to catch the data.

Data are available, but the data's correctness might be questioned

Even when required data are available, the quality of data might be questioned. In the previous section, the format of information provided by IT systems was discussed. Another issue is that IT systems do not always contain correct and reliable information. According to Hanken teachers, many companies do not really know what is in their systems and how these systems work. Reported by one of the Chalmers teachers, a student group at discovered that a company used a certain value for the ordering cost. Not knowing whether this value was correct, it was entered into the company's IT system by an external consultant when the system was installed ten years ago, just because a figure was needed.

When using data from different sources, the data might be contradictory or ambiguous (Xu et al., 2012; Green et al., 2017), a situation also identified by the Lund teachers. Sands et al. (2017) report that the data might have high variation. The investigator must then consider which data that is correct (if any) and how to proceed. The literature give examples where contradictory data was encountered regarding the time needed for certain activities. For example, in their master's theses Wallin and Westberg (2017) found contradictory data from interviews with different respondents, and Olsson (2017) from work observations.

The inventory rate is an example of how input data are often problematic. This rate, expressed as a percentage, reflects the capital costs and risk costs associated with keeping things in stock. Both these components are difficult to define correctly. The *capital* part depends on how the tied-up capital otherwise would have been used (i.e., opportunity costs). Because opportunity costs are difficult to define (Waller and Fawcett, 2012), these

are often based on assumptions. The *risk* part is supposed to correspond to the risks associated with obsolescence, pilferage, etc., but estimating these costs correctly is also difficult. Given these limitations, the inventory rate is more or less doomed to be uncertain. Moreover, almost without exceptions, the same inventory rate is used for all products even though in reality for example the risk of obsolescence often differs between products (Oskarsson et al., 2013). In addition, many organizations do not set the inventory rate to reflect the real costs; rather, they set the inventory rate to reflect a management mechanism that drives inventory levels in a certain direction (Chalmers teachers).

This example shows that although there might be cases where data are easily accessible, it is unclear how well these data reflect reality. The question to ask is then whether to use existing data or to dig deeper to retrieve more reliable input data for the calculations. That is, would it be worthwhile to make the necessary investigations to calculate a more correct inventory rate or is the existing one acceptable?

Listed below are the challenges related to data retrieval.

- *To define where to retrieve data*
- *To get access to data*
- *To assess the reliability in data*
- *To handle unreliable data and lack of desired data*
- *To balance the effort needed to capture data against the perceived value of additional data*

The problems mentioned with data retrieval sometimes necessitate processing the data. In practice, data retrieval and data processing are tightly connected, although here I have separated these issues into two sections. The next section focuses on data processing.

4.2.9 Step 9 - Processing input data

As indicated by several authors as well as teachers from the case universities, available data may be in a format not directly useable. Processing of some kind is sometimes necessary to reformat the data and this processing might require much effort. In this section, some examples of situations are given when data processing might be necessary.

Ambiguous or contradictory input data

Collected data often turn out not to be clear-cut. Mislick and Nussbaum (2015) state that *“There may be significant adjustments to the data necessary in order for it to support your needs”* (p. 62). Data might, for example, not be directly compatible, such as not being in the same format. For example, concerning life cycle costing, Nato (2009) states that *“there is generally a lack of uniformity in the data and therefore a certain amount of*

normalisation is unavoidable” (p. 42). Both Nato (2009) and Mislick and Nussbaum (2015) give examples of such normalisation to adjust costs/data due to:

- anticipated inflation.
- for specifications such as size, weight, complexity, etc.
- for different operating profiles, temperatures, mileage, etc.
- for quantities (since higher volumes tend to lead to lower costs per item)

There are situations when data vary due to some underlying factors. Finding out such relationships can be helpful when trying to set appropriate values for factors included in the cost model. For example, Corotis et al. (2012) and Olsson (2017) use statistical analysis as a help to understand the relations between parameters.

The use of multiple sources of data could result in respondents presenting different opinions or statements. As Xu et al. (2012) argue, such situations are problematic as statistical methods are of no help. Unless complementary information can be retrieved, in such situations it might be that data cannot be processed as desired, so it has to be accepted that the information is uncertain.

Even when the data format is compatible, there could be variation in the figures themselves. For example, sea freight tariffs are constantly changing, so shippers cannot rely on freight rates to be stable from one month to another (Menachof, 1996). In such a case, looking at freight rates from the last year will not give a direct indication of which level to use for cost predictions. Therefore, closer analysis of the data is necessary. Statistical analysis can then provide valuable information about the variance in data.²³ This approach might reveal usable trends. An average value might, for example, be sufficient. Strongly deviating data values, so-called outliers, might be removed since they are not representative (Ahire et al., 2007; Olsson, 2017). Outliers were discussed among the Lund teachers. One standpoint was that these should be ‘washed away’ from data sets as they are not representative. Another teacher replied that too strong washing could be dangerous: if all exceptionally long lead times are eliminated, it might give a false impression that lead times are always short.

Future and historical costs

Connected to step 3 (section 4.2.3), time considerations were discussed related to setting the scope of the investigation. Here, focus is on how to handle such issues in practice, connected to the retrieved data.

Although some costs may remain stable over the years, others might change. For example, the price for many raw materials fluctuates, the cost for maintenance and repair of certain machinery will likely increase, labour costs in low cost countries will most probably

²³ Details about statistical methods are not provided in this thesis. There are many texts available introducing statistical methods, e.g., Montgomery (2013).

increase, and a high inflation rate can make the development of costs uncertain.²⁴ Moreover, there could also be one-off future costs (e.g., disposal of equipment at the end of its lifetime).

Future costs are naturally more uncertain than historical or present costs. Therefore, historical figures might need to be adjusted to better represent the actual state. Corotis et al. (2012), for example, report on adjusting seven-year old figures to better match present conditions.

Concerning historical as well as future costs, Korpi and Ala-Risku (2008) and Mislick and Nussbaum (2015) stress the need to consider the time-value of money, due to e.g. inflation. Eggimann et al. (2016) recommend using estimated average yearly costs for the time period studied. Most authors, e.g. Wildern and Isaacs (1998), and Holweg et al. (2011), however, advocate that future costs are discounted using the Net Present Value method²⁵.

Semi-fixed costs

In their call for more research on TCA, Waller and Fawcett (2012) raise the issue of non-linear, or discontinuous costs, which causes problems in calculations. In many cases, this refers to so-called semi-fixed costs (i.e., they change stepwise, but in-between these steps they are fixed). Typical examples are costs for personnel and equipment. When the business expands, occasionally the capacity is filled and investment in more personnel or equipment is needed, which causes a sudden cost increase.

Schaefer (1958) and Ellram and Maltz (1995) point out that a certain change of action might lead to a decrease in workload, but it does not necessarily mean a cost reduction. If, for example, a rationalisation means that the workload for a certain operation is reduced with a time equivalent to 0.4 full-time employees, will this lead to a real cost reduction? Not as long as a 'tipping-point' is not reached, where this change together with other measures results in a situation where the business can be run sufficiently with one less employee.²⁶ The question is then how to treat such a *theoretically calculated* cost decrease; should it be included in the TCA? Ellram and Maltz (1995) argue that if the capacity made free (the 0.4 employee) can be used for other purposes which increases productivity, it should be included as a cost reduction.

²⁴ Sandung (2017) refers to an inflation rate of 800% in Venezuela. Although an extreme figure, this example shows the necessity to take future development into consideration.

²⁵ The Net Present Value method is a commonly used method for making investment alternatives comparable to each other. Readers interested in the method are referred to e.g. Götze et al. (2015).

²⁶ For simplicity, it is here assumed that only full-time employees are accepted even though this does not necessarily reflect reality.

Another reason for inclusion of such theoretically derived costs could be viewing the *potential* involved, as addressed by the Chalmers teachers. Together with other changes, some small (theoretical) cost savings will eventually result in real savings, because it will then be possible to manage with one fewer employee. If this potential is not viewed as real savings in the individual TCA, there is a risk that these changes are not implemented even though they would open up the potential for cost savings at a later stage. However, when deciding whether to include theoretical savings (or cost increases), the size of the cost as well as the future potential should be considered. The cost for one employee more or less might not be a significant issue for a large or mid-sized company, but if it concerns machines requiring multi-million euro investments, one machine more or less will probably be an important cost.

Bundled costs

Early discussions about total cost addressed the necessity and difficulty apportioning jointly incurred costs to individual activities or products (Greer, 1931; Walker, 1946; AMA, 1957). According to Phillips (1964), LeKashman and Stolle (1965), and others, costs are hidden in corporate accounting because these costs often overlap areas of responsibility. In addition, some costs are regarded as overhead costs and therefore accounting practices present them as lump sums or bundled costs, which hides some of the costs associated with a certain activity. White et al. (1993) express that: *“When costs are improperly allocated either by lumping them into overhead accounts and/or by assigning them incorrectly to ... processes, profitability analyses cannot proceed on a rational basis”* (p. 251). As long as these bundled costs are relatively small, this is not a major problem, but as Kosior and Strong (2006) argue: *“Overheads and indirect costs are becoming a larger component of the overall cost structure”* (p. 351).

To perform a proper TCA, indirect or bundled costs might need to be properly allocated to different activities and/or products. There are different ways of doing this, see e.g. Harrison et al. (2015) and Rushton et al. (2017), but in the reviewed literature most authors dealing with the problem of bundled costs recommend Activity-Based Costing²⁷ (ABC), a method which according to Christopher (2016) and Schönsleben (2016) is the method most frequently described and recommended in the literature.

However, ABC has several drawbacks. Kosior and Strong (2006) argue that ABC represents costs using linear functions although in reality costs do not behave in this simplistic manner. Oskarsson et al. (2013) mention that the method uses many resources due to its complexity. According to the Chalmers teachers, ABC requires so much work that its practical use is limited.

²⁷ It goes beyond the scope of this thesis to go into details about Activity-Based Costing. Interested readers are referred to e.g. Kaplan and Anderson (2007).

With calculation methods chosen, and with retrieved (and processed) input data at hand, the calculations as such most often do not pose a major problem. The challenges discussed above are shown below.

- *To identify and handle data that is contradictory, or not directly comparable*
- *To handle the uncertainties of future costs and relevance of historical data*
- *To take the time-value of money into consideration*
- *To distribute bundled costs in an appropriate way*
- *To understand whether semi-fixed costs really will change*

The calculations will render expected total costs for the alternatives. However, a critical review should be conducted to determine the reliability of the result.

4.2.10 Step 10 - Identifying uncertainties

As shown in previous sections, the decisions and choices made during the process affect the resulting costs for the alternatives. As there are many challenges connected to these decisions and choices and therefore many uncertain factors, a certain level of uncertainty is according to e.g. Nato (2009) inevitably embedded in the resulting costs. Although some uncertain factors have been touched upon in previous sections, focus here is specifically on the identification of all factors leading to uncertainties in the total cost.

Simplifications might have been made to make the costs calculable, input parameters might be more or less reliable, and assumptions might have been made when no input data were retrievable, etc. The need for careful data retrieval as well as critical reviews of uncertainties is highlighted by Xu et al. (2012): “*the centre of challenges lies in the availability and reliability of data*” (p. 304).

Xu et al. (2012) define uncertainty as: “*a potential deficiency in any phase of activity of the modelling process that is due to lack of knowledge which causes the model-based predictions to differ from reality*” (p. 302). They present a thorough review of types of uncertainties and categorize them as being either aleatory (random) or epistemic (dealing with knowledge). Aleatory uncertainty refers to inherent randomness, (i.e., given the certain setting, it cannot be reduced). Since this kind of uncertainty is quantifiable, it can be analysed using statistical methods. Examples related to logistics could be variation in lead time or incoming customer orders per day. Epistemic uncertainty is caused by lack of knowledge and is more difficult to quantify. Examples provided by Xu et al. (2012) include: the scope is not defined in enough detail; models are not properly selected; cost drivers are missing; data are vague and ambiguous; and incorrect extrapolation from

current costs. These uncertainties can be more diffuse and therefore difficult for the analyst to identify.

In the following, I provide some examples of uncertainties and how to analyse these uncertainties, issues that will serve as points of departure for the discussion in 4.2.11.

Too narrowly defined system

When defining a system (i.e., which parts such as processes, activities, and actors to include in the analysis), some parts will inevitably be excluded. Most cases require some delimiting to avoid an overly complex situation, but there is a risk that the system will be too narrowly defined, excluding aspects that have a substantial influence on the total costs. Therefore, it is important to review the choice of system boundaries and how this choice has influenced the resulting costs. For example, Hasselt et al. (2015) admit that their chosen system does not cover all relevant costs actually connected to patient care, the topic of their study. Bacchetti et al. (2018) also address the limitations of the applicability of their findings due to the system boundaries they set.

Inappropriate models and methods

The models and methods used to calculate costs might represent reality more or less correctly. Variability is embedded in most situations. If this variability is neglected when choosing calculation methods and calculations are made with methods based on a stable situation, the resulting costs might mislead the decision makers. Heinimann (1998) even expresses that the findings will depend heavily on the models chosen. For example, the order quantity (in purchasing or production) is (somewhat simplified) based on a trade-off between inventory carrying costs and ordering costs. Several models can be used to calculate a suitable order quantity. Some of these models assume stable demand and therefore are generally simpler to use than those dealing with fluctuating demand. If such a model is used for a situation with fluctuating demand, the calculated 'optimal' order quantity will in fact not be the optimal solution.

Predictions of the future

What the future will look like is always a kind of quest. We can try to predict the future, but we will most certainly be more or less wrong whether we talk about the coming weather, the life span of a machine, or customers' demand for our products. The longer the time horizon, the less precise the predictions will be. Within logistics, maybe the most frequent type of prediction is the one concerning future demand, which affects the costs for several activities, such as transportation, inventory carrying, and order handling. Therefore, predictions or assumptions of future demand might have a strong influence on the outcome of total cost calculations. Other examples of predictions that might be both difficult and influential are purchasing prices and wages, an issue addressed by Holweg et al. (2011) with respect to global sourcing.

Uncertain input data

It is not only future predictions that cause uncertainty in the cost calculation parameters. As discussed previously (section 4.2.8) it is often hard to retrieve reliable input data in the desired format. This might, for example, be related to insufficient information from potential suppliers, poor measurement of historical activities, or difficulties unbundling costs lumped together as overhead costs. Cole and Grossman (2002) describe this situation as follows: *“in the real world of incomplete information ... there is always going to be some degree of ... uncertainty”* (p. 226). Baines and Pulley (2003) state that: *“As important as absolute cost is its variability”* (p. 112), as adjustments in uncertain input data will result in other levels of total cost.

Assumptions and estimations

As addressed in section 4.2.8, uncertainty in input data, future behaviour, etc. means assumptions and estimations will be needed (Bacchetti et al., 2018; Corotis et al., 2012). By definition, assumptions or estimations imply uncertainty. Careful documentation of the cost analysis, including all assumptions is essential according to Mislick and Nussbaum (2015). Such documentation also helps the analyst see assumptions that are made more or less unconsciously.

Evaluator bias

Fisher (1956) stresses the risk of evaluator bias – i.e., the evaluator might favour one of the alternatives and therefore consciously or unconsciously bias the evaluation. When cost comparisons are based on hard facts (e.g., data based on reliable measurement), evaluator bias is minimized; however, when more assumptions are required, evaluator bias is more likely.

Hence, the following challenges are connected to the identification of uncertainties.

- *To identify the embedded uncertain factors*
- *To select the ones where the effect should be analysed*

Once identified, uncertainties can be tested to evaluate their impact on the total cost.

4.2.11 Step 11 - Analysing the effect of uncertainties

A critical analysis of assumptions, calculations, etc. produces more trustworthy results. Instead of presenting an absolute answer as *the* cost (distinct, but most probably incorrect) for a specific alternative, a more nuanced answer might be given, e.g. by presenting a presumed cost range. As Wildern and Isaacs (1998) put it, the total cost analysis will then *“not provide an absolute answer ... [but] ... provide important information to assist the decision maker in making a choice which is financially sound for the company”* (p. 5).

Sensitivity analysis

In an early account, Fisher (1956) discusses the need for sensitivity analysis to reflect how the total costs for a technical system is influenced by the size of the investment cost and by the system's expected lifespan. Since Fisher's work, several authors have addressed sensitivity analysis.²⁸ For data sets that vary randomly, Xu et al. (2012) recommend using statistical methods. Xu et al. (2012), Korpi and Ala-Risku (2008), and the Lund teachers specifically mention Monte Carlo simulations. Poist (1974) advocates assigning weights or probabilities to different alternatives such as future sales volumes. However, Prince (2016) stresses that assigning probabilities often is a highly subjective activity, so care must be taken not to build even more uncertainties into the result.

Davis (1991), Myerson (2015), and others propose examining the effect of changing parameters using 'what if' analysis, which is also the most frequently used way of performing sensitivity analysis in the examined literature, see e.g. Charni and Maier (2013). In such an analysis, different values are tested for each chosen parameter to see the effect on the result. Many different values can be tested or just a few, for example using minimum and maximum values, as IEC (2017) suggests. Which values to be tested is not obvious, however. The 'what if' analysis can also be used to find the 'tipping points', where the ranking of alternatives changes, an approach suggested by one of the Hanken teachers. Oskarsson et al. (2013) recommend that sensitivity analysis focus on the most critical factors, i.e. the most uncertain ones and/or the most impactful, see also Robert and Gosselin (2014). A procedure addressed by the Linköping teachers (however, not actively used by them) is to define the uncertainty of input variables numerically and from this calculate the resulting uncertainty in the total cost.

Sensitivity analysis can be performed on a single factor or by combining several factors into a number of scenarios, as shown by e.g. Eggimann et al. (2016) and Sands et al. (2017).

The challenges discussed in this section are summarised below.

- *To select values to be tested for each uncertain factor*
- *To select methods to evaluate the effect of uncertainties, for individual factors as well as for combinations of factors*

With calculations made and results and processes reviewed, the TCA is ready to be presented.

²⁸ Consequently, I have chosen to use 'sensitivity analysis' in the text although some authors prefer the term 'uncertainty analysis'.

4.2.12 Step 12 – Selecting content and presentation format

Once completed, the analysis is used as an input for decision making. Nato (2009) and IEC (2017) state that the outcome of the total cost analysis should be communicable to the audience as this will support the decision makers. Prince (2016) agrees: “... to make a convincing argument that your cost estimate is good, you have to tell a good story ... one that relates facts and data to logical action and speaks in a language that the customer understands” (p. 17).

This corresponds to Pettersson’s (2002) general statement on information design: “the task of the sender or source is actually not completed until the receivers or interpreters have received and understood the message” (p. 1). The challenge lies in deciding which information to present (the main message supported by underlying facts and data) and adapting the presentation to the audience’s needs and expectations. Pettersson (2002) stresses that excessive detail and complicated graphs should be avoided. Nato (2009) recommends using graphical presentations whenever possible (bar charts and pie charts are pointed out as good examples), since this will be more understandable for a broader audience. For Nato (2009), detailed cost figures should be provided in tables that are made available to interested audience members but not used during presentations.

When reporting TCA, focus is naturally on costs (possibly in combination with other important aspects of interest). The estimated costs for the alternatives should be clearly presented. Figure 19 shows a bar chart of costs for alternatives. Although the relative size of the respective cost factors is shown, the chart could be complemented with figures, as illustrated in Table 14.

Figure 19. Bar chart showing total and factor-specific costs for the alternatives

Table 14. Size of each cost factor for the respective alternatives

	Alt. A	Alt. B	Alt. C
Cost factor 1	138 000	220 000	141 000
Cost factor 2	13 000	11 000	38 000
Cost factor 3	622 000	575 000	410 000
Cost factor 4	96 000	62 000	230 000
Cost factor 5	111 000	98 000	111 000
Total cost	980 000	966 000	930 000

If the basic result is rather straight-forward to present, a greater challenge is to clearly present the sensitivity in results. Added to this, it is also important to declare how the analysis has been performed together with potential shortcomings. These two aspects are briefly discussed in the following.

Sensitivity in results

Nato (2009) highlights that it is insufficient to present the result as a single cost figure. Rather, a range within which the cost is supposed to land should be presented, a recommendation also made by Baines and Pulley (2003) and exemplified by Axelsson and Skogum (2016) in their master's thesis. Wildern and Isaacs (1998) agree: *"Although this TCA does not provide one absolute answer, it does provide important information to assist the decision maker in making a choice which is financially sound for the company."* (p. 5). A fictional example of how a cost range for a specific alternative can be presented is given in Figure 20.

Figure 20. Estimated range of total costs

As discussed in section 4.2.10, uncertain parameters should be identified, followed by a sensitivity analysis showing the influence a variation of these parameters would have on the result. Varying one parameter at a time, the result can be rather clearly visualized. In the fictional example in Figure 21, the ranking of alternatives changes when the fuel price increases by about 20%.

Figure 21. Sensitivity analysis on one selected input parameter

It might be valuable for decision makers to see the effect of simultaneous variation in two or more parameters. Although this situation is more challenging to visualize, it can be done using three-dimensional graphs with so-called response surfaces. In the example given in Figure 22, two parameters are varied (demand rate and shipping size), and the effect on total transportation cost is shown with a surface. Comparing the response surfaces for the different alternatives at stake can reveal how sensitive they are to changes in the examined parameters. It can be discussed though, whether such a graphic will make information easily understandable to a broad audience. Hence, it is desirable to present the result of a total cost analysis with sensitivities and nuances highlighted, but it is challenging to make such a presentation clear and understandable.

Figure 22. Example of total cost response surface

Reporting the premises of the study

Nato (2009) and Mislick and Nussbaum (2015) stress that a TCA report should include detailed information about how the study was conducted, for example, which options were considered, how boundaries were set, and what assumptions were made. This information allows the reader to evaluate the credibility of the study and its results, which is in line with Yin's (2018) recommendations about how to report a case study investigation. Harrysson and Landin (2015) describe in their master's thesis how their results depend on the data made available to them: *"The result of this thesis depends heavily on the information The Company has agreed to share with the authors ... [We had] no opportunity to examine neither accuracy [n]or trustworthiness"* (p. 96).

Challenges related to the presentation of the analysis are the following.

- *To identify the target audience and their preferences*
- *To balance completeness and accessibility*

4.2.13 Summary of challenges

In the previous sections, the challenges connected to each step were presented and discussed from different perspectives. These challenges are compiled in Figure 23.

STAGE	STEPS AND ASSOCIATED CHALLENGES
Setting the scope	STEP 1. Defining alternatives to compare a. To define potential alternatives b. To decide how many alternatives to include c. To select the ones to include from the potential alternatives
	STEP 2. Defining the system a. To understand and describe the system (flows, processes etc.) sufficiently b. To set the system boundaries c. To understand which system perspectives that are most important to consider
	STEP 3. Making time considerations a. To define the time period which the analysis should cover b. To define the expected lifetime of the different alternatives
	STEP 4. Identifying other aspects of importance a. To identify aspects that may be important b. To get to know decision-makers' priorities
Cost modelling	STEP 5. Selecting cost categories to include a. To construct a total cost model, or adjust a set model to suit the situation at hand b. To identify all cost categories that will be affected c. To select the most crucial cost categories to include
	STEP 6. Selecting calculation methods a. To construct or select calculation methods, and adapt these to the situation at hand b. To understand the relations between changing conditions and cost behavior c. To select reliable cost estimations methods when calculation is not possible
	STEP 7. Defining required input data a. To define which time period data should cover b. To define the desired format of data and level of detail
Calculations	STEP 8. Retrieving input data a. To define where to retrieve data b. To get access to data c. To assess the reliability in data d. To handle unreliable data and lack of desired data e. To balance the effort needed to capture data against the perceived value of additional data
	STEP 9. Processing input data a. To identify and handle data that is contradictory, or not directly comparable b. To handle the uncertainties of future costs and relevance of historical data c. To take the time-value of money into consideration d. To distribute bundled costs in an appropriate way e. To understand whether semi-fixed costs really will change
Critical review	STEP 10. Identifying uncertainties a. To identify the embedded uncertain factors b. To select the ones where the effect should be analyzed
	STEP 11. Analysing the effect of uncertainties a. To select values to be tested for each uncertain factor b. To select methods to evaluate the effect of uncertainties, for individual factors as well as for combinations of factors
Presentation	STEP 12. Selecting content and presentation format a. To identify the target audience and their preferences b. To balance completeness and accessibility

Figure 23. Summary of challenges when conducting total cost analysis

Although treated separately so far, there are interrelations between the different steps and challenges. These interrelations are discussed next.

4.3 Interrelations between the steps and challenges

This chapter has identified the 12 steps of TCA and the challenges associated to conducting these steps. The steps are presented in what is believed to be a logical sequence. For example, it is natural that cost categories are chosen (Step 5) before calculation methods are selected (Step 6), which in turn must be done before necessary data are defined (Step 7) and retrieved (Step 8). Hence, there are interrelations between the steps that guide the logical order of the steps.

Although investigations are often described as sequential processes, in practice they are performed iteratively as some steps are revisited during the investigation, as described by e.g. Cooper and Schindler (2003), Ghauri and Grønhaug (2005) and Patel and Davidson (2019). The findings from literature and the cases show that this is valid also for total cost investigations, although this is not mentioned by the authors describing the TCA process (see 4.1). A TCA is not performed in a straight-forward sequence. There are interrelations between the different steps of the analysis as well as between the different challenges that make it advisable (in some situations) and necessary (in other situations) to move back and forth between the steps. This will be addressed in the following sections, starting with a discussion derived from the literature on the amount of resources that should be devoted to a TCA, a question that connects to all steps in the process.

4.3.1 How much time and resources should be spent?

An overarching challenge for decision makers, relevant in every step of a TCA, is determining how much time and resources to spend. Although this question is almost impossible to answer, it must be considered as time and other resources are limited. There is certainly a ‘cost of measuring costs’. Waller and Fawcett (2012) state: *“The very act of measuring costs must be weighed against the benefits of measuring the costs”* (p. 2). This means that the aim of the TCA might not be to find the best solution, which is addressed by Alam et al. (2017): *“Aiming for an optimal solution may not be a computationally efficient solution. We need to trade off the optimal solution for reduced computation time.”* (p. 1489).

Such efficiency considerations apply to most stages in a TCA project. Asiedu and Gu (1998), for example, refer to the step of setting the scope: *“An important step is the classification of the analysis objectives and the bounding of the problem such that it can be studied in an efficient and timely manner”* (p. 892), while Alickovic and Behrman (2017) in their master’s thesis focus the data collection: *“It was quite difficult and time consuming to go through all sales data and transactions in the system”* (p. 29).

Sometimes, however, it might be worthwhile to spend significant effort on retrieving data. For example, when planning space missions, which are very long-term projects with large costs, “*one work year of and numerous consultations*” as reported by Remer et al. (1992), p. 196, might be a justified investment.

The examples put forward in this section show that TCA must be seen from a holistic perspective, where all the steps and the associated challenges are considered already from the start. With careful preparations, some potential problems will hopefully be avoided, and a satisfying result will be reached without spending unnecessary resources. In the next two sections, more specific examples are given to illustrate the relationships between the steps.

4.3.2 The advantages with looking ahead

Obviously, preparing and planning TCA requires keeping the later steps of the analysis in mind. However, sometimes it is also advisable to actually begin performing some later steps before finishing the earlier steps. In this way, some challenges can be anticipated, and potential problems avoided or diminished. Some examples are provided below.

Appropriate alternatives might depend on the decision criteria

The aspects important in decision-making might guide the choice of alternatives. If the decision concerns choosing an appropriate distribution structure, a minimum level of delivery service could be a pre-requisite for an alternative structure to be acceptable. A pre-study might then reveal some alternatives that cannot live up to this requirement, so they could be excluded from further examinations. That is, it might be wise to approach Step 4 before Step 1 is finished.

Available data put limitations on what can be included

The need to consider which data are available before deciding on calculation methods and required input is addressed by Asiedu and Gu (1998) and Nato (2009). Nato states that: “*The approach to be adopted needs to be tailored to suit the questions to be answered, the costing requirements and the availability of suitable data*” (p. 9). This implies that an investigation must be made to determine not only which data are available (Saccani et al., 2017), but also how difficult the data are to retrieve and which data formats are available. At first glance, this can be seen as something rather trivial, since there must be ‘experts’ in any organisation who know what data are available and where to retrieve these data. However, teachers in my study stressed that this is not the case. Often company representatives believe that it will be easy to find the required data only to discover they are mistaken. One teacher tells the students the following: “[You] *must be ‘total cost detectives’ at the company when you get out. It’s not enough just to ask. You must actively work with it yourself to get to know.*” (Linköping, teacher 3). That is, the initial steps of

data retrieval (Step 8) must be performed before deciding which calculation methods (Step 6) to use and which input data are needed (Step 7).

A critical view throughout the investigation

As one of the students pointed out, you cannot replace a non-critical view during the investigation by applying a sensitivity analysis afterwards: *“Not just making an analysis at the end, but critically reviewing it while working.”* (Linköping, student 1). If uncertain factors are identified (Step 10) together with the kind of sensitivity analysis to be performed (Step 11) at an early stage, data collection and calculation methods can be prepared (Steps 6 and 7) to facilitate the sensitivity analysis.

Working with the presentation in mind

If it can be made clear what is expected when presenting the results, this might guide parts of the investigation. The more details decision makers need, the more effort should be made to live up to this need. That is, data retrieval (Step 8), processing and calculations (Step 9), as well as sensitivity analysis (Step 11) should be adjusted to fit the needs of the audience (Step 12).

4.3.3 The necessity to go back and make adjustments

No matter how careful the analyst handles the various challenges, inevitably circumstances will change, making it necessary to adjust the plans and even redo some of the work already performed. Some factors are so fundamental, they are difficult to change at a later stage. Evaluator bias, for example (see 4.2.10), is hard to compensate for in retrospect. In other situations, shortcomings will be possible to repair. Some examples are presented below.

Changes due to lack of sufficient data

During the data collection (Step 8), it might turn out that some of the data are not available or that it is too time-consuming to retrieve the data. Even with data secured, it could require too much effort to process the data into a useable format (Step 9). In such cases, the plans might have to be changed. Maybe the ambition level concerning input data (Step 7) must be lowered (accepting less detail, smaller amount of data, etc.) or simpler (maybe less correct) calculation methods (Step 6) should be used. It might even be necessary to exclude a cost factor (Step 5) because information is unavailable.

The analysis gives a too uncertain result

When the calculations are done and the effects of embedded uncertainties have been analysed, the resulting costs can be so uncertain that it would be unwise to base a decision

on them. This might be solved by collecting more data, collecting more detailed data than previously defined, or by processing data more carefully (i.e., findings from Steps 9 and 11 may force the analyst to revisit Steps 6, 7, and 8).

A tight race could trigger more careful investigation

If the calculations (Step 9) and sensitivity analysis (Step 11) reveal that the costs for alternatives are too similar to guide the decision makers, it might be necessary to reconsider decisions made in previous steps. For example, if some cost factors were excluded (to limit the time spent on the investigation), these factors could be included in a new analysis. Here, the choice of cost categories (Step 5) is revised, necessitating going through all the subsequent steps for the new cost factors.

Modification of system boundaries

During the collection and processing of data (Steps 8 and 9) new insights are often gained about how the processes work and what actually drives the size of the included cost factors. It sometimes turns out that important aspects are outside the studied system – i.e., they are not considered although they are important for reaching a good result. The Lund teachers report that in many master's theses, the students set initial system boundaries (Step 2), but these have to be modified as the projects proceed, and they gain better insight in the context they study.

5 Difficulties and thresholds with learning total cost analysis

The second research question concerns the issue *What thresholds are there for learning how to conduct total cost analysis?*. Although a lot of things can be regarded as difficult, some aspects, the so-called ‘threshold concepts’, are more crucial to make learning come about. As described in section 2.3.3, learning difficulties were identified by successively visiting the four case universities. This chapter presents the findings from the case studies and analyses these empirical findings using theory.

In section 5.1, theory concerning threshold concepts is presented. Thereafter, in 5.2 the learning difficulties identified during the case studies are presented and analysed against the theoretically underpinned threshold characteristics.

5.1 Threshold concepts – an overview

The term ‘threshold concept’ was introduced by Meyer and Land (2003), who give the following description:

“A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress. ... This transformation may be sudden or it may be protracted over a considerable period of time, with the transition to understanding proving troublesome.” (p. 1)

Crossing a threshold can be further described as a journey through ‘liminal spaces’, by Cousin (2010) described as:

“... an unstable space in which the learner may oscillate between old and emergent understandings”. (p. 3)

That is, the learner progresses from a pre-liminal state (where old understandings rule) through a liminal state (when the balance between old and new understandings is changing), to a post-liminal state (where new understandings are fully established) (Baillie et al., 2013).

After this short introduction, the characteristics of threshold concepts are described in section 5.1.1, followed by a discussion on different kinds of thresholds in 5.1.2. In section 5.1.3, the focus is on how thresholds can be identified. Finally, in section 5.1.4, curriculum design with respect to thresholds is briefly discussed.

5.1.1 Characteristics of threshold concepts

The threshold concept framework, suggested by Meyer and Land (2003), is built-up by five characteristics:

Transformative – as described earlier, refers to passing through a threshold such that a previous understanding of a subject is significantly changed: a previously inaccessible way of thinking now becomes accessible.

Irreversible – refers to a change of perspective that is unlikely to be forgotten: once understood, the concept cannot become ‘not-understood’.

Integrative – refers to the integration of threshold concepts that expose previously hidden interrelations: aspects of the subject that had previously been regarded as disparate are now seen in a new light, revealing the integrative connections between them.

Bounded – threshold concepts may, but don’t have to, serve to define the border between different areas or disciplines and are then bounded to specific disciplinary areas.

Troublesome – refers to difficulties, challenges, and counter-intuitive thinking students often (but not necessarily) need to overcome. This counter-intuitive thinking might even be regarded as absurd.²⁹

This framework has been developed over the years. For example, Meyer and Land (2005) and Baillie et al. (2013) have proposed additional characteristics. Among these are *liminality*: a reference to the liminal spaces (see Cousin’s quotation above) that reflect the troublesome aspect of learning, the *reconstitution* of the learner’s identity, and a *change in discourse* that is marked by the use of a disciplinary language.

5.1.2 Different kinds of thresholds

Threshold concepts can exist on different levels. Meyer and Land (2005) point out that within a certain curriculum it might be necessary to pass through a series of thresholds to gain a proper understanding. Passing one threshold opens up new landscapes, revealing new thresholds. Perkins (2006) argues that while content-related concepts can be hard to grasp, it is even more difficult for learners to understand how these concepts fit into a discipline’s ways of explanation, problem solving, so-called ‘epistemes’:

“An episteme can be defined as a system of ideas or way of understanding that allows us to establish knowledge” (Perkins, 2006) p. 42.

²⁹ Meyer and Land (2003) give an example from Mathematics, where understanding ‘complex numbers’ is essential for conceptualization and therefore for solving many types of problems. For a novice, however, complex numbers may be absurd, since they include an abstract ‘imaginary part’ that cannot be represented using traditional mathematical concepts.

Drawing on Perkin's thoughts, Wright and Gilmore (2012) and Ramage (2014) suggest that understanding the 'underlying games' of thinking in a discipline is to be seen as a threshold *conception*. According to Burch et al. (2015), knowledge about topics leads to concepts, and multiple concepts are integrated to conceptions. Following this, threshold conceptions can be viewed as an integrative, more complex kind of threshold concepts, which is in line with Davies and Mangan's (2007) distinction between basic, disciplinary and procedural threshold concepts, drawing from experiences within economics. They concern the *basic thresholds* to deal with basic content-related issues, opening up the learner's mind about a subject, while the others connect groups of concepts into higher-level concepts. With *disciplinary thresholds*, they regard aspects that affect the learner's way of *thinking* within a discipline, while *procedural thresholds* affect the way of *practicing* a discipline. They argue that these two are intrinsically tied to each other, since learners not aware of the procedural thresholds in a discipline will have problems in understanding the disciplinary thresholds.

Leaning against capability theory, Baillie et al. (2013) introduce the term *threshold capability*, which refers to important capabilities within a discipline, closely related to the ways of thinking and acting in a discipline, i.e. the threshold conceptions. Threshold capability is an integration of threshold concept and knowledge capability, which Baillie et al. (2013)³⁰ define as the ability to:

- work out the key aspects to deal with in new situations
- relate these to already acquired knowledge
- determine tasks or problems in new situations
- design processes and solutions to deal with such situations
- complete the tasks, or solve the problems

As described above, different labels are used in literature (conceptions, capabilities, disciplinary thresholds etc.) to describe higher-level thresholds. When discussing thresholds connected to total cost analysis in this thesis, focus in on the thresholds as such, not on labelling them in a specific way. Except from when referring to specific literature, I have chosen to use the more general term *learning thresholds*.

5.1.3 Identification of learning thresholds

The literature identifies several methods for identifying threshold concepts. Both Osmond et al. (2009) and Smith (2013) describe cases where thresholds in design education were identified by interviewing students about their experiences. Providing examples from economics and history, Entwistle (2009) notes that students can use concept maps to gain insight into how they perceive a subject such as which topics are seen as essential and difficult. Heading and Loughlin (2018) argue that although students' perceptions are

³⁰ With reference to Bowden (2004): 'Capabilities-driven curriculum design', in Baillie & Moore (Eds): *Effective teaching and learning in engineering*, Kogan Page.

important, teachers' own experiences concerning student difficulties are also valuable. Knight et al. (2014) report on how thresholds were investigated in an undergraduate hydraulics course. To start with, the teachers drew concept maps and discussed these to identify crucial concepts covered in the course. Next, the students answered open-ended reflective questions regarding their learning. This informed the design of a student workshop that included concept mapping and discussions. Finally, a regression analysis was performed concerning the correlation between exam results and knowledge of specific concepts.

As reliance on a single method might give an incomplete or false understanding of the complexity inherent in thresholds, Knight et al. (2014) argue that multiple methods should be used to identify threshold concepts. The difficulties identifying thresholds are addressed by other authors. Rowbottom (2007) is rather tough in his critique:

"If there is one lesson to take away, it is that so-called 'threshold concepts' are not as easy to spot as anyone has previously thought, even if there are such things" (p. 268)

Among other things, Rowbottom's critique concerns the fact that the characteristics described by Meyer and Land (2003) are vague in that several of their descriptions are not absolute, but: "*not necessarily ... bounded [and] potentially ... troublesome*" (Meyer and Land (2003), p. 5, my emphasis). Moreover, Rowbottom (2007) continues, the challenge of acquiring a concept differ between individuals, depending on their preconceptions. For some, he claims, a threshold might not be troublesome at all.

A few years ago, Wright and Hibbert (2013) argued that within management education, learning thresholds are only beginning to be explored. This might according to Wright and Gilmore (2012) be because the management discipline has a less well-defined knowledge base compared to, for example, economics and mathematics (where thresholds are more thoroughly explored) and this makes threshold identification more difficult. They also note that the lack of discussion on possible thresholds within management might be because management teachers in general are not aware of the value of identifying thresholds.

5.1.4 Curriculum design based on learning thresholds

Meyer and Land (2005) argue that a curriculum should be designed so students can integrate new knowledge in a way that transforms their understanding. According to Burch et al. (2015), this requires that the curriculum is developed based on central conceptions. Examples are given by Wright and Gilmore (2012) in the management discipline and Barradell and Peseta (2017) within health sciences.

Bajada et al. (2016) note that:

“... according to threshold theory, students either understand a specific threshold concept in toto or not” (p. 554).

Based on this view, they raise a warning against assessment using traditional ‘part-marking’, where students by accumulation of part marks can gain enough marks to pass a course without demonstrating sufficient understanding of core concepts. Threshold concepts, Bajada et al. argue, should be embedded in the curriculum, in teaching as well as assessment. If the assessment is focused on non-critical aspects instead of thresholds, the consequences might be that students do not understand the essential knowledge, and that such misplaced assessment gives students a false sense of their acquired knowledge.

While this section has provided a theoretical base, the next section discusses thresholds related to TCA.

5.2 Difficulties and thresholds with learning Total Cost Analysis

This section presents the difficulties connected to learning TCA and analyses these difficulties using threshold theory. The section starts with a brief introduction in section 5.2.1 of the learning difficulties identified in the case studies. In the following sub-sections, each of these is more thoroughly described and analysed against the threshold characteristics. However, since the difficulties are chosen because they by definition are difficult (i.e., *troublesome*), this characteristic is automatically fulfilled. Therefore, the analysis addresses the other four characteristics, i.e. whether the difficulties are regarded to be *transformative*, *irreversible*, *integrative*, and *bounded*. Finally, in 5.2.6, the findings are summarized.

5.2.1 Introduction to the learning difficulties identified in the case studies

Although the actual calculations and comparisons in a TCA can be difficult, this is mostly not the major problem. One of the teachers expressed that for the students, the major challenge is:

“... not the theories and models, but to go out in a reality-like setting and apply these models.” (Linköping teacher 1)

This indicates that it is not the specific methods and models, but the application of these in various novel contexts that are most challenging for students. Consistent with this, the learning difficulties that were identified are of a rather generic character. When setting the scope for the analysis, a good *contextual understanding* is required. By understanding, I include having knowledge ‘as such’ as well as knowing how to use this knowledge, leaning on the perspective of ‘knowledge-in-use’ (De Jong and Ferguson-Hessler, 1996), which stresses the ability of using knowledge to perform tasks. Similarly, Biggs (2003) discusses ‘functioning knowledge’, which requires ‘conditional knowledge’, i.e., to know “*when, why, and under what conditions, one should do this as opposed to that*” (Biggs,

2003), p. 42. Teachers from all HEI cases as well as the Linköping students noted that understanding of the context is needed to perform TCA in a good way. In the following, contextual understanding is discussed under two headings: the more general *systems understanding* and the more specific *logistical understanding*. However, the two are closely related. Closely related to the contextual understanding is the ability for *contextual adaptation* of the cost modelling, (i.e., to select cost categories, calculation methods etc. that fit a specific context). Throughout a TCA, a *critical thinking approach* is essential to reach a reliable result. These four issues were addressed during the case studies as being problematic for the students. Therefore, each of them is discussed in the coming subsections.

5.2.2 Systems understanding

Systems understanding refers to the ability to approach problems with a system thinking perspective. As described in section 1.3.2, systems thinking can somewhat simplified be described as the ability to view a set of components and the relations between them in a holistic perspective.

Systems thinking is central to TCA as it requires adequately defining system boundaries (Waller et al., 2015; Abrahamsson and Aronsson, 1999; Williamson et al., 1990). The importance of a systems thinking was also raised by the Lund teachers, who claimed that TC thinking can be viewed as a subset of systems thinking:

“It’s the system view that’s important, not the total cost model. Total cost is a way of illustrating a system view that is classical within our field.”
(Lund teacher 3)

When the students have a poor understanding, they tend to focus too much on the costs as such without really reflecting about the system they are analysing. One Linköping teacher expressed this issue this way:

“[The students] go too quickly into costs, without really considering how the system works. ... Their conclusion is: ‘the cost difference is...’, instead of saying ‘this is a better system, because ... and the cost difference between them is...’ ”
(Linköping teacher 2)

Systems understanding – a learning threshold?

Systems understanding has been investigated from a threshold perspective in other disciplines. Using the threshold characteristics as a reference, Coughlan and Graham (2009) conclude that the ability to see product development as a complex system qualifies as a threshold. The same method is applied by Sandri (2013) investigating systems thinking as a threshold within sustainability education. Although applied in a different discipline, her findings might be valid within logistics since systems understanding (or

systems thinking, which is the term Sandri uses) is a generic perspective rather than discipline-specific. Sandri's way of describing systems thinking also correlates with the way it is used within logistics. She describes systems thinking as *transformative*:

“[Systems thinking has the] *potential to transform identity by changing the way learners conceptualise their roles both personally and professionally in larger systems. This in turn can influence how learners understand their responsibilities as a result of viewing themselves as part of larger systems.*” (Sandri, 2013), p. 815.

Similarly, Senge (2006) argues that to see the whole instead of the parts requires a shift in thinking. One of the Linköping teachers found that students with poor understanding focus on the costs without putting the costs in a context. For this teacher, better systems thinking will enable students to think about TCA in a more context-sensitive way, a transformation that will result in a more nuanced understanding, an understanding that can be applied to novel situations.

Concerning the *irreversible* aspect of systems thinking, Sandri does not take a clear stance. She states that it is ‘theoretically difficult’ to regress to a former way of thinking but does not comment on whether this is true also in practice. The participants in my study did not explicitly claim that systems thinking is irreversible. However, the teachers, especially in Lund and Linköping, stressed the importance of getting the students to adopt a systems perspective – i.e., to be ‘system thinkers’. That is, once this new way of thinking is gained, they believe students will not fall back into more fragmented thinking; they will not de-understand systems thinking once they have come to understand it.

According to Sandri (2013), systems thinking is *integrative* in that it views ‘wholes’ instead of parts, so understandings of the smaller parts are being integrated, and connections are made between different stakeholders, sub-systems, etc. This corresponds well to the reduced risk of sub-optimization in TCA, when larger systems are considered.

For Sandri, because systems thinking is boundary-crossing, it is also multidisciplinary and therefore not *bounded*. However, as Meyer and Land (2003) point out, boundedness is not a necessary characteristic for a threshold.

As the discussion above indicates that the threshold characteristics are fulfilled, systems understanding might well be a threshold for learning TCA.

5.2.3 Logistical understanding

To perform a logistics TCA requires an ability to visualize the situation, which requires a good understanding of logistics in general and of the situation or system that is to be studied. Hence, in a logistics context, an understanding of logistics operations and activities is needed when conducting a TCA. A proper understanding of the operations

also gives an understanding of the main costs and what drives these costs, which serves as a basis for a TCA:

“The cost is a consequence of having used a resource, which is a consequence of having performed an activity. And this is done because we have taken something through a process, a flow etc. ... So variable costs occur because of what we do. Therefore, it’s crucial to focus on what we do in order to understand how things work and are connected to each other.”

(Linköping teacher 1)

Another aspect, brought up by the Hanken teachers and also mentioned by Young et al. (2009), is that in practice there are situations, e.g. within the field of humanitarian logistics, where there is not time for detailed cost analyses. In these situations, decisions have to be made using quick cost estimates, although these should also be based on a proper logistical and systems understanding. More generally, rough cost estimates enable understanding which cost factors are more crucial than others and should be given most attention in a TCA. However, the ability to make such estimates relies on a good understanding of the logistics system.

As ‘logistical understanding’ is central for learning TCA, the Linköping teachers discussed whether students should demonstrate sufficient knowledge of logistics before TCA is introduced in the courses. Some of the teachers argued in this direction; however, others claimed that working with logistics costs is a way of making students interested in the logistics activities connected to the costs. In Lund, as illustrated in an above quotation, TCA thinking is seen as way of illustrating the more general understanding of logistics systems. Consequently, TCA as such is not that main focus for Lund teachers.

This understanding of the logistics activities and the interrelations between them (i.e., the ‘logistics system understanding’) is regarded as more difficult for the students to learn than TCA per se. As expressed by one of the teachers:

“I think this is a major threshold. I feel that standing in front of a hundred students I might scare them away if I’m too abstract. ... They don’t visualize it the way I do when two different logistics systems are to be compared. ... They have a hard time understanding what a logistics system is.”

(Linköping teacher 3)

Logistical understanding - a learning threshold?

Cohen and Billsberry (2014) write that it is commonly argued that management cannot be decomposed into building blocks due to its complexity and context-dependency. What is needed is an understanding of a discipline’s way of thinking and acting. Wright and Gilmore (2012) suggest that students may have problems with adapting a discipline-based understanding of management.

The teachers regard understanding logistics processes and activities and how these interact as important and difficult for students. Whether this should be regarded a threshold might depend on what level of understanding is discussed. For example, the specific insights concerning how *a certain* change in customer offering will affect costs and service (and thereby revenues) probably will not require a dramatic transformation in the students' understanding, nor will it be impossible to forget, (i.e. it is reversible). On the other hand, on a *more general* level, the understanding might be changed from a sales-oriented view focusing on revenues (and neglecting that customer offerings will drive costs) to an integrated view that acknowledges that both costs and revenues are affected. This kind of changed understanding is *integrative* (cost and revenue perspectives) and most likely *transformative* and *irreversible*. Being rather discipline-specific, it is also *bounded*.

Hence, logistical understanding might or might not be a learning threshold, depending on what is included in logistical understanding. Referring to the more general example above, logistical understanding might be regarded as 'thinking as a logistician', a view similar to Entwistle (2009) discussing 'thinking like a historian'. As such, there are parallels with Cohen and Billsberry's (2014) statement above as well as with findings from other disciplines. Tsang (2011) suggests that 'the ways of thinking, knowing and being a [healthcare] professional' is a threshold, which resembles the 'knowledge-in-use' view of understanding. However, as 'thinking as a logistician' is broadly understood, it could involve systems understanding (as stressed by the Lund teachers) and the following TCA-related difficulties.

5.2.4 Contextual adaptation

Closely related to contextual understanding is the ability to adapt the TCA to the specific context and the specific situation. For example, different cost categories are affected depending on the situation, and the proper way to calculate or estimate these costs also varies. Logistics textbooks present various TC models consisting of several cost categories included in the total logistics cost. The Lund and Linköping teachers discussed the pros and cons of such models. They agreed that a general ability for TC *thinking* is more important than mastering a TC *model*. The common view was that such pre-defined TC models have too defined 'cost boxes' and that the students tend to regard these boxes as 'the truth', thereby limiting their critical thinking. One teacher claimed:

"If viewing it principally, as a way of thinking, we are interested in the total cost, no matter how we label these costs." (Linköping teacher 1)

Referring to personal experiences from being a student, another teacher argued that cost factors were regarded as something rather abstract. They were 'words' with explanations to learn by heart – i.e., they were words to be memorized rather than to be understood. These models and 'concepts' (e.g., warehousing costs) might be necessary, but they might

also act as barriers to TC thinking. In line with this, some teachers advocated for not putting too much emphasis on TC models, because this might limit the students' thinking:

"What is important? It is to stress the understanding, that it is about total cost analysis, it's a principal way of viewing it. It will by definition be situation specific, and therefore you need to make a flow description to understand which parts that really are crucial to consider. ... A risk with models is that they might lock in the students and make them miss this step [of understanding]." (Linköping teacher 1)

Such a view gives students the false impression that TCA is easy:

"There is a sense of triviality in this total cost model: 'Hey, that's not strange, it's obvious that we should add costs. Really easy!' Our point is: 'No, it's rather difficult.' The difficulties are in the details, to get the hands on those and include them and choose which trade-offs to make. It's a lot of work with this, but conceptually it's a trivial model." (Lund teacher 3)

According to these statements, a problem with pre-set TC models is that they direct the students too much and that they give the students a false sense of simplicity regarding TCA and possibly a false sense of their own understanding.

Other teachers expressed more model-friendly arguments. One of the Lund teachers argued that TC models are appropriate for highlighting trade-offs in-between costs as well as between costs and other aspects. Another teacher argued that a TC model can be viewed as a conceptual model, and that such a conceptual model can help students learn TC thinking. In line with this are the following voices:

"It's difficult to show them everything. There's so much you'd have to describe to make them grasp it all. The total cost model is a tool to view the world, to trigger thinking about 'What have we got here?'. I still think there's a point with it – 'this is the tool which we use to view the world'. It might be a bit more boring, but still it helps them on their way towards understanding." (Linköping teacher 4)

"It's when using this tool, you really reach this understanding of reality." (Linköping teacher 5)

Although some teachers argue that it is hard for students to understand that TC models should be adapted to the specific situation, one of the Linköping teachers meant that the students *do* understand the logic that a proper TC understanding is a basis for adopting a certain TC model to a specific case, but that they stick to the model anyway, because it is easier and gives them a sense of comfort and security. This was confirmed by the Linköping students, who are clear about the need for case-specific adaptation of pre-set TC models. However, although they understand the need for adaptation, they argue that

in educational settings they become hesitant concerning how they are expected to behave. Excluding a pre-defined cost category because of irrelevance in the specific case feels according to one student more okay than adding a new cost category. The students' hesitation is connected to how they think they will be assessed:

"In the introductory course, it was explicit that all factors in the TC model not always had to be included, and that it should be adapted to fit the situation. Whether you [as a student] dare to rely on this is another thing."
(Linköping student 5)

"In educational settings I think it's hard to know when it's alright to trust my own ideas and knowledge and what I feel is reasonable and right, and when I'm supposed to stick to the given models." (Linköping student 2)

Although these students think that a certain TC model to some extent might be limiting, they believe that it would be confusing if TCA principles were taught without a TC model as support.

These student statements indicate that some of the perceived difficulties for students to adapt TCA to a specific context might depend on the educational setting as such, an issue that will be further discussed in section 6.1. However, even if this (at least partly) covers the issue of understanding *that* adaptations should be made, there is still the problem of *how* to properly select and implement adaptations. In addition, some aspects that could be included in practice could be too difficult to quantify as a cost, such as the costs related to environmental impacts. There are models including some environmental costs (i.e., in some situations these costs can be included), while in others the environmental costs cannot be quantified and therefore must be accounted for in alongside costs. Therefore, TCA should be done in context with other non-cost aspects, a strategy stressed by teachers at all the case universities.

Contextual adaptation - a learning threshold?

Davies and Mangan (2007) suggest that 'selection and improvement of economic models' is a potential threshold capability, since this requires integration of narrower concepts and might transform the student's understanding of economics in an irreversible way. The contextual adaptation of TC models is closely related to 'model selection and improvement'. The Linköping teachers noted that students often stick to the pre-set TC models found in textbooks because they assume that being assessed they might be 'punished' if stepping outside these models. However, there is also evidence that students make progress in their understanding by going beyond textbook models:

"Today, it feels natural to exclude cost factors you see won't change, but in the beginning, you were more doubtful: 'Is it really OK to do this?'." (Linköping student 3)

Once having understood and accepted that these models are starting points for the creation of context-specific TC models, they will not give up this understanding. Hence, it is *transformative* and *irreversible*. Because the selection of cost factors depends on an understanding of cost drivers for the logistical activities, there is also an *integrative* element embedded. The TC model adaptation procedure can be seen as *bounded* to TCA, although TCA can be performed in many different settings. Hence, the threshold characteristics fit the contextual adaptation of TC models.

5.2.5 Critical thinking approach

An issue brought up by teachers at all case universities is the students' limitations in approaching tasks critically. When conducting a TCA, many decisions must be made where it is not self-evident what to do. Therefore, a critical approach to the analysis is important. Such critical thinking should be adopted during the contextual adaptation discussed in the previous section as well as during other stages. In the following sections, three areas are highlighted: reviewing input data, prioritizing efforts, and reviewing results.

Reviewing input data

As discussed in section 4.2.8, input data are often difficult to retrieve in the desired format because data are unavailable or because data have to be processed further to be useable. Therefore, the initial analysis plan might be impossible to follow:

"Whatever you want to analyse, and what you have data for are two very different things." (Hanken, teacher 2)

"You shouldn't think that just because you say that you would like data about something from a company, they will be able to get it for you. This data is not always available, at least not in the format you would like it to be."
(Chalmers teacher 1)

However, according to the teachers, students tend to believe that data are readily available in organizations and that these data accurately reflect reality well. They seem to have an over-reliance that the 'real world' will fit the theoretical models. Rather, a critical approach is needed, in order to question whether the data are representative, including scrutinizing how the data were collected, measured, and defined. As referred to also in 4.3.2, one teacher encourages critical thinking by telling students to:

"... be 'total cost detectives' at the company when you get out. It's not enough just to ask. You must actively work with it yourself to get to know."
(Linköping teacher 3)

As previously noted, Chalmers students discovered that a company used an old value for ordering cost without knowing whether it was correct. In such a case, identifying the real cost might require a lot of time, so it might not be worthwhile, which leads us to the next topic – prioritization.

Prioritization

Especially in more complex TCA, ensuring accuracy in all details will be very time-consuming. Therefore, analysts should prioritize the efforts to best support the analysis. Because of the many uncertainties involved in a TCA, a ‘correct’ answer is almost never achievable. Although detailed calculations might be necessary in some situations, in other situations rough cost estimates will suffice, and focus should then be on the most important cost categories. One teacher clearly expressed the need for students practising this kind of critical reasoning:

“Where should we have detailed data? We might not be able to have it everywhere, because then we would never reach an end. [The reasoning should be] ‘Here are most probably our challenges, and this is probably where we should dig down deep for data.’ ... It is kind of a trade-off analysis. Look at the whole package, view the complete system and then see where the trade-offs are important, and which data is needed there in order to reach some result.”
(Lund teacher 3)

However, Chalmers and Linköping teachers argue that students are often eager to find ‘the correct answer’ (maybe because they are used to doing this in other courses and disciplines) and tend to calculate ‘everything’ without considering the relative importance between different costs. One teacher noted that this attitude is understandable as students want to demonstrate as much of their knowledge as possible, especially when their work is assessed:

“Say that seven cost factors can be calculated, and correct calculations on all factors gives a score of seven. But if you’ve made a prioritization that ... three factors are the important ones, and you only calculate these three, could you then be awarded with seven points? You’ve only calculated three. Is the prioritization worth four points?” (Linköping teacher 1)

The Linköping students confirm that assessment sometimes triggers them to act differently than they otherwise would have acted:

“If I am to be examined on a total cost analysis and investigate three of the five cost categories [from the theoretical model], I feel like I’ve only done 60%, even if these three represent 95% of the total cost. It feels like I am not showing what I can.” (Linköping student 1)

Hence, at least in some situations, students seem to differentiate between educational settings and more realistic settings and that the seemingly ‘non-criticality’ is a way of adapting the behaviour to the assessment:

“Taking the school perspective ... we should calculate it, it feels right to do so, but for the company it might be a small cost ... If I had been only in a working situation, I would never have considered this cost factor...”

(Linköping student 1)

“... but as a student you feel you should [include everything].”

(Linköping student 5)

A detailed calculation of all cost factors irrespective of their relative importance might also be driven by a true desire to learn rather than assessment pressure:

“When studying I want to go through all parts [of a TC analysis] in a structured way, and maybe include factors that are relatively unimportant. ... As a student, it’s important to learn all parts in detail, so even if it’s a small cost factor I want to go into it and understand how it works. The size is not important, but the connections between all aspects.” (Linköping student 1)

“You kind of hoover the information sources on everything you might possibly want to include, and try to check off it all, not to miss out anything.”

(Linköping student 6)

“And you might learn until next time what should be included ... it is in the back of your mind what’s relevant to look at.” (Linköping student 5)

The last of these three quotations also reveals that it is not obvious which factors to prioritize without practice – i.e., prioritization is difficult as it requires experience.

Critical review of the results

Although the results of a TCA might be based on uncertain data, assumptions, etc., the students tend to regard their calculated results as robust. Evaluating the robustness using sensitivity analysis was advocated by teachers at all the case universities. One teacher warned that there are often underlying assumptions not covered in students’ sensitivity analyses:

“They feel that this cost they have calculated, there is some truth in it. That the sales might increase, that the assortment might change, that there might be obstacles that might crash this solution, I think they regard such aspects too vague to abandon the solution. So, the fact that they reach a concrete figure, might create a ‘false robustness’.” (Linköping teacher 2)

The Lund teachers suggested that another aspect to consider is the usability of the suggested solution. When creating a TC model for an organization, the correctness in calculations is, of course, important, but it is also crucial that the model is understandable and easy to use and that the outputs serve to support decision-making processes. These aspects must also be critically evaluated.

Critical thinking – a learning threshold?

Rattray and Chen (2017) argue that critical thinking is a type of threshold. To become a critical thinker, one must be open to changing one's preconceptions – i.e., be willing to evaluate old evidence in new ways and/or be open to new evidence that *transforms* what one thinks. This process is *irreversible*, since one cannot give up critical thinking. Furthermore, viewing problems critically involves looking at them from different perspectives in an *integrative* way. Concerning *boundedness*, Rattray and Chen argue that some aspects of critical thinking might be discipline-specific and others might not.

The teachers in the case studies also highlighted that students tend to believe that there is one correct answer to be found when in reality a plethora of solutions might exist, and the question rather is to find a 'good enough' solution. This is discussed by Smith (2013), who identified that design students faced the similar problem as part of a threshold that Smith labels 'recognition of problem insufficiency'. For the students to move from the misconception that problems are well-defined with clear solutions, they have to widen their perspective (integration), a view that requires a transformative (and irreversible) shift in thinking.

5.2.6 Concluding thoughts concerning thresholds for total cost learning

The literature does not specifically address learning about total cost analysis. However, when TC learning difficulties identified in the case studies were compared to the literature about thresholds, all the identified difficulties qualified as being learning thresholds, necessary to pass in order to be able to think and act like a professional TC analyst.

The literature provides direct support that three of the categories discussed (systems understanding, contextual adaptation, and critical thinking) are threshold capabilities. All these match the three necessary threshold requirements posited by Meyer and Land (2003): these categories are *transformative*, *irreversible*, and *integrative*. Logistical understanding is not addressed in the threshold literature per se; however, based on findings from the case studies also logistical understanding corresponds to the three necessary characteristics.

The case studies also showed that all the identified learning difficulties associated with TCA are *troublesome*. Furthermore, logistical understanding is *bounded* to the logistics discipline. Contextual adaptation is bounded to the specific context. However, the other two learning difficulties are not bounded to a specific context or discipline. A compilation

of the match between TC learning difficulties and threshold characteristics is shown in Table 15, where the necessary characteristics are marked in bold text.

Table 15. TC learning difficulties vs. threshold characteristics (necessary characteristics in bold text)

Threshold characteristics	Total cost learning difficulties			
	Systems understanding	Logistical understanding	Contextual adaptation	Critical thinking
Transformative	Yes	Yes	Yes	Yes
Irreversible	Yes	Yes	Yes	Yes
Integrative	Yes	Yes	Yes	Yes
Bounded	No	Yes	Yes	No
Troublesome	Yes	Yes	Yes	Yes

Finally, there are connections between the learning difficulties. Contextual adaptation relies on an understanding of the context, i.e. logistical as well as systems understanding. If the context is poorly understood, it is impossible to make good adaptations to that context. A crucial part of the contextual understanding and adaptation is to view the context, or the system, from a critical stance. Therefore, critical thinking might be seen as a prerequisite for overcoming the other three learning difficulties.

Having discussed the thresholds for learning TCA, the next chapter deals with teaching methods to support total cost learning.

6 Methods for teaching total cost analysis

As described in previous chapters, conducting total cost analysis is a challenging task associated with difficulties for students to learn. This chapter deals with the third research question *How can total cost learning be supported by appropriate educational methods?*. Similar to the procedures for RQ2, educational activities were identified by successively visiting the four case universities (see 2.3.3 for details). In section 6.1, theory concerning constructivist approaches to teaching are presented, and in 6.2, the empirical findings are presented and compared with theory.

6.1 Enhancing learning with constructivist approaches

The ability to apply total cost analysis in real settings is essential. As discussed in 5.2.4, this requires contextual adaptation to the various settings where TCA is used to support decision-making. Students therefore should learn the basics about TCA as well as how to adapt and apply TC models to different contexts. However, such knowledge-in-use (De Jong and Ferguson-Hessler, 1996), or conditional knowledge (Biggs, 2003), is hard to learn without practising. Within constructivism, it is stated that knowledge is actively constructed by the individual learner and therefore cannot simply be transmitted from one person to another. In a context with adult learners, as in higher education, Cohen and Billsberry (2014) argue that one could expect that adult learners (e.g., university students) clearly understand the purpose of their studies and expect to be more deeply involved in the learning process, which means they are more willing to actively construct knowledge. Several pedagogical approaches are strongly influenced by constructivism. Some of these are briefly described in the following³¹:

- *Action learning*: Learning by working in small groups with actual projects and problems (Brook and Milner, 2014).
- *Active learning*: Students should be engaged in the learning process, and reflect on what they are doing to achieve meaningful learning (Prince, 2004).
- *Authentic learning*: Students are engaged in real-world experiences that are found meaningful to them (Stein et al., 2004).
- *Experiential learning*: Learning is driven by concrete experiences that the learner can reflect on and use to make hypotheses, which then can be tested, leading to new experiences, etc. (Kolb and Kolb, 2005).
- *Problem-based learning*: Students work collaboratively on problems with strong connection to the real world. The students are responsible for their learning process, and for integrating knowledge from different disciplines (Savery, 2006).

³¹ Definitions and descriptions of the learning approaches differ between authors. However, my ambition here is not to give a complete picture, but to briefly present the different approaches.

- *Project-based learning*: Structured around complex, authentic questions and tasks performed in projects where students have a strong influence in forming the learning process (Jeon et al., 2014).
- *Situated learning*: Knowledge and skills should be learned in contexts reflecting real life (Collins, 1988).

These approaches differ from each other. However, as indicated by the descriptions in the list above, they also share many aspects (Prince, 2004; Savery, 2006; Davidson and Major, 2014). For the purpose of this thesis, these common aspects are central irrespective of how the approaches are labelled. Section 6.1.1 presents some essential aspects of these constructivist approaches, 6.1.2 deals with educational activities in line with the constructivist approaches, and 6.1.3 summarizes the essential aspects of constructivist teaching.

6.1.1 Aspects stimulating learning

Several things are highlighted in the literature as being fruitful for stimulating students' learning, i.e. their construction (or re-construction) of knowledge.

Activity and engagement

Bonwell and Eison (1991) identify central aspects of the constructivist approaches:

“... students must do more than just listen: They must read, write, discuss, or be engaged in solving problems. Most important, to be actively involved, students must engage in such higher-order thinking tasks as analysis, synthesis, and evaluation. Within this context, it is proposed that strategies promoting active learning be defined as instructional activities involving students in doing things and thinking about what they are doing.” (p. iii)

Embedded in this quotation, and specifically stressed by Perkins (2006) is that it is not enough for students to be active, they must also *engage* in the learning process to develop their understanding. Another voice stressing the need for engagement is given in the following quotation, where the connection also is made to the enhancement of cross-disciplinary generic skills.

“... teaching activities that are associated with engaging and encouraging learning are those that are personally meaningful to the student, and also purposeful from a societal point of view. ... not only to promote the subject domain ... [but also] skills such as creativity, critical thinking and problem solving capability.” (Svård et al., 2017), p. 3

By examining a number of articles dealing with the different constructivist approaches introduced above, some aspects were identified that enhances student activity and

engagement. These are presented in the following. For more details concerning the identification procedure, see section 2.3 and appendix 8.

Reflection

To encourage engagement, several authors stress the importance of reflection. Entwistle (2009) argues that reflection helps students reach a more rich and nuanced understanding. Therefore, teachers should use reflective activities in the courses, to help students become aware of their learning (Stein et al., 2004), consolidate what they have learned (Savery, 2006), and even transform their knowledge (Marsick and O'Neil, 1999).

Collaboration

Reflection is preferably performed in interaction with others, since knowledge and understanding is co-constructed in dialogue with others (Perkins, 2006). As Marsick and O'Neil (1999) put it:

“Individuals learn as individuals, but their experience is shaped and understood within social contexts” (p. 170)

Collaborative reflection gives students opportunities to learn by supporting and challenging each other (Jennings, 2002; Coorey, 2016). Explaining to others also requires clarification, rethinking, and reconceptualization (Ge and Land, 2003), which contributes to a developed understanding. Collaboration can take place in classroom settings as well as in other contexts. Kayes et al. (2005) refer to research that shows that students who collaborate outside the classroom learn significantly more than those who do not.

In addition, collaboration can in some educational settings be between students and experienced practitioners, which provide insights for the students into contemporary problem solving in organizations (Sroufe and Ramos, 2011).

Connecting to the already known

Biggs (2003) states that:

“Cognitive growth lies not just in knowing more, but also in the restructuring that occurs when new knowledge becomes connected with what is already known” (p. 75)

In line with this, Kolb and Kolb (2005) argue that all learning is *relearning*, since learning builds on and transforms the existing knowledge. Hence, the learning experiences should be designed to be meaningful and relevant to the learners (Marsick and O'Neil, 1999; Stein et al., 2004). Therefore, teachers should know what knowledge students bring with them, since according to Entwistle (2009), the students' pre-understanding is the single most important factor influencing learning.

Authenticity

If connecting previous knowledge to new knowledge helps advance understanding, then connecting to real-world contexts is essential to motivating students and making new knowledge meaningful (Jollands et al., 2012). According to Hunter (2015), a deeper, more nuanced, and more useful understanding is gained by anchoring learning experiences to real-life situations, thereby connecting theory and practice. Some authors, such as Fortuin and Bush (2010) and Bootsma et al. (2014), believe that an important aspect of authenticity is to provide insight into the complexity of real-world settings. Murphy et al. (2006) state that there are two important aspects of authenticity: personal authenticity and cultural authenticity. *Personal authenticity* means that the learners must perceive tasks to be meaningful. *Cultural authenticity* refers to that the educational activities should correspond closely to activities actually performed in real settings.

Learning experiences might take place in sharp settings, dealing with real organizational problems. However, authenticity does not necessarily mean that a perfect representation of reality is needed. Maximum fidelity does not assure the best learning (Jennings, 2002; Ornellas et al., 2019). The desired learning experience may be favoured by emphasizing some aspects and de-emphasizing other aspects. According to Stein et al. (2004), Svård et al. (2017) and Roach et al. (2018), the crucial thing is that the learning situation is personally authentic to the learner (a credible real-world connection), as well as culturally authentic to the community of practice (a true representation of the real world).

Ill-structured and open-ended problems

Since reality is complex, ‘messy’, and ‘ill-structured’, a way of creating authenticity in education is to let students encounter ill-structured or messy problems. Karagiorgi and Symeou (2005) argue that such problems help students generate new knowledge, for example by learning to distil relevant information from irrelevant (Tang, 2019). Savery (2006) and Peddibhotla (2016) pinpoint that the starting point in such problems is to identify what the problem really is, something which reflects reality well. The importance of problem identification is highlighted by Marsick and O'Neil (1999):

“The key to learning is in finding the right questions to ask.” (p. 162)

Open-ended problems are such tasks that do not have one single correct answer. Instead, competing solutions and a diversity of outcomes are allowed (Herrington et al., 2003). Open-endedness is embedded in ill-structured as well as more structured problems. The idea is that students should investigate the issue from different angles and explore alternative solutions (Collett, 2000). This way, students learn that ‘truth’ and ‘certainty’ seldom exist in the real world (Karagiorgi and Symeou, 2005). Instead, their focus should be on finding viable solutions – i.e., reasonably supported answers that they can defend (Bean, 2011).

However, Karagiorgi and Symeou (2005) stress that tutoring and guidance is needed to support students working with this kind of problems. Davidson and Major (2014) suggest that students should be exposed to problems in a progressive sequence, i.e., more structured problems before less structured. Nesbitt and Cliff (2008) add that teachers must be able to handle a multitude of different ideas and suggested solutions, which can be challenging, both when supervising and when assessing student work. Stein et al. (2004) stress that also the assessment must allow for this multitude of answers, i.e. assessment and teaching must be interrelated (Herrington et al., 2003).

6.1.2 Educational activities promoting engagement

Educational activities should be designed to address the aspects described above: reflection, collaboration, authenticity, ill-structuredness, and open-endedness. In the literature, some educational activities are discussed that address these issues.

Teaching cases can be designed in many ways, limited or extensive in scope, and used in as well as outside classroom settings. Cases should relate theory to practice (Jennings, 2002), support the acquiring of problem-solving skills (Bootsma et al., 2014), and apply learning from previous courses (Peddibhotla, 2016). However, not all researchers are in favour of case teaching. Collett (2000) refers to such critique stating that cases provide limited experiential learning since they are tightly defined compared to real-world projects. Although some cases are tightly defined, this criticism seems too categorical to be generally valid for all cases. All the above-mentioned learning- and engagement aspects can certainly be addressed in cases if appropriately designed.

Compared to teaching cases, *projects* have the possibility for adding experiences, especially if performed in real-world settings. Working with real problems in organizations requires students to step out of their comfort zone, according to O'Leary (2015). They are exposed to the complexity and uncertainty in real settings and are given the opportunity to collaborate with practitioner experts. Such experiences are essential according to Ardley and Taylor (2010), who argue that:

“Without some experience gained in the workplace by students, actual practice cannot be well understood.” (p. 857)

In congruence with Davidson and Major's (2014) recommendation of gradually introducing more and more ill-structured problems, Collett (2000) suggests that live open-ended projects should only be conducted when students have considerable experience of simulated (fictional) less complex projects.

Although cases and projects are the most frequently discussed experiential learning activities, a few others were identified, for example, *business simulations*, which refers to artificial settings (physical or IT-based), often in the form of games. Realistic activities,

constraints, consequences, and links between them can be simulated (Korhonen et al., 2007) in a risk-free, repeatable and controllable environment (Gabrielsson et al., 2010).

6.1.3 Essential aspects of constructivist teaching

As the previous sections indicate, constructivist approaches to teaching and learning are multi-faceted. This section provides a brief summary of essential aspects from a teaching perspective.

Learning deals with increasing one's knowledge. From a constructivist perspective, knowledge is constructed rather than acquired. Such knowledge construction requires *reflection* on how new aspects relate to the learner's existing knowledge. Reflection is facilitated by *collaborative* work, which influences two other features stimulating learning: *activity* and *engagement*. However, to become engaged, the learner must feel that topics and tasks are *authentic*, i.e. reflecting *reality* and being relevant for the learner's future. Authenticity is achieved, in part, by using educational activities with *ill-structured* (since in real life all necessary information is seldom easily available) and *open-ended* problems (as multiple solutions are often possible in real settings). Educational activities recommended for embedding authenticity in exercises – thereby stimulating engagement, reflection and learning – are primarily *teaching cases* and *projects in real-world settings* are advocated. Another example is *business simulations*.

Many authors believe it is important to tightly connect teaching and assessment. That is, when teaching is based on authenticity, reflection, etc., students should be assessed accordingly, a view that resembles the theory of constructive *alignment* presented by Biggs (2003). Moreover, as the real world can be very complex, with many degrees of freedom, exposing novice learners to all this complexity is not recommended. A gradual increase of ill-structuredness and open-endedness is recommended, establishing a *learning progression* within courses and between courses in an educational program. Figure 24 visualises the aspects highlighted here.

Figure 24. Essential aspects of constructivist teaching

In the following section, the educational activities used at the case universities are presented and discussed in light of the theories presented above.

6.2 Total Cost teaching at the case universities

In section 6.2.1, educational activities used at the studied HEIs are described, including some concrete examples. In the following sections, the findings from the case studies are related to the constructivist teaching theories presented in 6.1.

6.2.1 Teaching methods used

At all four universities, cases and projects are used as they are regarded suitable for teaching complex issues such as TCA. Although traditional lecturing is used to various degrees at the four HEIs, the teachers are all in favour of methods where students are engaged and actively participating, strategies that are in line with the constructivist teaching theories. Linköping and Chalmers offer specific project courses, where students face real-world projects at sponsoring organizations, and at all four HEIs, the master's thesis projects are predominantly conducted with external organizations that provide real problems for the students to work with. These projects and master's theses sometimes deal with TCA. Cases in different forms are used in the courses. Some of these specifically addressing TCA, while in others TC issues are part of a bigger picture. In Lund, two of the cases are run in the form of business games.

Examples from the courses at the case universities

The following discussion provides short descriptions of how TCA is addressed in some of the courses at the universities. The examples are chosen to illustrate the above-mentioned teaching methods. Appendix 9 provides more detailed descriptions.

The 'Logistics' course in Lund

After being introduced to a TC model in lectures, the students work with minor inventory management exercises, where total cost minimization is focused. In a larger teaching case, ChainSim, an on-line business simulation case that can be run at different levels,³² the students work in teams to manage the supply chain in a small fictional manufacturing company to satisfy the customers and improve profitability. Reduction of total costs is thereby an important aspect to consider.

The 'Management of physical distribution' course at Chalmers

Various total cost issues are covered in lectures, for example, trade-offs between transportation costs and material handling costs and cost comparisons between performing logistics services in-house or buying them from an external company. In the teaching case 'Apelsin', the students work in teams to compare new distribution set-ups with the present one for a fictional company. Total cost is one of the aspects addressed in

³² See <http://www.chainsim.com/> for more information.

the case. A certain amount of redundant data is provided to make the case more realistic and force students to make prioritizations.

The ‘Purchasing’ course in Linköping

This case exercise, performed in teams, specifically focuses TCA. The fictional case company is in the process of selecting a supplier from a few potential companies. In the case description, the decision situation is well described, but almost no data are given. First, the students should consider which cost factors they find relevant to include and request the input data they need to make the necessary calculations. The teacher provides a data set in line with their request. Some of the requested data might be unavailable – i.e., students will have to handle the lack of data. On the other hand, depending on their requests, they might also receive some redundant data. Second, they use their data to perform calculations, analyse the results, and recommend a supplier. This exercise design creates a situation where all student groups might have different data sets for their TCA – i.e., the task is open-ended, so the groups will come to different results and give different recommendations.

The ‘Supply chain management’ course in Lund

A major part of this course is devoted to The Fresh Connection, a web-based business simulation game that deals with sales, operations, supply chain, and purchasing issues for a fruit juice producer.³³ In teams of four students, each student is assigned responsibility for one of these four areas. The decisions made by the students in these four areas will affect costs as well as other performance measures influencing the company’s profitability. Therefore, analysing the cost effects an important part of the students’ work.

The ‘Logistics project’ course in Linköping

Private and public organisations are asked to come up with logistics-related assignments. Under academic supervision, students work in teams to come up with solutions. Frequently, but not always, TCA is part of these projects. Since every assignment is unique, there are no correct answers available. Furthermore, the students start the project without knowing what information is needed to get the assignment solved.

A compilation of the examples

In Table 16 below, the examples briefly described above are mapped against the educational methods and problem features described in 6.1 concerning constructivist teaching approaches. All examples except the dedicated project course deal with teaching cases in one form or another. They are all realistic in the sense that they deal with real problems or fictional ones created to reflect real problems. Moreover, they are all more or less ill-structured, so the students have to make sense of the data given and decide how

³³ See <https://www.thefreshconnection.biz/> for more information

to use the data. Since all the courses provide problems where multiple solutions are possible, these are open-ended.

Table 16. Examples from the cases vs. constructivist teaching aspects

Course	Educational method			Problem feature for authenticity		
	Teaching case	Project in real setting	Business simulation	Realistic	Ill-structured	Open-ended
Logistics	x		x	x	x	x
Mgmt of phys. distribution	x			x	x	x
Purchasing	x			x	x	x
Supply chain mgmt	x		x	x	x	x
Logistics project course		x		x	x	x

These examples show that TCA is taught at the investigated HEIs using educational methods corresponding to the constructivist teaching literature and providing the students opportunities to work with problems that incorporate authentic features that according to the literature are supposed to create authenticity to the students. Based on teacher and student observations and against the background of theory, the next sections discuss whether this type of teaching really creates the desired authenticity and increases student activity, engagement, and reflection. Since these issues were not discussed specifically for each course during the focus groups and interviews, the following discussion is held from a more general perspective. Separate sections are dedicated to authenticity (6.2.2), alignment (6.2.3), and learning progression (6.2.4). In 6.2.5, the findings are summarized.

6.2.2 Authenticity and its effects

The Linköping teachers highlight that they strive to use cases that are challenging, forcing the students to face different difficulties associated with TCA. In Lund, the teachers believe cases to contribute to students' understanding and critical thinking skills, especially when the cases are open-ended. In addition, the students see cases as a favourable way of learning because the cases force them to apply knowledge and to think about how things work:

“What I think I’ve gained from the cases is ... thinking deeper, or from a different angle on it all. Things I might not have considered before.”
(Linköping student 6)

The Lund students stress that although complex cases are challenging, the work is often rewarding since the complexity makes a case more realistic. Students and teachers agree that cases should be realistic enough to give an authentic feeling even though they are fictional or adapted to fit a teaching situation. The Linköping students believe that the more realistic cases are, the funnier to work with, which makes you encouraged to spend more time on the cases. This corresponds to the constructivist idea that authentic learning experiences engage and motivate students. As some authors highlight (Jennings, 2002; Ornellas et al., 2019), true authenticity is not needed, a view also expressed by Lund

students, who argue that fabricated cases could be easier to work with and more rewarding as long as they are realistic enough:

“You can make learning points clearer ... it can be more spot-on the specific subject if you can make things up a little.” (Lund student 1)

To find an appropriate level of realism is not an easy task, though. In real situations, a crucial skill is to sift out the most important data from large amounts of data. Although ill-structured problems are advocated, a balance between the need for realism and the risk of data overload has to be considered when deciding how much information to make available to the students. Murphy et al. (2006) conclude that learning experiences should be both culturally and personally authentic. Although very ill-structured problems with data overload may reflect reality well (i.e., culturally authentic), it might not be perceived as realistic by the students (i.e., lacking personal authenticity). A Chalmers teacher gave an example from a case in one of the courses. Previously, more data were provided, but the amount of data was reduced due to work overload – i.e., the students tended to get stuck in data processing and spend too little time on other important issues. However, reducing the data volumes has made the case less realistic, so the teacher considers adding more data to a specific part of the case to make input data for the cost calculations more realistic. The Lund teachers are reasoning in a similar way. They say that because many cases are too basic, it is problematic to find cases that show the complexity well enough:

“The challenge is to make it complex enough to make it relevant, but not too complex, they really must understand.” (Lund teacher 2)

An issue brought up by the Linköping teachers was that if you want students to make good choices concerning which cost factors to include in the analysis (even if much data and information are available) it should be rather clear from the assignments or case instructions that some factors are less relevant than others. It is also important to guide the students, so they understand that you expect them to do certain kind of prioritizations, e.g. to leave out less relevant cost factors from the analysis.

Support and feedback

Teacher support seems to be crucial for acquiring deep understanding of how to tackle TC problems. This is in line with Karagiorgi and Symeou (2005), who stress the importance of tutoring and guidance. The more complex the case, the more is required from the teachers, according to the Lund teachers. The following quotation indicates that case teaching might be a rather demanding activity for students as well as teachers.

“I think rather much follow-up and discussions are required to make them really get it ... You sort of have to get the feedback face-to-face.”
(Lund teacher 2)

Although support along the road will help solve a case or assignment, the general opinion among the Linköping students was that they often learned more when they encountered problems they had to tackle, even if they did not really succeed to solve the problem – i.e., too much support in the beginning might be counter-productive. After struggling with tasks, good feedback and discussions will enhance the learning. This view is in line with the Linköping teachers' opinion that the teacher's role is both to put students in problematic situations and help them out again:

“At first, [the problem] might look rather simple, but when getting deeper down it becomes more complex, but this is where we lead them. ... and then all these questions come. But then you must somehow get up again, and that's when we [discuss] assumptions, estimations etc., that it's OK.”

(Linköping teacher 4)

The teachers' view is that this way of working encourages the students to be more autonomous and take responsibility for their work and their learning, and that reflective discussions between teachers and students are essential:

“I would say that it's during discussions [we can make them learn TCA]. The thing is that the students must work with it, face different problems and challenges.” (Linköping teacher 6)

However, the students add that when being assessed on their performance on a teaching case problem, the support before and during the case work should be sufficient enough to enable them to solve the case in a way to achieve good marks.

To conclude...

Teachers and students agree that cases and projects are teaching forms that create engagement, and that exercises and problems reflecting reality are stimulating. Although true authenticity is not necessarily favourable, a certain level of complexity and vagueness (e.g. ill-structured and open-ended problems) contribute to the activity and engagement. However, the students and teachers stress that appropriate support and feedback from teachers is needed throughout the process to favour reflection and learning.

6.2.3 Alignment between teaching and assessment

The constructive alignment theory (Biggs, 2003; Pettersen, 2008) states that assessment should be aligned with instructional activities and with intended learning outcomes. The Lund, Chalmers and Linköping teachers stressed that they want their students to learn how to apply and use TCA rather than learn theoretical TC models. Whether this is reflected in the assessments is however not clear. One of the Linköping teachers gave an example that demonstrates this ambiguity:

“Say that seven cost factors can be calculated, and correct calculations on all factors gives a score of seven. But if you’ve made a prioritization that ... three factors the important ones, and you only calculate these three, could you then be awarded with seven points? You’ve only calculated three. Is the prioritization worth four points?” (Linköping teacher 1)

This teacher concluded that of course full score could be given provided that the prioritization is well performed. This connects to Bajada et al. (2016) stating that if the intended learning aspects (in this example critical evaluation and contextual adaptation) are not assessed, the students might misunderstand what is essential to learn. However, it is crucial that the students know and trust the teacher’s intentions; otherwise, they might still think that they should include everything. The same teacher continued:

“This is connected to how the task is designed. ... If we want them to calculate all seven, the parameters should be set in a way that all seven factors are relevant. If we want them to make prioritizations, then the parameters should be set to support this.” (Linköping teacher 1)

As the following quotations (used as illustrations also in 5.2) show, the Linköping students confirmed that their behaviour is affected by what they assume to be expected from them on assessments.

“If I am to be examined on a total cost analysis and investigate 3 of the 5 cost categories [from the theoretical model], I feel like I’ve only done 60%, even if these 3 represent 95% of the total cost. It feels like I don’t show what I can.” (Linköping student 1)

A student’s answer might not fully correspond to what the teacher had anticipated, but this does not necessarily indicate poor alignment between teaching and assessment or that the student does not grasp the subject matter. As the following quotations show, exam questions might be answered in a specific way for tactical reasons:

“Taking the school perspective ... we should calculate it, it feels right to do so, but for the company it might be a small cost ... If I had been only in a working situation, I would never have considered this cost factor...” (Linköping student 1)

“... but as a student you feel you should.” (Linköping student 5)

Projects and cases are not only teaching activities as the students might also be assessed on their performance. That is, more authentic scenarios could be given as a basis for the assessment. However, the teacher statement above that the design of the task is crucial is of course true for cases as well as projects.

Referring to some of the teaching examples in 6.2.1, the business game in the ‘Supply chain management’ course in Lund forces the students to attach a holistic perspective on the costs, since the total costs heavily influence profitability, which is the main performance indicator. Hence, the students are at least partly assessed on their understanding of total cost. However, in this specific case, cost factors and how they are calculated are pre-set, so students might perform well without explicitly showing their total cost understanding. The case used in the ‘Management of physical distribution’ course in Lund involves redundant data so as to reflect real cases. However, when a lot of redundant data is provided (in order to test students’ ability to prioritize), students tend to get stuck in data processing and miss other important aspects in the case. In the ‘Purchasing’ course in Linköping, the students have to decide which cost factors to include as well as what data they need for their calculations. Therefore, the students are at least partly assessed on how well they understand TCA.

At both Chalmers and Linköping, the curriculum includes courses where projects are conducted for external organizations. The students are then assessed on their ability to handle these authentic situations. The same goes for master’s theses, which predominantly are performed in collaboration with external organizations at all four universities. In some of these projects and master’s theses, TCA is an important ingredient.

To conclude...

Students are assessed, at least to some extent, in line with the intended learning (e.g., demonstrating a critical review of available information). However, both teachers and students witness about the ambiguity that occurs when it is not clearly defined what is expected from the students.

6.2.4 Learning progression

As argued by Kolb and Kolb (2005) and Entwistle (2009), educational activities should connect to what the learners already know since new knowledge will add to and transform the existing knowledge. Hence, teachers should strive to support a progression in learning. A program design supporting such a progression throughout the courses is therefore desired. The students’ actual learning progression has not been investigated in this study, so I refer to progression in content and level of complexity that can be designed into courses and programs, intended to support an actual learning progression. For example, as noted in the literature (Collett, 2000; Davidson and Major, 2014), complexity should gradually increase – i.e., to cover less structured and more open-ended tasks.

However, the possibility for progression is not the same for the investigated universities. In Lund, the international master’s program contains a lot of mandatory courses, giving the opportunity to design for a learning progression. However, the master’s specializations (for the Swedish students) are arranged as a smorgasbord, with no mandatory

courses but many course options. In addition, a majority of the Swedish students spend half a year studying abroad during their master's studies, making it even harder for the teachers to know what they have learned in previous courses. Therefore, deliberate progression is hard to achieve, and the actual progression in TC learning is hard to grasp. The students confirm that there is no clear progression over time concerning TCA in the course package, although cost aspects are in focus in several courses. Despite this lack of 'controlled' progression concerning TCA, the Lund teachers consider the students to be prepared for undertaking TC oriented master's thesis projects, since they have acquired a systems view.

At Chalmers, eight mandatory courses in the master's program provide a good condition for learning progression. TC aspects are dealt with in several courses, but there is not a deliberate progression concerning TCA from the teachers' side. Subsequent courses are not built on students' TC learning from previous courses. Challenges and problems with conducting TCA are, according to the teachers, not really discussed.

At Hanken, there are some mandatory courses, opening up the possibility for progression. However, TC issues are not in focus at Hanken, so a deliberate progression concerning TCA courses is not an issue.

In Linköping, the TC learning progression is more deliberate compared to the other universities. Although there is a certain level of open-endedness, redundant information, etc. in the introductory course, complexity is increased gradually in the master profile. The students consider the master profile adequately connects the courses, which in effect gives a good TC learning progression. One of the student states that:

"Similar things have been treated [in different courses], and teachers' assessment in these courses have been fairly consistent each time. This has made you dare to step away a bit [from the basic models]. Today, it feels natural to exclude cost factors you see won't change, but in the beginning, you were more thoughtful: 'Is it really OK to do this?' " (Linköping student 3)

Another student says that with different examiners in the courses, the focus has been slightly different, which makes the students look at things from different perspectives. This student compares the situation today (i.e., during the final semester, working with the master's thesis) with when taking the introductory course in the master profile:

"You feel more comfortable today. You dare to have a free rein, knowing that it usually works out well in the end. In the beginning, it was more about learning a method from step one to five. Having made some TCAs, getting some experience ... we've learned that if we don't find certain cost data ... we might skip it and continue. We've starting to find our feet." (Linköping student 4)

To conclude...

Due to different restrictions in program structure, the pre-conditions for designing progression into the programs differ between the universities. The best possibilities are in Linköping. The Linköping student statements support the literature as they consider the learning progression throughout the courses to have helped them understand and use TCA.

6.2.5 *Conclusions concerning teaching total cost analysis*

At all four universities, teaching cases and projects are frequently used since this is supposed to create realistic settings that enhance total cost learning. Teaching cases are constructed using realistic problems that are more or less open-ended and ill-structured. Both students and teachers find this kind of education rewarding, since it creates activity, engagement, and reflection among the students, who work in teams to collaboratively find viable solutions.

Hence, all the constructivist teaching features expected to stimulate learning (presented in section 6.1) are visible in the empirical data from the case studies. Despite some problems concerning assessment, these learning-stimulating features make it reasonable to believe that the described educational methods contribute to the students' learning of TCA.

7 Connections between challenges, thresholds, and teaching

So far, the research questions have been dealt with separately. Chapter 4 was dedicated to the challenges associated with conducting TCA (RQ1), Chapter 5 examined the thresholds associated with learning TCA (RQ2), and Chapter 6 investigated how teaching activities support learning TCA (RQ3). However, the research questions are connected. In Figure 25, the three research questions are positioned in the pedagogic triangle model (presented in section 1.4). RQ1 focuses on the *knowledge* component in that the total cost challenges pinpointed are important knowledge to be included in the curricula and part of the intended learning outcome for the students. RQ2 focuses on the learning thresholds to create a link between *learners* and *knowledge*. Finally, RQ3 focuses on how *teachers* can mediate the *knowledge* with help from methods supporting the *learners*.

Figure 25. The research questions connected to the pedagogic triangle

This chapter connects these three parts. Connections between challenges and learning thresholds are discussed in 7.1, between learning thresholds and teaching activities in 7.2, and between challenges and teaching activities in 7.3. A concluding discussion is given in 7.4.

7.1 Total cost challenges vs. learning thresholds

All the learning thresholds identified are generic and do not apply specifically to a single total cost challenge. Rather, they all relate to several challenges, spanning over the different steps in a total cost project.

A good contextual understanding is required when setting the scope for the analysis (Steps 1-4). Such an understanding consists of a combination of a *systems understanding* (giving a general ability to apply a systems perspective) and a *logistical understanding* (an under-

standing of the specific context). The selection of a distribution structure can serve as an example, with specific attention on the definition of the system (Step 2). A general *systems understanding* is needed to understand how different system components will interact and how the setting of system boundaries will affect the outcome, but that would not be enough. A *logistical understanding* is also needed to understand and describe the system sufficiently (Challenge 2a), to set the system boundaries (2b), and to understand which system perspective(s) to consider (2c). The same goes for the other ‘setting the scope’ steps (Steps 1, 3, and 4) and their associated challenges. In addition, the subsequent steps use systems and logistics understanding to identify what cost categories are affected (Challenge 5b), how changing conditions will affect the costs (6b), where certain data can be retrieved (8a), and which values are relevant to test (11a). The logistical understanding might be the more visible part when practically performing TCA, but it presumably rests on a systems understanding. For example, Waller et al. (2015) claim that: “... *systems thinking is at the core of the total cost concept of logistics*” (p. 303). In addition, the Lund teachers clearly stressed the importance of a general systems understanding.

A good understanding of the context is a necessary prerequisite for a proper *contextual adaptation* of the cost analysis. In the ‘Cost modelling’ stage (Steps 5-7), the need for contextual adaptation is rather evident. For example, Challenge 5a deals with adjusting set models to the situation at hand, and Challenge 6a deals with adjusting calculation methods, which in turn influences which data is needed, and in which format (7b). However, contextual adaptation is prevalent in all the subsequent steps – e.g. finding good ways to get access to data (Challenge 8b), in order to distribute costs in an appropriate way (9d), selecting uncertain factors to examine (10b), and identifying appropriate methods for sensitivity analysis (11b). Presentations (Step 12) must also be adapted to the context in order to find a good balance in the presentation (Challenge 12b) that fits the target audience (12a). Moreover, in the introductory stage (Steps 1-4) adaptations are made to identify the number of alternatives (Challenge 1b), to set system boundaries (2b), and to define the time period to be analysed (3a).

A *critical thinking approach* could also be argued to be essential in all stages of a TCA in order to reach a reliable result. Critical thinking is embedded in the cost modelling stage (Steps 5-7) when adapting cost models (Challenge 5a) and calculation methods (6a) to the specific situation, as well as when scoping the study (Steps 1-4) by setting system boundaries (2b) or defining the period for analysis (3a). A critical stance is also necessary in Steps 8 and 9, where the reliability of the retrieved data is scrutinized (8c) and decisions are made for how to handle contradictory data (9a). Obviously, these aspects are also central in the critical review stage (Steps 10 and 11). Concerning the presentation (Step 12), a certain level of strategic critical thinking is needed when selecting what to present and how to present it in order to provide the decision-makers with the information they will need to make good decisions.

Hence, all four identified learning thresholds appear to be relevant throughout the total cost analysis process. Although some connections between certain thresholds and certain

steps and challenges are more obvious than others, each threshold is connected to every step in the process.

7.2 Learning thresholds vs. teaching activities

As described in the previous chapters, TCA is a challenging task for students to learn. The constructivist teaching aspects discussed in Chapter 6 match the learning thresholds to a great deal. In real settings, TCA needs to be *adapted to the situation at hand*, which requires an understanding of the context – i.e., the *systems* as well as *logistical understanding*. Acquiring this understanding is difficult, especially for novice investigators as real-world settings often are complex, ill-structured, and hard to grasp. A lot of decisions have to be made, desired information might be lacking, and available information might not be representative. Learning to deal with these situations is according to e.g. Jollands et al. (2012) and Hunter (2015) promoted by using authentic scenarios in educational activities as perceived authenticity stimulates activity, engagement, and reflection, features that in turn promote learning.

Some of the learning thresholds presented in Chapter 5 are explicitly addressed in the constructivist learning literature. For example, Palmer and Hall (2011) argue that project-based learning exposes students to the systems nature of problems, and Jollands et al. (2012) conclude that projects help students develop their *systems thinking skills*.

Several authors address the positive impact constructivist approaches have on students' critical thinking abilities. Nelson and Crow (2014) argue that critical thinking is supported by learning activities designed to engage and stimulate thinking in a relevant context. Hunter (2015) believe that ill-structured problems encourage critical thinking, and Nesbitt and Cliff (2008) and Nelson and Crow (2014) believe open-ended problems stimulate critical thinking. Adding to the above observations, Bean (2011) concludes that collaborative work and teaching cases also stimulate critical thinking. These researchers do not explicitly address projects and simulations, but since real-world projects and business simulations often are ill-structured and open-ended, they can analogically also be presumed to stimulate students' critical thinking abilities.

Hence, the constructivist-based teaching methods and problem features found in the literature and highlighted in Chapter 6 are (explicitly or implicitly) considered to promote learning connected to the identified thresholds.

All these constructivist-approved approaches appear in the studied cases. *Teaching cases* in different forms are commonly used by all four universities. *Real-world projects* are prevalent in specific project courses at Chalmers and in Linköping as well as in master's theses at all four universities. Cases and projects are mainly used in student teams collaborating to find solutions. Real-world projects are most often by their nature *ill-structured* and *open-ended*, but in Lund, Chalmers, and Linköping, the teachers strive to

include these features in the artificial teaching cases to enhance *realism* and *authenticity*. This is valid also for the *business simulation* game used in Lund.

7.3 Total cost challenges vs. teaching activities

Connections between teaching activities and the identified total cost challenges have not been identified in the literature. However, the learning thresholds create an indirect link, as these connect both to the steps and challenges (section 7.1) and to the teaching activities (7.2). This study did not specifically examine whether the specific challenges are addressed in the educational activities at the universities. When discussing educational activities during the case studies, these activities were connected to the process steps in a TCA rather than to specific challenges. In a teaching case at Chalmers, in the ‘Management of physical distribution’ course, redundant data are provided to the students, exposing them to the need to process input data (Step 9). This is an example of ill-structuredness. Another example of the use of ill-structured as well as open-ended problems is found in the ‘Purchasing’ course in Linköping, where the students must decide which cost factors to include (Step 5), how to calculate these costs (Step 6), and which data are required (Step 7). These students are also expected to critically review their results, which is then explicitly discussed during feedback sessions (Steps 10 and 11).

Many of the challenges with conducting TCA are not specific to total cost issues. The only cost-specific step is Step 5 – ‘Selecting cost categories to include’. All the other steps and the associated challenges are probably valid also for investigations that do not focus on costs. Therefore, some of the challenges might be addressed in the teaching at the case universities, although not with reference to TCA, and therefore not brought up during the interviews and discussions. However, although the students might learn how to deal with these unidentified challenges in other courses, this was outside the scope of my study.

7.4 Connections between the RQ’s – a concluding discussion

In Figure 26, the findings for the three research questions are summarized (however, with the total cost process showing only the steps, not the challenges, for space saving purposes), and the connections between them are principally visualised.

Figure 26. The total cost process related to learning thresholds and teaching methods

The challenges (RQ1) were derived by combining findings from literature and the case studies. The learning thresholds (RQ2) were developed by empirically identifying learning difficulties, and then using threshold theories to determine whether they qualify as being learning thresholds. From constructivist teaching theory, teaching methods and problem features (RQ3) supposed to promote authenticity and stimulate learning were identified, and these were also supported by the empirical data.

Figure 27 revisits the pedagogical triangle. The arrows illustrate how the findings relate to each other. The research clearly indicates that all four identified learning thresholds connect to the challenges associated with all the steps in TCA process (albeit with various intensity) and that the identified teaching methods and problem features appear to help students overcome the learning thresholds. My research does not explicitly investigate the connection between teaching methods and total cost challenges; however, the learning thresholds create an indirect link, suggesting that the teaching methods and problem features stimulate students to learn about the challenges associated with TCA. Because this connection has less support in the research than the other two connections, this arrow is drawn with a dashed line.

Figure 27. Connections between the findings for each RQ

8 Findings, reflections, and suggestions

This final chapter starts with a presentation of the main conclusions in section 8.1, followed by a discussion in 8.2 on the contributions of this research. Methodological reflections are given in 8.3, and finally in section 8.4 some suggestions for further research are presented.

8.1 Main conclusions

To recall, the purpose of the research was the following:

To contribute to the understanding of conducting, learning, and teaching total cost analysis.

To serve this purpose, the following three research questions were defined:

RQ1 What challenges are connected to the process of conducting total cost analysis?

RQ2 What thresholds are there for learning how to conduct total cost analysis?

RQ3 How can total cost learning be supported by appropriate educational methods?

The steps and challenges in the total cost analysis process

Corresponding to RQ1, Chapter 4 described total cost analysis as a 12-step process, divided into five major stages. The interrelations between these steps were discussed, and for each step, a number of challenges were identified. The stages, steps, and challenges are shown in Figure 28.

Every challenge is not necessarily encountered in every TCA project. The presented challenges should rather be viewed as potential challenges that an analyst should bear in mind and be prepared to handle when conducting TCA. Furthermore, although a basic logic connects the process steps, the process is most often not performed in a strictly sequential manner. During the early steps, subsequent steps and challenges should be considered in order to design and perform the total cost investigation to fit the conditions for each specific context. Depending on the outcome of the analysis, it might also be necessary to revisit previous steps and iteratively make adjustments.

STAGE	STEPS AND ASSOCIATED CHALLENGES
Setting the scope	STEP 1. Defining alternatives to compare a. To define potential alternatives b. To decide how many alternatives to include c. To select the ones to include from the potential alternatives
	STEP 2. Defining the system a. To understand and describe the system (flows, processes etc.) sufficiently b. To set the system boundaries c. To understand which system perspectives that are most important to consider
	STEP 3. Making time considerations a. To define the time period which the analysis should cover b. To define the expected lifetime of the different alternatives
	STEP 4. Identifying other aspects of importance a. To identify aspects that may be important b. To get to know decision-makers' priorities
Cost modelling	STEP 5. Selecting cost categories to include a. To construct a total cost model, or adjust a set model to suit the situation at hand b. To identify all cost categories that will be affected c. To select the most crucial cost categories to include
	STEP 6. Selecting calculation methods a. To construct or select calculation methods, and adapt these to the situation at hand b. To understand the relations between changing conditions and cost behavior c. To select reliable cost estimations methods when calculation is not possible
	STEP 7. Defining required input data a. To define which time period data should cover b. To define the desired format of data and level of detail
Calculations	STEP 8. Retrieving input data a. To define where to retrieve data b. To get access to data c. To assess the reliability in data d. To handle unreliable data and lack of desired data e. To balance the effort needed to capture data against the perceived value of additional data
	STEP 9. Processing input data a. To identify and handle data that is contradictory, or not directly comparable b. To handle the uncertainties of future costs and relevance of historical data c. To take the time-value of money into consideration d. To distribute bundled costs in an appropriate way e. To understand whether semi-fixed costs really will change
Critical review	STEP 10. Identifying uncertainties a. To identify the embedded uncertain factors b. To select the ones where the effect should be analyzed
	STEP 11. Analysing the effect of uncertainties a. To select values to be tested for each uncertain factor b. To select methods to evaluate the effect of uncertainties, for individual factors as well as for combinations of factors
Presentation	STEP 12. Selecting content and presentation format a. To identify the target audience and their preferences b. To balance completeness and accessibility

Figure 28. The steps and challenges connected to the total cost analysis process (identical to Figure 23)

The learning thresholds connected to total cost analysis

A learning threshold is something that needs to be understood to reach a higher level of understanding, but learning thresholds are often difficult for students to overcome. Perceived difficulties with learning TCA were investigated in Chapter 5. As a response to RQ2, these difficulties were then analysed using the threshold characteristics identified in the literature – i.e., whether they are transformative, irreversible, integrative, bounded, and troublesome (Meyer and Land, 2003). The four learning thresholds identified connected to total cost analysis are:

- Systems understanding
- Logistical understanding
- Contextual adaptation
- Critical thinking

Teaching methods supporting learning of total cost analysis

Constructivist teaching theories were visited to identify teaching activities supporting total cost learning, thereby addressing RQ3. The literature identifies student engagement and stimulating reflection as essential features to promote learning. A way to achieve this is to create authentic learning situations, that reflect the real world in a good way and are perceived as meaningful by the students. For problems and tasks to be authentic, certain features are recommended in literature, together with some teaching methods. Corresponding to the suggestions in literature, problem features and teaching methods that at the case universities were regarded to support total cost learning are the following:

Teaching methods:

- Teaching cases
- Real-world projects
- Business simulations

Problem features promoting authenticity:

- Realistic problems
- Ill-structured problems
- Open-ended problems

Connections between the research questions

Based on the findings presented above, connections between the findings associated with the three research questions were examined in Chapter 7. There are indications that the suggested educational activities support overcoming the four identified learning thresholds, which in turn are connected to all the steps in the total cost process and their associated challenges. Therefore, thresholds create an indirect link between the teaching methods and the challenges, as illustrated in Figure 29.

Figure 29. Connections between the findings for each RQ (identical to Figure 27)

Hence, all three research questions are addressed, and together the findings give new insight into understanding the difficulties associated with conducting, learning, and teaching total cost analysis.

8.2 Contributions and discussion

This research is positioned in the intersection between the discipline of logistics management and higher education. The contributions have implications for several stakeholders, who are addressed in separate subsections below. Section 8.2.1 focuses on contributions to logistics research and 8.2.2. focuses on logistics practitioners. The implications for the logistics teaching profession are highlighted in 8.2.3, contributions to higher education research are described in 8.2.4 , and the generalizability of findings are discussed in 8.2.5.

8.2.1 Contributions to logistics research

For many years, total cost analysis has been considered central to the logistics discipline. Despite this history, Waller and Fawcett (2012) discovered that research concerning TCA is sparse, and they called for more research on this topic. In addition (although not specifically addressed by Waller and Fawcett), the logistics literature rarely investigates TCA procedures and the challenges associated with conducting TC investigations.

Thorough description of the procedures for conducting total cost analysis

As concluded in section 4.1, with very few exceptions, procedures for conducting TCA are not clearly described in the logistics literature. However, procedural descriptions are found (although to a limited extent) in other disciplines, such as defence (Mislick and Nussbaum, 2015) and information technology (Perng et al., 2012). Primarily, the

procedures are described in light of Life Cycle Costing (LCC), an approach most commonly used to predict costs related to projects or investments with a long lifespan, for example, within environmental management or civil engineering. Although a procedural description was not an aim of my research, it was needed to give structure to the challenges. That is, the procedure and its 12 steps (illustrated in e.g. Figure 26) was not the main focus in this research. Nonetheless, the steps are thoroughly described using several logistics-related examples. This clarifies the TCA process, giving a more complete description of this process than previously presented in logistics literature.

Systematic compilation of challenges when conducting total cost analysis

The literature identifies potential problems encountered during a total cost investigation. However, these evidence are sporadic and not systemized. To the best of my knowledge, no previous study has specifically addressed the challenges associated with TCA, neither within the logistics management field, nor within other disciplines. Hence, the systematic compilation and description of challenges is novel and therefore a main contribution of this research.

8.2.2 Contributions to logistics practice

A potential for better total cost analyses

Failing to effectively analyse costs can result in poor decisions, leading to increased costs for organizations and for society. Using a structured procedure and being aware of the challenges associated with TCA, logistics professionals can take precautions to avoid the pitfalls associated with conducting TCA. This approach should lead to better total cost analyses, resulting in better informed decisions. In addition, avoiding the pitfalls will reduce the time needed to conduct the analysis, leading to more resource efficient investigations.

8.2.3 Contributions to the logistics teaching profession

Revisiting the PCK (pedagogical content knowledge) model presented in Chapter 1, the research contributes to expanding logistics teachers PCK by addressing some of the PCK components. The steps and challenges associated to the TCA process expand *subject-matter knowledge*, the identified thresholds refer to *knowledge about students' understanding*, and the identified teaching methods and problem features contribute to *knowledge about instructional strategies* and *knowledge about assessment*, see Figure 30.

Figure 30. PCK components supported by the research findings

The following sub-sections present more in detail how the findings are valuable for teachers and textbook authors within logistics higher education.

More informative textbooks

Textbooks provide important support for students (when studying) as well as for teachers (when planning education); however, logistics textbooks rarely address the complexity of TCA. Textbook authors can use the findings in this study to more clearly and thoroughly present the complexity of TCA.

Including the total cost procedure and challenges in the curriculum

Higher education teachers can use the findings to help them integrate the total cost procedure and challenges into their course curricula to better prepare students for conducting TCA in their professional careers. In addition, courses directed at active professionals can highlight the total cost procedure and challenges.

Including the learning thresholds in the curriculum

As stressed by Burch et al. (2015) and Bajada et al. (2016), threshold concepts should be embedded in course syllabi and curricula to emphasize the importance of these concepts. The identification of thresholds in this research contributes to teachers' understanding of what aspects to include as learning outcomes in the curricula, as well as to determine what aspects to give extra attention in the teaching and assessment. For example, as critical thinking is suggested to be a threshold for learning TCA, special attention might in some educational activities be given to promote critical thinking.

The choice of educational methods

Although it is important to include the thresholds in the curriculum, these should also be properly addressed in teaching and assessment (Bajada et al., 2016), in line with the

principles of constructive alignment presented by Biggs (2003). The constructivist teaching activities pointed out in this research will be helpful for teachers when developing their teaching to support overcoming the thresholds. For example, open-ended ill-structured teaching cases can be used to promote authenticity, and thereby stimulate learning, according to teachers' and students' in both Lund and Linköping.

It should be noted, however, that the studied teachers' choice to use teaching methods and problem features congruent with the constructivist literature does not necessarily mean that these teachers deliberately lean on the constructivist-based ideas on teaching and learning. I did not specifically examine whether the teachers had any theoretical underpinning for their choice of teaching methods. However, constructivism (or any pedagogical theory) was not mentioned by any of the respondents during the interviews and focus group sessions, which might be a sign of low theoretical awareness of the educational field. Nonetheless, the teaching methods used and identified as helpful in my study are the methods promoted by constructivist literature. This (potentially) unintentional alignment of practice and theory might be explained by the fact that logistics management is an applied discipline, with a strong emphasis on understanding and developing real-world practice and therefore incorporating realistic examples and cases comes easily to logistics teachers. Hence, the use of constructivist teaching approaches might be due to the nature of the discipline rather than a pedagogical awareness.

Insight into teachers' thoughts on logistics education

According to Rowbotham (2015), insight and understanding of effective teaching practices contribute to teachers' confidence and self-efficacy. The case studies give insight into how logistics teachers think about logistics education in general and TCA in particular. As far as I know, these kinds of investigations have not previously been performed within the logistics management discipline. Therefore, logistics teachers can use the case reports as inspiration to further develop logistics education.

8.2.4 Contributions to higher education research

In addition to the contributions specifically connected to the intersection between logistics and higher education, there are some aspects of a more general relevance for the educational field.

Identification of thresholds in management disciplines

According to Wright and Hibbert (2013), thresholds are typically ignored in management education. Wright and Gilmore (2012) argue that this is partly because management teachers are unaware of the value of identifying thresholds. To the best of my knowledge, thresholds have not been investigated in neither the logistics management discipline (irrespective of topic) nor concerning TCA (irrespective of discipline). Therefore, the

research presented in this thesis is a novel contribution to the building of an understanding concerning thresholds not only in the logistics discipline, but also generally in management-related areas.

Disciplinary understanding as a learning threshold within management

Logistical understanding and contextual adaptation, two of the learning thresholds identified in this research, are related to the ways of thinking and acting in the discipline, which in the literature is labelled disciplinary thresholds (Davies and Mangan, 2007), threshold capabilities (Baillie et al., 2013), or threshold conceptions (Burch et al., 2015). While logistical understanding is discipline-specific, in more general terms it could be labelled disciplinary understanding. Hence, the findings in this research support and strengthen the suggestions from Wright and Gilmore (2012) and Cohen and Billsberry (2014), that disciplinary understanding is a major threshold in management disciplines because management as such is complex and context-dependent.

Boundedness – a questionable threshold characteristic

Meyer and Land (2003) define five characteristics of thresholds. One threshold concerns *boundedness* of specific disciplinary areas – i.e., boundedness defines the border between different areas or disciplines. However, Meyer and Land (2003) note that this is not always the case; therefore, Rowbottom (2007) questions whether boundedness really is a threshold characteristic if it is not always necessary. Rowbottom (2007) also argues that the issue of boundedness is ‘uninteresting’ (p. 264).

Based on the threshold investigation in this thesis, I agree with Rowbottom’s critique that the disciplinary boundedness is uninteresting when identifying thresholds. That is, TCA is used across disciplines and therefore disciplinary boundedness is irrelevant when searching for thresholds. An exception to this is the *logistical understanding* identified as one TCA-related learning threshold. As discussed in section 5.2, logistical understanding is a special case of disciplinary understanding – i.e., in any context (such as logistics, healthcare, and civil engineering) a certain level of discipline-specific understanding is needed (and may be a threshold). However, although not specifically examined in my research, my reflection is that knowing whether a concept is disciplinary bounded or not will not be of any help when identifying thresholds. That is, my research revealed no support for boundedness to be a relevant characteristic for identification of thresholds.

8.2.5 Discussion on the usefulness of the findings to other contexts

Logistics vs related disciplines

It should be noted that even though the focus of this research has been on the logistics management discipline, the findings are supposedly relevant for a broader audience. TCA

is (under various labels) conducted in a variety of fields, including healthcare, product development, energy distribution, agriculture, and business management. Costs are investigated, estimated, and analysed to facilitate decision-making in all organizations, private as well as public. Irrespective of discipline, TCA comes with problems and challenges. The procedure and challenges presented in this research are generic, rather than specific for the logistics field, i.e. they should be applicable to many fields. Evidence about challenges was collected from literature covering a variety of disciplines, and none of the evidence suggests that these challenges are discipline specific.

The total cost analysis process

According to this research, the TCA process is sparsely described in the literature, irrespective of discipline. An exception is the life cycle cost literature, where there are rather detailed total cost process descriptions available. However, these focus specifically on projects or investments with long time horizons and estimations of future costs as a main issue. Compared to this, the process I describe is more general and seems applicable to a variety of TCA contexts, within and outside the logistics discipline.

Teaching total cost analysis

As procedures and challenges associated with conducting TCA are supposed to be valid across disciplines, so are also the findings concerning learning thresholds and teaching methods. These findings are supposed to be generally relevant wherever TCA is considered in higher education.

Total cost analysis in textbooks

The potential to improve how textbooks cover TCA is not limited to the logistics discipline. The textbooks I have examined from other disciplines (e.g., purchasing and quality management) do not present total cost procedures or discuss the challenges associated with TCA. Hence, the findings in this research might be incorporated in textbooks that address other disciplines.

Total cost analysis vs other investigations of a similar kind

Investigations that do not focus on costs might follow a similar procedure and face similar challenges (at least partly) as are encountered in total cost investigations. For example, if the focus is on delivery reliability or carbon dioxide emissions instead of costs, there would probably be a number of similarities. In these cases, it would for instance be important to go through the steps of selecting alternatives to compare, defining the system, retrieving data, and critically reviewing the results. Within these steps, the challenges encountered are also believed to coincide to a high degree with the ones in TCA. On the other hand, selecting cost categories would not be relevant. Hence, a certain level of adjustment would be needed, but for the most part, the procedure, with its steps

and challenges, are believed to be valid for similar types of investigations. Therefore, the findings concerning total cost education would also be relevant for such investigations.

8.3 Methodological reflections

Section 2.7 describes the measures I took to build trustworthiness into the study. Here, I reflect upon this in retrospect.

8.3.1 Credibility

Each case description was checked by the contact persons at the universities. Since the descriptions were accepted with minimal comments, I regard the descriptions to be credible. Where both student and teacher respondents were targeted (i.e., Lund and Linköping), their opinions confirmed each other to a high extent. However, for those cases where access to data was more limited (Chalmers and Hanken), the descriptions are less comprehensive and therefore can be regarded as less credible. Empirically, my findings lean primarily on the Lund and Linköping cases. Based on this, the selection of cases could be questioned, why this is discussed in the following section.

The selection of cases

There is a certain discrepancy between how much information was gained from the selected cases. The Linköping and Lund cases rendered the most thorough information, Chalmers somewhat less, and Hanken even less. Although to some extent this was due to a certain level of saturation, this is not the full story. At Chalmers, it turned out that the teachers did not have the time nor the possibility to participate in my research project. For example, the focus group had to be run with just two teachers due to last-minute cancellations. In addition, despite efforts by one teacher, it was not possible to arrange a session with students. If I would have been able to meet students as well as more teachers, this likely would have provided contrasting opinions, topics would have been seen from different angles, and more course documents would have been provided. Whether this would have led to additional data expanding the findings is not clear, but certainly possible. When it comes to Hanken, it turned out that TCA is not addressed to the extent that I thought before my visit. Although the Hanken teachers were very generous with their time, the outcome of this case was not as valuable to my research as I believed it would be.

Because of these limitations, it is relevant to consider the selection of cases. The lack of time the Chalmers teachers were able to spend was nothing I could foresee, and neither was the weak interest from the students. Therefore, I do not consider Chalmers to be a poor choice of case to study. As for Hanken, upon reflection, I might have been able to recognize at an early stage that TCA was a bit out of their focus. However, it is hard to tell from official documents what is really covered in curricula, and since I got a very

good response to my request for participation, I considered it to be a good choice. Given the time and effort necessary to approach yet another HEI to compensate for the shortcomings described here and weighing this effort with what I could expect to gain from further data collection (since I also experienced an increasing data saturation), I chose to accept the situation and not add a new case.

The use of focus groups and concept maps

Drawing concept maps during the focus group sessions helped me identify steps and challenges in the TCA process, including how these are related to each other. Tentative concept maps (based on discussions with minimal intervention from me) were checked with the participants during the sessions, and the final versions were part of the case descriptions reviewed by the contact persons (discussed above).

There was a good interaction in all focus group sessions, where the participants stimulated each other to contribute to the discussion. I believe this helped to reveal more – and more contrasting – information concerning the research topics than I otherwise had been able to catch. This goes for information regarding each of the research questions, but also the connections between them, as it came natural for the participants to move back and forth between challenges in the TCA process, learning difficulties, and teaching activities.

8.3.2 *Transferability*

In qualitative research, the transferability of results to other contexts is according to e.g. Larsson (2005) up to the reader to assess. Reader assessment is only possible if the research is adequately transparent and well described. By providing thick descriptions of the case studies (Appendix 9) and numerous examples from the literature, I argue that the reader has a good base for making such assessments.

However, even though the ‘burden of proof’ could be handed over to the reader, I believe that the results are transferable to a certain extent. As discussed in section 8.2, although logistics management is the discipline my research examines, many of the findings would probably be valid outside the logistics domain since TCA is used in many disciplines. Moreover, the literature does not suggest that the applications of TCA differ between the disciplines. Provided that many of the procedures and challenges for conducting TCA are relevant across disciplinary borders, the findings concerning learning thresholds and teaching methods are also supposed to be transferable to other settings.

Moreover (also addressed in section 8.2), in major parts the total cost analysis procedure with its steps and challenges are believed to be valid also for similar types of investigations that do not specifically focus on costs.

8.3.3 Dependability

A clear description of assumptions, research procedures, etc. is important to enable other researchers to perform similar investigations. Following the recommendations by Yin (2018) to establish a 'chain of evidence', I have included thorough presentations of data, such as case descriptions, and carefully presented the research methods using detailed descriptions of procedures used for finding relevant literature and extracts from the protocol used to categorize total cost challenges.

8.3.4 Confirmability

As I describe in section 2.7, the research was partly conducted at my own department at Linköping University. I have very good insight into the curricula and teaching methods and have a personal relationship with all the teacher respondents. Although I have tried my best to keep an objective stance, it might be questioned whether I have succeeded. However, the intention of the research has not been to contrast the cases and evaluate them against each other, but to come up with suggestions concerning total cost challenges, learning difficulties, etc. My deeper insight in one of the cases has enabled me to catch more information than otherwise possible. Hence, with the exploratory direction of my research, I do not consider the potential subjectivity due to the close familiarity to one of the cases a confounding problem. However, with more information at hand, descriptions can be written more thoroughly, and there is a risk that the reader therefore mistakenly will see the Linköping case to be 'better' than other cases. However, this discrepancy is due to differences in available information and my tacit knowledge data rather than actual differences.

Another aspect to consider is that my experience with TCA as a teacher and author of educational material (i.e., my preconceptions) could have biased my research even though I tried to keep an open mind. However, I would argue that my experience and knowledge about the topic has been a precondition for the research. It is through my teaching experience that I have discovered the blank spaces in literature concerning total cost challenges and have become interested in how to teach TCA to enhance students' learning.

8.4 Suggestions for further research

Being an exploratory study, the findings not only provide new knowledge, but also reveal opportunities for further research. In this section, I make suggestions further research.

8.4.1 Further analysis of the total cost challenges

The set of challenges identified does not claim to be the definite one. Further research is welcome to test the proposed challenges at other higher education institutions and/or in practical settings.

Each one of the proposed challenges might be further developed. The descriptions of the challenges could be made more distinct and 'available' to someone not as informed as the reader of this thesis. Perhaps even more interesting, strategies for how to handle each challenge could be investigated. Focusing a specific challenge, a literature search specifically directed to this challenge would probably give additional information compared to what has been described in this thesis. In addition, information could be gathered from more focused case studies of HEIs or practitioners with experience in TCA. Research directed towards experienced practitioners could also render much practical input concerning the content, relevance, and importance of each TCA step. A better understanding of the procedures and challenges could be used to enrich the higher education in TCA.

8.4.2 Exploring how total cost analysis is conducted in practice

Although many articles are based on empirical findings from real cases where total cost analysis has been conducted, these articles focus on the specific decisions to be made (e.g., which supplier to select or how many regional warehouses to have in the distribution structure). The TCA procedure as such is not examined in any of the articles investigated for this research.

A better perception of the total cost procedure

Studying several real applications would provide more information about the real procedures used when conducting TCA. These findings could be compared with the procedure suggested in this research identify variations in topics or disciplines, and to identify areas where further research attention is needed.

Critically evaluating real-world total cost analysis

By conducting deep case studies, specific TCA projects can be analysed. For example, estimated total costs (the basis for decisions) can be compared to real costs, deviations can be analysed, and the source of the deviations can be traced. The findings from such studies could increase the understanding of how better to conduct TCA (e.g., how to handle challenges) and produce better, more reliable foundations for decision-making.

8.4.3 Further exploration of the learning thresholds

In this research, learning as such has not been studied. The presented thresholds are suggested based on perceptions from teachers and students in combination with findings from the literature. Although several authors indicate that threshold identification is difficult, some methods are suggested for how to make such identification. Studies specifically directed to investigate the suggested thresholds might give further evidence to whether these truly are thresholds.

8.4.4 Exploring the effect of using certain educational activities

The constructivist approaches presented are supposed to promote learning, both concerning the learning thresholds and concerning the total cost challenges. However, this relationship needs to be confirmed. Although difficult to quantify, this relationship might be investigated by carefully designed learning studies to see if it is possible to confirm a relationship between certain teaching approaches and features (e.g., open-ended cases and ill-structured problems) and learning of thresholds (e.g., systems understanding) or total cost challenges (e.g., the selection of crucial cost categories to include in the analysis).

References

- Abrahamsson, M. (1993), Time Based Distribution, *International Journal of Logistics Management*, 4 (2), 75-82.
- Abrahamsson, M. & Aronsson, H. (1999), Measuring Logistics Structure, *International Journal of Logistics: Research & Applications*, 2 (3), 263-284.
- Ackermann, F., Eden, C. & Cropper, S. (1992), Getting Started with Cognitive Mapping, *University of Warwick*.
- Adelfar, M. & Beythien, H. (2017), *Balancing Inventory Levels and Setup Times - An Analysis and Outline of a Decision-Making Model*, MSc Thesis, Lund University.
- Agarwal, A. (2008), Partitioning Bottleneck Work Center for Cellular Manufacturing: An Integrated Performance and Cost Model, *International Journal of Production Economics*, 111 (2), 635-647.
- Ahire, S. L., Gorman, M. F., Dwiggins, D. & Mudry, O. (2007), Operations Research Helps Reshape Operations Strategy at Standard Register Company, *Interfaces*, 37 (6), 553-565.
- Alam, M. R., St-Hilaire, M. & Kunz, T. (2017), An Optimal P2P Energy Trading Model for Smart Homes in the Smart Grid, *Energy Efficiency*, 10 (6), 1475-1493.
- Alickovic, D. & Behrman, J. (2017), *A Cost Comparison Between an Outsourced and In-House Storage Solution*, MSc Thesis, Chalmers University of Technology.
- Alonzo, A. C., Kobarg, M. & Seidel, T. (2012), Pedagogical Content Knowledge as Reflected in Teacher–Student Interactions: Analysis of two Video Cases, *Journal of Research in Science Teaching*, 49 (10), 1211-1239.
- AMA (1957), The Values and Uses of Distribution Cost Analysis. [American Marketing Association: Statement of the Committee on Distribution Costs and Efficiency], *Journal of Marketing*, 21 395-400.
- Anderson, P. F. & Taylor, B. (1977), Marketing/Quality Control Interface: The GERT Approach, *Industrial Marketing Management*, 6 (1), 420-428.
- Andersson, B. C. (1994), *Punken är död, leve tvåans buss*, Bonnier Alba.
- Arbnor, I. & Bjerke, B. (1994), *Företagsekonomisk metodlära*, 2 ed, Studentlitteratur.
- Ardley, B. & Taylor, N. (2010), The Student Practitioner: Developing Skills Through the Marketing Research Consultancy Project, *Marketing Intelligence & Planning*, 28 (7), 847-861.

- Arlbjörn, J. S. & Halldórsson, Á. (2002), Logistics Knowledge Creation: Reflections on Content, Context and Processes, *International Journal of Physical Distribution and Logistics Management*, 32 (1), 22-40.
- Ashenbaum, B. (2008), The Global Sourcing and Logistics Exercise: A Group Exercise to Demonstrate Basic Global Supply Chain Principles, *Decision Sciences Journal of Innovative Education*, 6 (2), 355-364.
- Asiedu, Y. & Gu, P. (1998), Product Life Cycle Cost Analysis: State of the Art Review, *International Journal of Production Research*, 36 (4), 883-908.
- Asklund, R. & Johansson, E. (2017), *Internet of Things och Smartsensorers påverkan av en lågspänningsmotors tillhörande kostnader och kundnöjdhet - En analys över hur ABB:s serviceverksamhet förändras vid kommande teknologiskifte*, MSc Thesis, Linköping University.
- Axelsson, L. & Skogum, S. (2016), *Cost of Poor Quality - Development of a Tool for Identification and Quantification of CoPQ*, MSc Thesis, Chalmers University of Technology.
- Bacchetti, A., Bonetti, S., Perona, M. & Saccani, N. (2018), Investment and Management Decisions in Aluminium Melting: A Total Cost of Ownership Model and Practical Applications, *Sustainability* 10 (9), 1-36.
- Baillie, C., Bowden, J. & Meyer, J. (2013), Threshold Capabilities: Threshold Concepts and Knowledge Capability Linked Through Variation Theory, *Higher Education*, 65 (2), 227-246.
- Baines, R. & Pulley, D. (2003), A Total Cost Approach to Evaluating Different Reconfigurable Architectures for Baseband Processing in Wireless Receivers, *IEEE Communications Magazine*, 41 105-113.
- Bajada, C., Jarvis, W., Trayler, R. & Bui, A. T. (2016), Threshold Concepts in Business School Curriculum – A Pedagogy for Public Trust, *Education + Training*, 58 (5), 540-563.
- Barradell, S. & Peseta, T. (2017), Putting Threshold Concepts to Work in Health Sciences: Insights for Curriculum Design from a Qualitative Research Synthesis, *Teaching in Higher Education*, 22 (3), 349-372.
- Bean, J. C. (2011), *Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom*, 2 ed, Wiley.
- Berg, M. & Karlström, G. (2017), *Evaluation of Sea Freight Distribution - A Case Study From an Aftermarket Perspective*, MSc Thesis, Lund University.
- Bertrand, Y. (1994), The Bermuda Triangle of Education, *Annual Meeting of the American Educational Research Association*.
- Bertrand, Y. & Houssaye, J. (1999), Pédagogie and Didactique: An Incestuous Relationship, *Instructional Science*, 27 (1/2), 33-51.

- Biggs, J. B. (2003), *Teaching for Quality Learning at University: What the Student Does*, 2 ed, The Society for Research into Higher Education.
- Björklund, M. (2018), *Hållbara logistiksystem*, 2 ed, Studentlitteratur.
- Blomgren, O. & Eriksson, S. (2016), *Improving Demand Planning and Inventory Management - A Supply Chain Evaluation from a Distributor's Perspective*, MSc Thesis, Chalmers University of Technology.
- Bodehed, E. (2008), *Utveckling av en totalkostnadsmodell för utvärdering av inköp på Saab Microwave Systems*, MSc Thesis, Lund University.
- Bonwell, C. C. & Eison, J. A. (1991), *Active Learning: Creating Excitement in the Classroom*, ERIC Clearinghouse on Higher Education.
- Bootsma, M. C., Vermeulen, W. J., van Dijk, J. & Schot, P. P. (2014), Added Value and Constraints of Transdisciplinary Case Studies in Environmental Science Curricula, *Corporate Social Responsibility and Environmental Management*, 21 155-166.
- Bowersox, D. J., Closs, D. J., Cooper, M. B. & Bowersox, J. C. (2013), *Supply Chain Logistics Management*, 4 ed, McGraw-Hill.
- Braun, V. & Clarke, V. (2006), Using Thematic Analysis in Psychology, *Qualitative Research in Psychology*, 3 (2), 77-101.
- Brontë, E. (1847), *Wuthering Heights*, Thomas Cautley Newby.
- Brook, C. & Milner, C. (2014), Reflections on 'Creative' Action Learning in Business Education: Some Issues in its Theory and Practice, *Teaching in Higher Education*, 19 (2), 126-137.
- Bryman, A. & Bell, E. (2011), *Business Research Methods*, 3 ed, Oxford University Press.
- Bränberg, A., Gulliksson, H. & Holmgren, U. (2013), *Didaktik för ingenjörslärare: Konsten och glädjen med att utbilda ingenjörer*, Studentlitteratur.
- Burch, G. F., Burch, J. J., Bradley, T. P. & Heller, N. A. (2015), Identifying and Overcoming Threshold Concepts and Conceptions: Introducing a Conception-Focused Curriculum to Course Design, *Journal of Management Education*, 39 (4), 476-496.
- Burke, J. G., O'Campo, P., Peak, G. L., Gielen, A. C., McDonnell, K. A. & Trochim, W. M. K. (2005), An Introduction to Concept Mapping as a Participatory Public Health Research Method, *Qualitative Health Research*, 15 (10), 1392-1410.
- Bäckström, A. & Magnuson, O. (2015), *The Development of a Purchasing Cost Model Facilitating Decision-Making at Tetra Pak Packaging Solutions*, MSc Thesis, Lund University.

- Calmfors, T. & Werdin, A. (2017), *Utveckling av beräkningsmetoder för effekten av transportåtgärder med fokus på miljöpåverkan för Runsvengruppen AB*, MSc Thesis, Linköping University.
- Cavinato, J. L. (1992), A Total Cost/Value Model for Supply Chain Competitiveness, *Journal of Business Logistics*, 13 (2), 285-301.
- Cedulf, I. & Andreasson, M. (2017), *Coastal Shipping - A Competitive Alternative for Container Transportation?*, MSc Thesis, Chalmers University of Technology.
- Charni, R. & Maier, M. (2013), Impact Study of Collaborative Implementation Models on Total Cost of Ownership of Integrated Fiber-Wireless Smart Grid Communications Infrastructures, *IEEE SmartGridComm 2013 Symposium*.
- Chopra, S. & Meindl, P. (2016), *Supply Chain Management: Strategy, Planning, and Operation*, 6 ed, Pearson.
- Christopher, M. (1972), The New Science of Logistics Systems Engineering, *International Journal of Physical Distribution*, 2 (1), 5-13.
- Christopher, M. (2016), *Logistics and Supply Chain Management*, 5 ed, Financial Times Publishing.
- Churchman, C. W. (1968), *The Systems Approach*, Dell Publishing.
- Claesson, J. & Rehme, E. (2017), *En jämförelse av logistikkostnader för framtida distributionsstrukturer – En studie på ESSVE och Bergman & Beving*, MSc Thesis, Linköping University.
- Clinton, V. (2019), Reading from Paper Compared to Screens: A Systematic Review and Meta-Analysis, *Journal of Research in Reading*, 00 (00), 1-38.
- Cohen, L., Manion, L. & Morrison, K. (2011), *Research Methods in Education*, 7 ed, Routledge.
- Cohen, M. & Billsberry, J. (2014), The Use of Marking Rubrics in Management Education: Issues of Deconstruction and Andragogy, *Journal of Management Education*, 38 (3), 352-358.
- Cole, D. & Grossman, P. (2002), Toward a Total-Cost Approach to Environmental Instrument Choice, *Research in Law and Economics*, 20 223-241.
- Colicchia, C. & Strozzi, F. (2012), Supply Chain Risk Management: A New Methodology for a Systematic Literature Review, *Supply Chain Management*, 17 (4), 403-418.
- Collett, N. (2000), Innovation or Renovation: Effective Project Design for Accounting and MBA Students, *Accounting Education*, 9 (1), 67-92.
- Collins, A. (1988), *Cognitive Apprenticeship and Instructional Technology. Technical Report*, BBN Labs Inc.

- Considine, C., Kauffmann, P. & Dryer, D. (2006), Integration of Quality Cost into a Total Cost Model for a Distribution Network, *Journal of Parametrics*, 25 (1), 73-85.
- Cooper, D. R. & Schindler, P. S. (2003), *Business Research Methods*, 8 ed, McGraw-Hill.
- Coorey, J. (2016), Active Learning Methods and Technology: Strategies for Design Education, *International Journal of Art & Design Education*, 35 (3), 337-347.
- Corotis, R. B., Lynch, K. P., Beams, B. & Hattan, D. (2012), Including User Cost and Risk Analysis During Construction in Highway Bridge Structure Selection, *Journal of Transportation Safety & Security*, 4 (3), 211-224.
- Coughlan, P. & Graham, A. (2009), Embedding a Threshold Concept in Teaching and Learning of Product Development Management, *Creativity and Innovation Management*, 18 (3), 190-198.
- Cousin, G. (2010), Neither Teacher-Centred nor Student-Centred: Threshold Concepts and Research Partnerships, *Journal of Learning Development in Higher Education*, 2 1-9.
- Cowell, J. W. (1988), *The Effects of Inadequate Component Inspection on Facility Repair Projects*, MSc Thesis, University of Florida.
- Coyle, J. J., Langley Jr, C. J., Novack, R. A. & Gibson, B. J. (2017), *Supply Chain Management: A Logistics Perspective*, 10 ed, Cengage Learning.
- Crocker, B., Jessop, D. & Morrison, A. (2012), *Inbound Logistics Management : Storage and Supply of Materials for the Modern Supply Chain*, 7 ed, Harlow Pearson.
- CSCMP. (2019), *Definitions of Supply Chain Management* [Online]. Available: https://cscmp.org/imis0/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms/CSCMP/Educate/SCM_Definitions_and_Glossary_of_Terms.aspx?hkey=60879588-f65f-4ab5-8c4b-6878815ef921 [Accessed 13 March 2019].
- Cui, Y., Ingalz, C., Gao, T. & Heydari, A. (2017), Total Cost of Ownership Model for Data Center Technology Evaluation, *16th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems*. IEEE.
- Cyr, J. (2014), The Pitfalls and Promise of Focus Groups as a Data Collection Method, *Sociological Methods and Research*, 45 (2), 231-259.
- Dahlin Ivanoff, S. & Holmgren, K. (2017), *Fokusgrupper*, Studentlitteratur.
- Dahlström, M. & Peterson, J. (2013), *Developing a Cost Estimation Model for Packaging Material*, MSc Thesis, Lund University.
- Dale, B. G. & Cunningham, M. T. (1984), The Importance of Factors Other Than Cost Considerations in Make or Buy Decisions, *International Journal of Operations & Production Management*, 4 (3), 43-54.
- David, M. & Sutton, C. (2011), *Social Research : An Introduction*, 2 ed, Sage.

- Davidson, N. & Major, C. H. (2014), Boundary Crossings: Cooperative Learning, Collaborative Learning, and Problem-Based Learning, *Journal on Excellence in College Teaching*, 25 (3-4), 7-55.
- Davies, P. & Mangan, J. (2007), Threshold Concepts and the Integration of Understanding in Economics, *Studies in Higher Education*, 32 (6), 711-726.
- Davis, M. M. (1991), How Long Should a Customer Wait for Service?, *Decision Sciences*, 22 (2), 421-434.
- Davis, M. M., Aquilano, N. J. & Chase, R. B. (2003), *Fundamentals of Operations Management*, 4 ed, McGraw-Hill.
- Dayama, P. S. & Jidugu, B. (2009), Multi-Strategy Supplier Selection for Commodity Sourcing, 2009 *IEEE International Conference on Automation Science and Engineering*.
- De Jong, T. & Ferguson-Hessler, M. G. M. (1996), Types and qualities of knowledge, *Educational Psychologist*, 31 (2), 105-113.
- DeCorla-Souza, P., Everett, J., Gardner, B. & Culp, M. (1997), Total Cost Analysis: An Alternative to Benefit-Cost Analysis in Evaluating Transportation Alternatives, *Transportation*, 24 (2), 107-123.
- Denyer, D. & Tranfield, D. (2009), Producing a Systematic Review. In: Buchanan, D. A. & Bryman, A. (eds.) *The Sage Handbook of Organizational Research Methods*. Sage Publications Ltd.
- Dönmez, S. & Zemmouri, M. (2016), *Analyzing the Value of Vehicle Maintenance Activities*, MSc Thesis, Chalmers University of Technology.
- Eden, C., Ackermann, F. & Cropper, S. (1992), The Analysis Of Cause Maps, *Journal of Management Studies*, 29 (3), 309-324.
- Eggimann, S., Truffer, B. & Maurer, M. (2016), The Cost of Hybrid Waste Water Systems: A Systematic Framework for Specifying Minimum Cost-Connection Rates, *Water Research*, 103 472-484.
- Eisenhardt, K. M. (1989), Building Theories from Case Study Research, *Academy of Management Review*, 14 (4), 532-550.
- Eisenhardt, K. M. & Graebner, M. E. (2007), Theory Building from Cases: Opportunities and Challenges, *The Academy of Management Journal*, 50 (1), 25-32.
- Ellram, L., M. (1993), Total Cost of Ownership: Elements and Implementation, *Journal of Supply Chain Management*, 29 (4), 3-11.
- Ellram, L., M. & Maltz, A. (1997), *Outsourcing: Implications for Supply Management*, Centre for Advanced Purchasing Studies.

- Ellram, L. M. (1995), Total Cost of Ownership; An Analysis Approach for Purchasing, *International Journal of Physical Distribution & Logistics Management*, 25 (8), 4-23.
- Ellram, L. M. & Maltz, A. B. (1995), The Use of Total Cost of Ownership Concepts to Model the Outsourcing Decision, *International Journal of Logistics Management*, 6 (2), 55-66.
- Ellram, L. M. & Siferd, S. P. (1993), Purchasing: The Cornerstone of the Total Cost of Ownership Concept, *Journal of Business Logistics*, 14 (1), 163-184.
- England, W., B. (1967), *The Purchasing System*, Irwin.
- Entwistle, N. (2009), *Teaching for Understanding at University: Deep Approaches and Distinctive Ways of Thinking*, Palgrave Macmillan.
- Eriksson, J. & Sterner, E. (2016), *Total Cost of Purchasing at Duni AB: Development of a Cost Model*, MSc Thesis, Lund University.
- Esper, T. L., Fugate, B. S. & Davis-Sramek, B. (2007), Logistics Learning Capability: Sustaining the Competitive Advantage Gained Through Logistics Leverage, *Journal of Business Logistics*, 28 (2), 57-81.
- Farr, J. V. (2011), *Systems Life Cycle Costing : Economic Analysis, Estimation, and Management*, CRC Press.
- Fernandez-Balboa, J.-M. & Stiehl, J. (1995), The Generic Nature of Pedagogical Content Knowledge among College Professors, *Teaching and Teacher Education*, 11 (3), 293-306.
- Ferrin, B. G. & Plank, R. E. (2002), Total Cost of Ownership Models: An Exploratory Study, *Journal of Supply Chain Management*, 38 (2), 18-29.
- Finfgeld-Connett, D. (2014), Use of Content Analysis to Conduct Knowledge-Building and Theory-Generating Qualitative Systematic Reviews, *Qualitative Research*, 14 (3), 341-352.
- Fisher, G. H. (1956), Weapon-System Cost Analysis, *Operations Research*, 4 (5), 558-571.
- Fortuin, I. K. P. J. & Bush, S. R. (2010), Educating Students to Cross Boundaries Between Disciplines and Cultures and Between Theory and Practice, *International Journal of Sustainability in Higher Education*, 11 (1), 19-35.
- Frankel, R., Bolumole, Y. A., Eltantawy, R. A., Paulraj, A. & Gundlach, G. T. (2008), The Domain and Scope of SCM's Foundational Disciplines : Insights and Issues to Advance Research, *Journal of Business Logistics*, 29 (1), 1-30.
- Freyschuss, E. & Hallenberg, P. (2017), *Effekterna av att konsolidera leverantörers gods vid en terminal*, MSc Thesis, Linköping University.

- Gabrielsson, J., Tell, J. & Politis, D. (2010), Business Simulation Exercises in Small Business Management Education: Using Principles and Ideas from Action Learning, *Action Learning: Research and Practice*, 7 (1), 3-16.
- Ge, X. & Land, S. M. (2003), Scaffolding Students' Problem-Solving Processes in an Ill-Structured Task Using Question Prompts and Peer Interactions, *Educational Technology Research and Development*, 51 (1), 21-38.
- Gerdin, J. (1995), *ABC-kalkylering*, Studentlitteratur.
- Ghauri, P. N. & Grønhaug, K. (2005), *Research Methods in Business Studies: A Practical Guide*, 3 ed, Financial Times Prentice Hall.
- Gleissner, H. & Femerling, J. C. (2013), *Logistics : Basics - Exercises - Case Studies*, Springer.
- Goetsch, D. L. & Davis, S. B. (2010), *Quality Management for Organizational Excellence*, 6 ed, Pearson.
- Goodnough, K. (2006), Enhancing Pedagogical Content Knowledge through Self-Study: An Exploration of Problem-Based Learning, *Teaching in Higher Education*, 11 (3), 301-318.
- Goyal, S. K. (1987), Economic Ordering Policy for Deteriorating Items over an Infinite Horizon, *European Journal of Operational Research*, 28 298-301.
- Grant, D. B., Lambert, D. M., Stock, J. R. & Ellram, L. M. (2006), *Fundamentals of Logistics Management*, McGraw-Hill Education.
- Grant, D. B., Trautrim, A. & Wong, C. Y. (2017), *Sustainable Logistics and Supply Chain Management : Principles and Practices for Sustainable Operations and Management*, 2 ed, 2017.
- Grant, M. J. & Booth, A. (2009), A Typology of Reviews: An Analysis of 14 Review Types and Associated Methodologies, *Health Information and Libraries Journal*, 26 (2), 91-108.
- Green, D. E., Hamory, B. H., Terrell, G. E. & O'Connell, J. (2017), A Case Report: Cornerstone Health Care Reduced the Total Cost of Care Through Population Segmentation and Care Model Redesign, *Population Health Management*, 20 (4), 309-317.
- Greer, H. C. (1931), The Technique of Distribution Cost Accounting, *Accounting Review*, 6 (2), 136-139.
- Gummesson, E. (2000), *Qualitative Methods in Management Research*, 2 ed, SAGE Publications, Inc.
- Gunasekaran, A. (1999), A Framework for the Design and Audit of an Activity-Based Costing System, *Managerial Auditing Journal*, 14 (3), 118-127.

- Götze, U., Northcott, D. & Schuster, P. (eds.) (2015), *Investment Appraisal: Methods and Models*, Springer.
- Hagberg, C. & Daadooch, S. (2017), *Evaluation of Air Freight Replenishments*, MSc Thesis, Lund University.
- Halkjaer, T. & Nybonn, A. (2018), *Distributed Production of Spare Parts Using Additive Manufacturing*, MSc Thesis, Chalmers University of Technology.
- Halldórsson, Á. & Aastrup, J. (2003), Quality Criteria for Qualitative Inquiries in Logistics, *European Journal of Operational Research*, 144 (2), 321-332.
- Hamparsomian, A. & Milesson, G. (2017), *Establishing a Total Cost of Ownership model for purchasing of capital equipment*, MSc Thesis, Linköping University.
- Harris, F. W. (1913), How Many Parts to Make at Once, *The Magazine of Management*, 10 (2), 135-136.
- Harrison, A., van Hoek, R. & Skipworth, H. (2015), *Logistics Management and Strategy - Competing Through the Supply Chain*, 5 ed, Pearson.
- Harrysson, H. & Landin, L. (2015), *A Total Cost Analysis of the Return Process Online and In Store*, MSc Thesis, Lund University.
- Hasselt, M., McCall, N., Keyes, V., Wensky, S. G. & Smith, K. W. (2015), Total Cost of Care Lower among Medicare Fee-for-Service Beneficiaries Receiving Care from Patient-Centered Medical Homes, *Health Services Research*, 50 (1), 253-272.
- Hassmiller Lich, K., Urban, J. B., Frerichs, L. & Dave, G. (2017), Extending Systems Thinking in Planning and Evaluation Using Group Concept Mapping and System Dynamics to Tackle Complex Problems, *Evaluation and Program Planning*, 60 254-264.
- Hatamleh, M. T., Hiyassat, M., Sweis, G. J. & Sweis, R. J. (2018), Factors Affecting the Accuracy of Cost Estimate: Case of Jordan, *Engineering, Construction and Architectural Management*, 25 (1), 113-131.
- Heading, D. & Loughlin, E. (2018), Lonergan's Insight and Threshold Concepts: Students in the Liminal Space, *Teaching in Higher Education*, 23 (6), 657-667.
- Heinimann, H. (1998), A Computer Model to Differentiate Skidder and Cable-Yarder Based Road Network Concepts on Steep Slopes, *Journal of Forest Research*, 3 (1), 1-9.
- Helu, M., Behmann, B., Meier, H., Dornfeld, D., Lanza, G. & Schulze, V. (2012), Total Cost Analysis of Process Time Reduction as a Green Machining Strategy, *Proceedings of the 19th CIRP International Conference on Life Cycle Engineering*.
- Herrington, J., Oliver, R. & Reeves, T. (2003), Cognitive Realism in Online Authentic Learning Environments, *Conference on Educational Multimedia, Hypermedia*

- and Telecommunications (EDMEDIA). Edith Cowan University, Research Online, Perth, Western Australia.
- Heye, C. F. (1957), Book Review: 'The Role of Air Freight in Physical Distribution', by Howard T. Lewis, James W. Culliton and Jack D. Steele., *Journal of Marketing*, 22 (1), 109-110.
- Ho, C.-J. (2007), Measuring System Performance of an ERP-Based Supply Chain, *International Journal of Production Research*, 45 (6), 1255-1277.
- Holweg, M., Reichhart, A. & Hong, E. (2011), On Risk and Cost in Global Sourcing, *International Journal of Production Economics*, 131 (1), 333-341.
- Hunter, B. (2015), Teaching for Engagement: Part 1 - Constructivist Principles, Case-Based Teaching, and Active Learning, *College Quarterly*, 18 (2).
- Håkansson, J. & Sundberg, D. (2012), *Utmärkt undervisning: Framgångsfaktorer i svensk och internationell belysning*, Natur & Kultur.
- IEC (2017), International Standard, Dependability Management, *Part 3-3: Application Guide - Life Cycle Costing*.
- Jennings, D. (2002), Strategic Management: An Evaluation of the Use of Three Learning Methods, *Journal of Management Development*, 21 (9), 655-665.
- Jeon, K., Jarrett, O. S. & Ghim, H. D. (2014), Project-Based Learning in Engineering Education: Is it Motivational?, *International Journal of Engineering Education*, 30 (2), 438-448.
- Jonsson, P. F. & Flynn, A. E. (2015), *Purchasing and Supply Management*, 15 ed, McGraw-Hill.
- Jollands, M., Jolly, L. & Molyneaux, T. (2012), Project-Based Learning as a Contributing Factor to Graduates' Work Readiness, *European Journal of Engineering Education*, 37 (2), 143-154.
- Jonsson, A. & Tolstoy, D. (2013), A Thematic Analysis of Research on Global Sourcing and International Purchasing in Retail Firms, *International Journal of Retail & Distribution Management*, 42 (1), 56-83.
- Jonsson, P. (2008), *Logistics and supply chain management*, McGraw-Hill.
- Jonsson, P. & Mattsson, S.-A. (2014), Lagerstyrning i hög- och lågpresterande företag. Available: www.lagerstyrningsakademin.se [Accessed 13 May 2017].
- Jonsson, P. & Mattsson, S.-A. (2016), *Logistik: Läran om effektiva materialflöden*, 3 ed, Studentlitteratur.
- Kaplan, R. S. & Anderson, S. R. (2007), *Time-Driven Activity-Based Costing: A Simpler and More Powerful Path to Higher Profits*, Harvard Business School Press.

- Karagiorgi, Y. & Symeou, L. (2005), Translating Constructivism into Instructional Design: Potential and Limitations, *Educational Technology and Society*, 8 (1), 17-27.
- Kayes, A. B., Kayes, D. C. & Kolb, D. A. (2005), Experiential Learning in Teams, *Simulation & Gaming*, 36 (3), 330-354.
- Kenderdine, J. M. & Larson, P. D. (1988), Quality and Logistics: A Framework for Strategic Integration, *International Journal of Physical Distribution & Logistics Management*, 18 (6), 5-10.
- Kim, J. (2014), *Activity-Based Cost Modeling and Dynamic Simulation Study of an International Reusable Packing System*, Dissertation, Michigan State University.
- Kitchenham, B. & Charters, S. (2007), *Guidelines for Performing Systematic Literature Reviews in Software Engineering*, EBSE Technical Report, Keele University / Durham University.
- Knight, D. B., Callaghan, D. P., Baldock, T. E. & Meyer, J. H. F. (2014), Identifying Threshold Concepts: Case Study of an Open Catchment Hydraulics Course, *European Journal of Engineering Education*, 39 (2), 125-142.
- Kolb, A. Y. & Kolb, D. A. (2005), Learning Styles and Learning Spaces: Enhancing Experiential Learning in Higher Education, *Academy of Management Learning and Education*, 4 (2), 193-212.
- Korhonen, K., Pekkanen, P. & Pirttilä, T. (2007), Role Game as a Method to Increase Cross-Functional Understanding in a Supply Chain, *International Journal of Production Economics*, 108 (1), 127-134.
- Korpi, E. & Ala-Risku, T. (2008), Life Cycle Costing: A Review of Published Case Studies, *Managerial Auditing Journal*, (3), 240-261.
- Kosior, J. M. & Strong, D. (2006), Supply/Demand Chain Modeling Utilizing Logistical-Based Costing, *Journal of Enterprise Information Management*, 19 (3), 346-360.
- Kotler, P. (2002), *Kotlers marknadsföring - Att skapa, vinna och dominera marknader*, Liber ekonomi.
- Kovács, G. & Spens, K. M. (2007), Logistics Theory Building, *Journal of Supply Chain Management*, 4 (4), 7-27.
- Kumar, N., Andersson, D. & Rehme, J. (2010), Logistics of Low Cost Country Sourcing, *International Journal of Logistics - Research and Applications*, 13 (2), 143-160.
- Kumar, S. & Kopitzke, K. K. (2008), A Practitioner's Decision Model for the Total Cost of Outsourcing and Application to China, Mexico, and the United States, *Journal of Business Logistics*, 29 (2), 107-139.

- Lambert, D. M. (1975), *The Development of an Inventory Costing Methodology: A Study of the Costs Associated with Holding Inventory*, PhD Dissertation, Ohio State University, Department of Marketing.
- Lambert, D. M. & Burduroglo, R. (2000), Measuring and Selling the Value of Logistics, *International Journal of Logistics Management*, 11 (1), 1-18.
- Lambert, D. M. & Mentzer, J. T. (1980), Is Integrated Physical Distribution Management a Reality?, *Journal of Business Logistics*, 2 (1), 18-34.
- Larson, P. D. (1992), Business Logistics and the Quality Loss Function, *Journal of Business Logistics*, 13 (1), 125-147.
- Larsson, S. (2005), Om kvalitet i kvalitativa studier, *Nordisk Pedagogik*, 25 16-35.
- LeKashman, R. & Stolle, J. F. (1965), The Total Cost Approach to Distribution, *Business Horizons*, 8 (4), 33-46.
- Lichtenvort, K., Rebitzer, G., Huppel, G., Ciroth, A., Seuring, S., Schmidt, W. P., Günther, E., Hoppe, H., Swarr, T. & Hunkeler, D. (2008), Introduction History of Life Cycle Costing, Its Categorization, and Its Basic Framework. In: Hunkeler, D., Lichtenvort, K. & Rebitzer, G. (eds.) *Environmental Life Cycle Costing*. CRC Press.
- Lindskog, M. (2012), *On Systems Thinking in Logistics Management - A Critical Perspective*, PhD Dissertation, Linköping University, Dept of Science and Technology.
- Lumsden, K. (2012), *Logistikens grunder*, 3 ed, Studentlitteratur.
- Lundell, A. & Nilsson, M. (2017), *Distribution Quantities of Spare Parts Through Industry Supply Chains – Case Study at Atlas Copco Rock Drills AB*, MSc Thesis, Linköping University.
- Lundqvist, J. & Stenström, C. (2017), *Lagerstyrning för produktionslager – Framtagning av en lagerstyrningsmodell för Sandvik Coromant*, MSc Thesis, Linköping University.
- Mahmood, S., M., A. S., Panthi, K. & Kureshi, N. I. (2014), Determining the Cost of Poor Quality and its Impact on Productivity and Profitability, *Built Environment Project and Asset Management*, (3), 296-311.
- Mangan, J. & Lalwani, C. (2016), *Global Logistics and Supply Chain Management*, 3 ed, Wiley.
- Manners-Bell, J. (2017), *Introduction to Global Logistics : Delivering the Goods*, 2 ed, Kogan Page.
- Mariotto, A. B., Robin Yabroff, K., Shao, Y., Feuer, E. J. & Brown, M. L. (2011), Projections of the Cost of Cancer Care in the United States: 2010-2020, *Journal of the National Cancer Institute*, 103 (2), 117-128.

- Marsick, V. J. & O'Neil, J. (1999), The Many Faces of Action Learning, *Management Learning*, 30 (2), 159-176.
- Mattsson, S.-A. (2003), Några synpunkter på att reducera kapitalbindning. Available: www.lagerstyrningsakademin.se [Accessed 13 May 2017].
- McGuire, P. (2019), *Cost to fix Maine's busiest highway bridge 50% higher than expected* [Online]: Portland Press Herald. Available: www.pressherald.com [Accessed 17 March 2019].
- Menachof, D. (1996), Risk Management Methods for the Liner Shipping Industry: The Response to Customer Service Demands, *Journal of Business Logistics*, 17 (1), 259-290.
- Menezes, F. G. & Chibana, V. (2015), Cost-Minimization Analysis and Total Cost Analysis for A Weight Range In Crohn's Disease Treatment With Anti-Tnf Biologics Under Brazilian Private Health Care System Perspective, *Value in Health*, 18 (7), 670.
- Mentzer, J. T., Stank, T. P. & Esper, T. L. (2008), Supply Chain Management and its Relationship to Logistics, Marketing, Production, and Operations Management, *Journal of Business Logistics*, 29 (1), 31-46.
- Merriam, S. B. (1998), *Qualitative Research and Case Study Applications in Education*, Jossey-Bass.
- Merriam, S. B. & Tisdell, E. J. (2016), *Qualitative Research - A Guide to Design and Implementation*, 4 ed, Jossey-Bass.
- Meyer-Aurich, A., Gandorfer, M., Trost, B., Ellmer, F. & Baumecker, M. (2016), Risk Efficiency of Irrigation to Cereals in Northeast Germany with Respect to Nitrogen Fertilizer, *Agricultural Systems*, 149 132-138.
- Meyer, J. & Land, R. (2003), *Threshold Concepts and Troublesome Knowledge: Linkages to Ways of Thinking Practising Within the Disciplines*, Enhancing Teaching-Learning Environments in Undergraduate Courses Project, School of Education, University of Edinburgh.
- Meyer, J. H. F. & Land, R. (2005), Threshold concepts and troublesome knowledge (2): Epistemological considerations and a conceptual framework for teaching and learning, *Higher Education*, 49 (3), 373-388.
- Miser, H. J. & Quade, E. S. (1988), Analytic Strategies and Their Components. In: Miser, H. J. & Quade, E. S. (eds.) *Handbook of Systems Analysis, Volume Two - Craft Issues and Procedural Choices*. Wiley.
- Mislick, G. K. & Nussbaum, D. A. (2015), *Cost Estimation: Methods and Tools*, Wiley.
- Mjörne, A. & Patel, J. (2017), *Förflyttning av kundorderpunkten uppströms med hjälp av SkyMakers verktyg - En fallstudie av logistiska effekter och framtagning av passande produkttegenskaper*, MSc Thesis, Linköping University.

- Moeller, K. (2002), Evaluation of Supply Chains by a Transaction Based Total Cost Approach, *SAE Technical Paper Series*, (2002-01-2109), 7.
- Momanu, M. (2012), The Role of Context in Didactic Knowledge Building: An Epistemological Approach, *Scientific Annals of the 'Alexandru Ioan Cuza' University of Iasi: Educational Sciences Series*, 16 45-56.
- Monczka, R. M., Handfield, R., B., Giunipero, L., C., Patterson, J., L. & Waters, D. (2010), *Purchasing and Supply Chain Management, European Ed.*, South-Western Cengage Learning.
- Montgomery, D. C. (2013), *Statistical Quality Control - A Modern Introduction*, 7 ed, Wiley.
- More, P. R. & Vu, T. T. M. (2017), *Identifying the Best-Cost Countries for Sourcing SKF's Direct Materials*, MSc Thesis, Chalmers University of Technology.
- Morrison, J. R., Johnson, J. D., Barnes, J. H., Summers, K. & Szeinbach, S. L. (1997), Predicting Total Health Care Costs of Medicaid Recipients: An Artificial Neural Systems Approach, *Journal of Business Research*, 40 (3), 191-197.
- Murphy, P., Lunn, S. & Jones, H. (2006), The Impact of Authentic Learning on Students' Engagement with Physics, *Curriculum Journal*, 17 (3), 229-246.
- Murphy, P. R. & Knemeyer, A. M. (2018), *Contemporary Logistics*, 12 ed, Pearson.
- Myerson, P. A. (2015), *Supply Chain and Logistics Management Made Easy*, Pearson.
- Mäkinen, M. & Runér, A. (2017), *Differentierad lagerstyrning av inköpt material - En fallstudie vid Bosch Rexroths produktionsverksamhet i Stockholm*, MSc Thesis, Linköping University.
- Nakandala, D., Lau, H. & Zhang, J. (2016), Cost-Optimization Modelling for Fresh Food Quality and Transportation, *Industrial Management & Data Systems*, 116 (3), 564-583.
- Nato (2007), *Methods and Models for Life Cycle Costing*, North Atlantic Treaty Organisation, Research and Technology Organisation.
- Nato (2009), *Code of Practice for Life Cycle Costing*, RTO Publication, North Atlantic Treaty Organisation, Research and Technology Organisation.
- Needy, K. L., Billo, R. E. & Warner, R. C. (1998), A Cost Model for the Evaluation of Alternative Cellular Manufacturing Configurations, *Computers and Industrial Engineering*, 34 (1), 119-134.
- Nelson, L. P. & Crow, M. L. (2014), Do Active-Learning Strategies Improve Students' Critical Thinking?, *Higher Education Studies*, 4 (2), 77-90.
- Nesbitt, L. M. & Cliff, W. H. (2008), How the Story Unfolds: Exploring Ways Faculty Develop Open-Ended and Closed-Ended Case Designs, *American Journal of Physiology - Advances in Physiology Education*, 32 (4), 279-285.

- Niine, T. & Koppel, O. (2015), Typology of Logistics Curricula – Four Categories of Logistics of Logistics Undergraduate Education in Europe, *International Journal of Engineering Pedagogy*, 5 (2), 4-11.
- Novack, R. A., Rinehart, L. M. & Fawcett, S. A. (1993), Rethinking Integrated Concept Foundations: A Just-in-Time Argument for Linking Production/Operations and Logistics Management, *International Journal of Operations & Production Management*, 13 (6), 31-43.
- Novack, R. A., Rinehart, L. M. & Wells, M. V. (1992), Rethinking Concept Foundations in Logistics Management, *Journal of Business Logistics*, 13 (2), 233-267.
- Novak, J. D. & Gowin, D. B. (1985), *Learning How to Learn*, Cambridge University Press.
- Nydick, R. L. & Hill, R. P. (1992), Using the Analytic Hierarchy Process to Structure the Supplier Selection Procedure, *International Journal of Purchasing & Materials Management*, 28 (2), 31-38.
- Nye, T. J., Jewkes, E. M. & Dilts, D. M. (2001), Optimal Investment in Setup Reduction in Manufacturing Systems with WIP Inventories, *European Journal of Operational Research*, 135 (1), 128-141.
- O'Leary, S. (2015), Integrating Employability into Degree Programmes Using Consultancy Projects as a Form of Enterprise, *Industry and Higher Education*, 29 (6), 459-468.
- Ochs, E. (1979), Transcription as Theory. In: Ochs, E. & Schieffelin, B. (eds.) *Developmental Pragmatics*. Academic Press.
- Okano, K. (2001), Life Cycle Costing - An Approach to Life Cycle Cost management: A Consideration from Historical Development, *Asia Pacific Management Review*, 6 (3), 317-341.
- Olayinka, R. A. (2015), *A Knowledge Management Framework for Reducing the Cost of Poor Quality on Construction Projects*, Dissertation, University of Wolverhampton.
- Olsson, J. (2016), Total Cost Analysis in Sweden, Comparison of 4 Different Dialysis Modalities, *Nephrology Dialysis Transplantation*, 31 (Suppl. 1), 222.
- Olsson, J. (2017), *Tidsdriven ABC-kalkylering inom tredjepartslogistik – Tillämpningar för att driva produktivitet hos PostNord Logistics TPL i Norrköping*, MSc Thesis, Linköping University.
- Ornellas, A., Falkner, K. & Edman Stålbrandt, E. (2019), Enhancing Graduates' Employability Skills through Authentic Learning Approaches, *Higher Education, Skills & Work-based Learning*, 9 (1), 107-119.
- Oskarsson, B. (2014), *Towards Pedagogical Content Knowledge in Logistics*, Licentiate thesis, Linköping University.

- Oskarsson, B., Ekdahl, B. & Aronsson, H. (2013), *Modern logistik: för ökad lönsamhet*, 4 ed, Liber.
- Osmond, J., Bull, K. & Tovey, M. (2009), Threshold Concepts and the Transport and Product Design Curriculum: Reports of Research in Progress, *Art, Design & Communication in Higher Education*, 8 (2), 169-175.
- Palmer, S. & Hall, W. (2011), An Evaluation of a Project-Based Learning Initiative in Engineering Education, *European Journal of Engineering Education*, 36 (4), 357-365.
- Park, S. & Oliver, J. S. (2008), Revisiting the Conceptualisation of Pedagogical Content Knowledge (PCK): PCK as a Conceptual Tool to Understand Teachers as Professionals, *Research in Science Education*, 38 (3), 261-284.
- Patel, A. B. & Desai, T. N. (2018), A Systematic Review and Meta-Analysis of Recent Developments in Sustainable Supply Chain Management, *International Journal of Logistics Research and Applications*, 22 (4), 349-370.
- Patel, R. & Davidson, B. (2019), *Forskningsmetodikens grunder : att planera, genomföra och rapportera en undersökning*, 5 ed, Studentlitteratur.
- Paton, W. A. (1966), Guidelines for Make-or-Buy Decisions, *Management Review*, 55 (5), 27-30.
- Peddibhotla, N. (2016), Toward an Understanding of Development of Learning to Solve Ill-Defined Problems in an Online Context: A Multi-Year Qualitative Exploratory Study, *Online Learning*, 20 (1), 95-109.
- Perkins, D. (2006), Constructivism and Troublesome Knowledge. In: Meyer, J. H. F. & Land, R. (eds.) *Overcoming Barriers to Student Understanding: Threshold Concepts and Troublesome Knowledge*. Routledge Taylor & Francis Group.
- Perng, C.-S., Chang, R., Tao, T., So, E., Choi, M. & Shaikh, H. (2012), Universal Economic Analysis Methodology for IT Transformations, *2012 IEEE Network Operations & Management Symposium*.
- Pettersen, R. C. (2008), *Kvalitetslärande i högre utbildning: introduktion till problem- och praktikbaserad didaktik*, Studentlitteratur.
- Pettersson, R. (2002), *Information Design: An introduction*, John Benjamins Publishing Company.
- Pezeshki, S. & Wang, F. (2016), *The Effects of Consolidation on Volvo Group's LCL Transportation Network*, MSc Thesis, Chalmers University of Technology.
- Phillips, L. G. (1964), An Application of Distribution Cost Analysis to a Small Company, *The Accounting Review*, 39 1040-1044.

- Pirvulescu, P. & Enevoldsen, P. (2019), Supply Chain Management in the Age of Digitalization: Revealing the Trends of SCM 4.0, *International Journal of Supply Chain Management*, 8 (2), 414-428.
- Poist, R. F. (1974), The Total Cost vs. Total Profit Approach To Logistics Systems Design, *Transportation Journal*, 14 (1), 13-24.
- Porporato, M. M. (2016), Logistics Costs Behavior and Management in the Auto Industry, *Issues in Accounting Education*, 31 (4), 389-408.
- Prince, A. (2016), The Psychology of Cost Estimating, *Annual ICEAA Canada Workshop*. NASA Center for Aerospace Information (CASI).
- Prince, M. (2004), Does Active Learning Work? A Review of the Research, *Journal of Engineering Education*, 93 (3), 223-231.
- Pring, R. (2004), *Philosophy of Educational Research*, 2 ed, Continuum.
- Pumpe, A. & Vallée, F. (2017), A Typology for Selecting an Appropriate Total Landed Cost Method in International Supplier Selection Decisions, *Transportation Research Procedia*, 25 853-869.
- Quade, E. S. (1985), Predicting the Consequenses: Models and Modelling. In: Miser, H. J. (ed.) *Handbook of Systems Analysis, Volume One - Overview of Uses, Procedures, Applications, and Practice*. Wiley.
- Ramage, C. (2014), Learning to Learn Through University Accredited Work-Based Learning: A Threshold Conception, *Journal of Workplace Learning*, 26 (8), 488-510.
- Ramsberg, J. & Ekelund, M. (2011), Stuprörstänkande gör samhällets kostnader för ohälsa onödigt höga, *Ekonomisk debatt*, 39 (5), 41-53.
- Rattray, J. & Chen, D. (2017), Transforming Thinking through Problem-Based Learning in the News Media Literacy Class: Critical Thinking as a Threshold Concept towards Threshold Capabilities, *Practice and Evidence of the Scholarship of Teaching and Learning in Higher Education*, 12 (2), 272-293.
- Remer, D. S., Sherif, J. S. & Buchanan, H. R. (1992), Modeling the Deep Space Network Costs for Future Space Missions by Using Major Cost Drivers, *International Journal of Production Economics*, 28 (2), 193-202.
- Roach, K., Tilley, E. & Mitchell, J. (2018), How Authentic Does Authentic Learning Have to Be?, *Higher Education Pedagogies*, 3 (1), 495-509.
- Robert, C. P. & Casella, G. (2004), *Monte Carlo Statistical Methods*, Springer-Verlag, New York.
- Robert, F. & Gosselin, L. (2014), New Methodology to Design Ground Coupled Heat Pump Systems Based on Total Cost Minimization, *Applied Thermal Engineering*, 62 (2), 481-491.

- Rodrigues, V. S., Potter, A., Naim, M., Piecyk, M., McKinnon, A. & Edwards, J. (2010), Assessing the Application of Focus Groups as a Method for Collecting Data in Logistics, *International Journal of Logistics Research and Applications*, 13 (1), 75-94.
- Romeyke, T. & Stummer, H. (2012), Clinical Pathways as Instruments for Risk and Cost Management in Hospitals - a Discussion Paper, *Global Journal Of Health Science*, 4 (2), 50-59.
- Rowbotham, M. A. (2015), *The Impact of Faculty Development on Teacher Self-Efficacy, Skills and Perspectives.*, Policy Research: IERC FFR 2015-1, Illinois Education Research Council.
- Rowbottom, D. P. (2007), Demystifying Threshold Concepts, *Journal of Philosophy of Education*, 41 (2), 263-270.
- Rushton, A., Croucher, P. & Baker, P. (2017), *The Handbook of Logistics and Distribution Management*, 6 ed, Kogan Page.
- Saccani, N., Perona, M. & Bacchetti, A. (2017), The Total Cost of Ownership of Durable Consumer Goods: A Conceptual Model and an Empirical Application, *International Journal of Production Economics*, 183 (Part A), 1-13.
- Sakao, T. & Lindahl, M. (2015), A Method to Improve Integrated Product Service Offerings Based on Life Cycle Costing, *CIRP Annals - Manufacturing Technology*, 64 33-36.
- Sandberg, E. & Abrahamsson, M. (2019), *Logistikdriven affärsutveckling*, Studentlitteratur.
- Sanders, N. R. (2017), *Supply Chain Management: A Global Perspective*, 2 ed, Wiley.
- Sandri, O. J. (2013), Threshold Concepts, Systems and Learning for Sustainability, *Environmental Education Research*, 19 (6), 810-822.
- Sands, J., Li, Q. & Hornberger, J. (2017), Urine Circulating-Tumor DNA (ctDNA) Detection of Acquired EGFR T790M Mutation in Non-Small-Cell Lung Cancer: An Outcomes and Total Cost-of-Care Analysis, *Lung Cancer*, 110 19-25.
- Sandung, M. (2017), *The Effects of International Standards on the Design of a Micro Grid in a Rural Area*, MSc Thesis, Lund University.
- Saunders, M., Lewis, P. & Thornhill, A. (2007), *Research Methods for Business Students*, 4 ed, Financial Times/Prentice Hall.
- Savery, J. R. (2006), Overview of Problem-Based Learning: Definitions and Distinctions, *Interdisciplinary Journal of Problem-Based Learning*, 1 (1), 9-20.
- Schaefer, H. P. (1958), The Distribution Cost Problem, *The Accounting Review*, 33 (4), 625-631.

- Scherer, F. M. (2001), An Early Application of the Average Total Cost Concept, *Journal of Economic Literature*, 39 (3), 897-931.
- Schönsleben, P. (2016), *Integral Logistics Management: Operations and Supply Chain Management Within and Across Companies*, 5 ed, Routledge.
- Senge, P. M. (2006), *The Fifth Discipline: The Art and Practice of the Learning Organization*, 3 ed, Random House Business.
- Seuring, S. & Gold, S. (2012), Conducting Content-Analysis Based Literature Reviews in Supply Chain Management, *Supply Chain Management*, 17 (5), 544-555.
- Sevin, C. H. (1947), Some Aspects of Distribution Cost Analysis, *Journal of Marketing*, 12 (1), 92-98.
- Shapiro, J. F. & Wagner, S. N. (2009), Strategic Inventory Optimization, *Journal of Business Logistics*, 30 (2), 161-173.
- Shulman, L. S. (1986), Those Who Understand: Knowledge Growth in Teaching, *Educational Researcher*, 15 (2), 4-14.
- Shulman, L. S. (1987), Knowledge and Teaching: Foundations of the New Reform, *Harvard Educational Review*, 57 (1), 1-22.
- Shutes, G. M. (1960), Airfreight from a Marketing Viewpoint, *Journal of Marketing*, 25 (2), 39-43.
- Siggelkow, N. (2007), Persuasion with Case Studies, *The Academy of Management Journal*, 50 (1), 20-24.
- Singh Srai, J., Christodoulou, P., Settanni, E., Harrington, T. S., Greitemann, J., Kumar, M., Tsolakis, N., Hennelly, P., Trokanas, N. & Beecher, P. (2017), *Next Generation Supply Chains: Making the Right Decisions about Digitalisation*, University of Cambridge, Centre for International Manufacturing.
- Singhry, H. B. (2015), An Extended Model of Sustainable Development from Sustainable Sourcing to Sustainable Reverse Logistics: A Supply Chain Perspective, *International Journal of Supply Chain Management*, 4 (4), 115-125.
- Sjöberg, M. (2017), *Framtagning av modell för utformning av lagerlayout till färdigvarulager – med verifiering genom layoutförslag till Nolato Cerbo*, MSc Thesis, Linköping University.
- Smith, K. M. (2013), Recognition of Problem Insufficiency: A Proposed Threshold Concept Emergent in Student Accounts of Memorable Interior Design Educational Experiences, *Journal of Interior Design*, 38 (4), 37-54.
- Sroufe, R. & Ramos, D. (2011), MBA Program Trends and Best Practices in Teaching Sustainability: Live Project Courses, *Decision Sciences Journal of Innovative Education*, 9 (3), 349-369.

- Stapleton, D., Pati, S., Beach, E. & Julmanichoti, P. (2004), Activity-Based Costing for Logistics and Marketing, *Business Process Management Journal*, 10 (5), 584-597.
- Stein, S. J., Isaacs, G. & Andrews, T. (2004), Incorporating Authentic Learning Experiences within a University Course, *Studies in Higher Education*, 29 (2), 239-258.
- Stock, G. N., Greis, N. P. & Kasarda, J. D. (1998), Logistics, Strategy and Structure: A Conceptual Framework, *International Journal of Operations & Production Management*, 18 (1), 37-52.
- Stock, J. R. & Lambert, D. M. (1982), *Strategic Logistics Management*, Irwin.
- Svärd, J., Schönborn, K. & Hallström, J. (2017), Design of an Authentic Innovation Project in Swedish Upper Secondary Technology Education, *Australasian Journal of Technology Education*, 4 (1), 1-15.
- Sörqvist, L. (1998), *Kvalitetsbristkostnader: ett hjälpmedel för verksamhetsutveckling*, Studentlitteratur.
- Tang, T. (2019), Assessment of Economic Threshold Concepts in Higher Education, *International Review of Economics Education*, 30 (100152), 1-9.
- Tranfield, D., Denyer, D. & Smart, P. (2003), Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review, *British Journal of Management*, 14 (3), 207-222.
- Trochim, W. M. K. (1989), An Introduction to Concept Mapping for Planning and Evaluation, *Evaluation and Program Planning*, 12 (1), 1-16.
- Tsang, A. K. L. (2011), Students as Evolving Professionals: Turning the Hidden Curriculum Around through the Threshold Concept Pedagogy, *Transformative Dialogues: Teaching & Learning Journal*, 4 (3), 1-11.
- Turchetti, G., Pierotti, F., Palla, I., Manetti, S., Freschi, C., Ferrari, V. & Cuschieri, A. (2017), Comparative Health Technology Assessment of Robotic-Assisted, Direct Manual Laparoscopic and Open Surgery: a Prospective Study, *Surgical Endoscopy*, 31 (2), 543-551.
- Tyworth, J. E. & Grenoble, W. L. (1991), Spreadsheet Modeling In Logistics: Advancing Today's Educational Tools, *Journal of Business Logistics*, 12 (1), 1-25.
- Ulrich, W. (1987), Critical Heuristics of Social Systems Design, *European Journal of Operational Research*, 31 (3), 276-283.
- Walker, Q. F. (1946), The Nature of the Distribution Cost Problem, *Journal of Marketing*, 11 (2), 151-158.

- Waller, M. A. & Fawcett, S. E. (2012), The Total Cost Concept of Logistics: One of Many Fundamental Logistics Concepts Begging for Answers, *Journal of Business Logistics*, 33 (1), 1-3.
- Waller, M. A., Fawcett, S. E. & Johnson, J. L. (2015), The Luxury Paradox: How Systems Thinking and Supply Chain Collaboration Can Bring Sustainability Into Mainstream Practice, *Journal of Business Logistics*, 36 (4), 303-305.
- Wallin, E. & Westberg, F. (2017), *Digitaliseringslösningar för försörjning av indirekt material - En studie om potentiella kostnadseffekter på Saab.*, MSc Thesis, Linköping University.
- Wang, H.-F. & Gupta, S. M. (2011), *Green Supply Chain Management: Product Life Cycle Approach*, McGraw-Hill.
- Veal, W. R. & MaKinster, J. G. (1999), Pedagogical Content Knowledge Taxonomies, *Electronic Journal of Science Education*, 3 (4).
- Weingarten, J. L. (1992), *A Determination of Military and Civilian Personnel Costs as Related to a Member of Technical Staff*, Aeronautical Systems Division, Air Force Systems Command.
- White, A. L., Becker, M. & Savage, D. E. (1993), Environmentally Smart Accounting Using Total Cost Assessment to Advance Pollution Prevention, *Pollution Prevention Review*, Summer 1993 247-259.
- Wibeck, V., Dahlgren, E. M. & Öberg, A. G. (2007), Learning in Focus Groups: An Analytical Dimension for Enhancing Focus Group Research, *Qualitative Research*, 7 (2), 249-267.
- Więcek, D., Więcek, D. & Kuric, I. (2019), Cost Estimation Methods of Machine Elements at the Design Stage in Unit and Small Lot Production Conditions, *Management Systems in Production Engineering*, 27 (1), 12-17.
- Wikipedia. (2019), *Economic Order Quantity* [Online]. [Accessed April 09 2019].
- Wildern, N. L. & Isaacs, J. A. (1998), Total Cost Analysis of Lead-Free Automotive Electrocoating, *SAE Transactions*, 107 953-958.
- Williamson, K. C., Spitzer, D. M. & Bloomberg, D. J. (1990), Modern Logistics Systems: Theory and Practice, *Journal of Business Logistics*, 11 (2), 65-86.
- Wilson, V. (1997), Focus Groups: A Useful Qualitative Method for Educational Research?, *British Educational Research Journal*, 23 (2), 209-224.
- Wisner, J. D., Tan, K.-C. & Leong, G. K. (2017), *Principles of Supply Chain Management: A Balanced Approach*, 5 ed, Cengage Learning.
- Wohlin, C. & Prikladniki, R. (2013), Systematic Literature Reviews in Software Engineering, *Information and Software Technology*, 55 919-920.

- Voorhees, R. D. & Sharp, M. K. (1978), The Principles of Logistics Revisited, *Transportation Journal*, 18 (1), 69-84.
- Wouters, M., Anderson, J. C. & Wynstra, F. (2004), The Adaption of Total Cost of Ownership for Sourcing Decisions - A Structural Equations Analysis, *Accounting, Organizations and Society*, 30 167-191.
- Wright, A. L. & Gilmore, A. (2012), Threshold Concepts and Conceptions: Student Learning in Introductory Management Courses, *Journal of Management Education*, 36 (5), 614-635.
- Wright, A. L. & Hibbert, P. (2013), Special Issue: Threshold Concepts in Management Education: Research, Teaching, and Learning, *Journal of Management Education*, 37 (5), 734.
- Wu, C. (2005), *Total Supply Chain Cost Model*, MSc Thesis, Massachusetts Institute of Technology.
- Xie, D., Yu, L., Jiang, T. & Zou, Y. (2018), Distributed Energy Optimization for HVAC Systems in University Campus Buildings, *IEEE Access*, 6 59141-59151.
- Xu, Y., Erkoyuncu, J. A., Bankole, O., Goh, Y. M., Cheung, W. M., Baguley, P., Wang, Q., Arundachawat, P., Shehab, E., Newnes, L. & Roy, R. (2012), Cost Engineering for Manufacturing: Current and Future Research, *International Journal of Computer Integrated Manufacturing*, 25 (4/5), 300-314.
- Yin, R. K. (2018), *Case Study Research and Applications: Design and Methods*, 6 ed, Sage.
- Young, R. R., Swan, P. F., Thomchick, E. A. & Ruamsook, K. (2009), Extending Landed Cost Models to Improve Offshore Sourcing Decisions, *International Journal of Physical Distribution & Logistics Management*, 39 (4), 320-335.

Appendix 1 – Focus Group Invitation

E-mail invitations to the focus group sessions were sent to the targeted teachers and students. Below is an example of one of the invitations and the project description that was attached to the invitation.

Example of invitation

Dear colleagues,

I'm looking forward to meeting you tomorrow. To make you better prepared for what will happen, I here send you some information. I'd appreciate if you could read it through before we meet. Except from this e-mail (and the attached file) there is nothing you'll have to read to prepare for our meeting.

My research project

In the attached file, you'll get a brief presentation of my research project. In brief, my ambition is to:

- Describe the complexity and challenges with practical use of total cost analysis (TCA)
- Clarify the challenges students meet when learning TCA
- Give examples of educational activities that contribute to TCA learning

An important part of the research design is to study some higher education cases where students specialize in logistics management, and where TCA is discussed/used in some of the courses. Within these cases I speak with teachers and students, read through course documents etc.

The teacher focus group discussion

I will let you discuss rather freely. My role is not the traditional interviewer, putting questions for you to answer. Rather, I will act as a moderator to make sure the discussion keep within the desired frames. Focus will be on how you view TCA, which problems and challenges you see with practical use of TCA, what you regard to be difficult for students connected to TCA learning, and how you tackle this in the education.

To support my coming work, I will record the discussion. I suppose it goes without saying, but your participation is of course voluntary.

Other parts of the "Hanken case"

- **Personal interviews/discussions with some of you**, to enable deeper discussions, concerning e.g. specific cases you work with in your courses. We'll talk about this when we meet, and arrange meetings if appropriate.
- **Looking through course material with TCA connection. This could be lecture slides, case descriptions, exercises etc. If you could provide me with such material, I'd be grateful.**
- **Looking through master's theses.** If possible, I would like to scan through some master's theses to see if and how TCA problems is treated by the students.
- **Focus group discussion with students**, to catch the students' view of TCA

How I will use the material

All data I collect will be analyzed, and appropriate parts will be used in my dissertation. I will let someone from you read through parts that describe Hanken in order to get the facts correct.

I also plan to invite all participants from the different cases to a workshop, where I present preliminary results and open up for a joint discussion. Dates for this is not yet decided.

Welcome!

*Björn Oskarsson
Assistant Lecturer
Div. of Logistics & Quality Management*

Challenges with Total Cost Analysis

- for practical execution and for education

Background

Changes will often lead to an increase of some costs and a decrease of others. Therefore, the *total* cost effect should be regarded when comparing different alternatives of action.

Describing the principles is easy, but practically performing the analyses is associated with a number of challenges. Within logistics, total cost analysis is regarded an important cornerstone. However, literature does not give much support when it comes to practical use. This makes it hard for Higher Education Institutions to prepare students for total cost analysis in their future careers.

Purpose & Design

The project aims at identifying important challenges/problems at stake when practically performing total cost analysis, and to exemplify how education can be designed and executed to support student learning.

Extensive literature studies will be performed, as well as interviews with teachers and students at some Higher Education Institutions with a comprehensive education within logistics.

Expected result

The project is supposed to result in:

- A clarification of the challenges connected to performing total cost analyses in practice.
- An indication of what students regard to be especially difficult when learning total cost analysis.
- Good examples on how total cost analysis learning can be supported in higher education.

Time plan

The project was started in spring 2017, data collection is performed during 2018, and the project is planned to finish during 2019, resulting in a PhD Thesis.

The project is performed by:

Björn Oskarsson,
PhD Student;
Assistant Lecturer
in Logistics Management

Empirical data will be collected at the following Higher Education Institutions:

- Chalmers University of Technology
- Hanken School of Economics
- Lund University
- Linköping University

The project is in part sponsored by the Family Knut & Ragnvi Jacobsson foundation.

Appendix 2 – Request for complementary information

Following the visits to the case universities, I asked all the teachers participating in focus groups or individual interviews to send me supplementary information by e-mail. I asked some other teachers for information about the courses they were responsible for. Example of the e-mail sent out to the teachers is given here.

Request to other teachers for specific course information

Dear xxx,

As part of my PhD project, I visited Hanken late October to speak with some of the teachers about challenges with total cost analysis (which I somewhat simplified define as comparison of all relevant costs connected to different alternative of action).

At present, I'm working on a description of the "package" of your courses within Logistics and Supply Chain Management, and part of this is to give a short view on how total cost related aspects are dealt with in different courses. In the course "xxx" which you run (correct me if I'm wrong), such cost aspects might well be included, but from the official course documents I can't see whether this is the case.

Does the course include aspects of total cost analysis? If so, could you tell me a little bit more about this (or send some relevant course material), e.g.: Is it covered on lectures/on seminars? Is it included in student exercises? Does the course literature deal with it?

Thankful for your input, best regards,

*Björn Oskarsson
Assistant Lecturer
Div. of Logistics & Quality Management*

Request to the respondents for complementary information

To be noted: The follow-up meeting mentioned in the following e-mail did not take place. Despite planning the date in cooperation with the contact persons, I was only able to recruit a few respondents; therefore, the meeting was cancelled.

Dear colleagues!

Except for some complementary information I've now finished my data collection at the different Higher Education Institutions, i.e. Hanken (Helsinki), Chalmers (Gothenburg), Lund University and Linköping University. During the spring period I will spend much time working on my dissertation. I hereby provide some information about the follow-up meeting I've told you about, and concerning the case descriptions, where I would like some complementary information from you. Please reply to this e-mail by filling in marked fields below. Note that I would like to get information from you even if you can't attend the follow-up meeting.

Follow-up meeting

As promised, I invite all teacher respondents to a follow-up meeting. I will present some preliminary results based on my literature and case studies, followed by discussions about challenges with, and education about, total cost analysis. More details will come in due time.

The meeting is planned for Tuesday April 16th approx. 10 am to 3 pm at Linköping University. I hope many of you will be able to come and would now like to get an advance notice from you.

Follow-up meeting April 16	I hope to be able to attend		I will probably not be able to come	
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Case descriptions – complementary information

As respondents, you will be treated anonymously, but for each case I will give a collective description of the respondents' background and experience in the field, including how well the different courses are covered by the respondents. To be able to give this description, I need some information from each one of you. For some persons, I think I have sufficient information, but to be sure I'd like you all to provide me the following information. Please fill in the grey fields where suitable. If you want to add comments, feel free to do so where you consider it relevant.

Years as logistics teacher:	Hanken		Total	
------------------------------------	--------	--	-------	--

I have experience from total cost analysis in companies/organizations (Yes/No)	
---	--

I am / have been director of studies, program director or similar, with responsibility for the logistics courses (Yes/No)	
--	--

I have created educational material dealing with total cost analysis (Yes/No)	
--	--

Past or present experience from the logistics courses (mark with a cross in suitable fields)

Course	Examiner/responsible	Actively participating
Logistics Management		
Operations Management		
Sustainable Logistics		
Supply Chain Management		
Supply Chain Strategy for Sustainability		
Humanitarian Logistics		
Degree Project - Master's Thesis		

Thanks for your cooperation and best regards!

Appendix 3 – Total cost literature review

The procedure followed for searching and selecting literature about total cost analyses is shown here, together with the outcome.

Database search

Search engine and search procedure

UniSearch (available via Linköping University Library) includes a large number of relevant databases (ASP, BSP, Scopus, Web of Science, etc.).

Various ‘total cost’ phrases (see search result table below) were tested in the ‘Title’ OR ‘Abstract’ field. If there were too many matches, the search was limited to ‘Title’ only and in some cases to ‘Abstract’ only.

The option ‘Peer reviewed only’ was selected. Except for this, there was no limitation concerning the type of source.

Selection procedure

First selection – removal of duplicates and non-understandable sources

Since UniSearch includes several databases, the same source can be found in more than one database. Moreover, a specific source might be found using different search phrases. For example, an article with ‘Total Cost of Ownership’ in the title, and ‘Total cost model’ in the abstract will render a match for both these search phrases. Only sources written in English, German, Swedish, or other Scandinavian language were included.

Second selection – reading abstracts and checking availability

The abstracts were read to check if the source matched the following inclusion criteria:

- ‘Total cost’ does refer to monetary aspects
- TCA is central (if treated too vaguely or peripherally, the article was excluded)

In addition, it was checked whether the source was electronically available. If not, it was excluded (However, if a non-available article was deemed to be highly relevant, it was included, and a paper copy was ordered). All remaining sources were entered into a spreadsheet (example shown below).

Third selection – reading the full text

The full text was read to check at least one of the following inclusion criteria was fulfilled:

- Describes or defines total cost analysis
- Addresses how total cost analysis is used in practice
- Describes difficulties/challenges connected to total cost analysis
- Addresses educational/pedagogical aspects on total cost analysis

For all sources remaining, notes were entered into the spreadsheet describing the most interesting aspects. For the excluded sources, the reason for exclusion was entered. An extract from the spreadsheet is shown in the figure below.

Source				Context		Description
Author	Year	Title	Journal	Subject field	Specific area	Major content of relevance for my purpose
LeKashman & Stolle	1965	The Total Cost Approach to Distribution	Business Horizons	Logistics	Distribution	An early example of TC Analysis with a focus on practical application
Wildern & Isaacs	1998	Total Cost Analysis of Lead-Free Automotive Electrocoating	Design and Manufacture for the Environment	Environmental engineering	Manufacturing	A structured approach for TCA is presented, where costs are divided into different categories. A number of complexities are addressed. It is stressed that TCA does not give the final answer, but serves a decision support.
Liu et al	2015	Determination of Optimum Insulation Thickness of Exterior Wall with Moisture Transfer in Hot Summer and Cold Winter Zone of China	9 th International Symposium on Heating, Ventilation and Air Conditioning	Construction	Insulation of buildings	Excluded Life Cycle Cost with two parametres. No discussion about complexities.
Pan	2015	The Optimization Model of the Vendor Selection for the Joint Procurement from a Total Cost of Ownership Perspective	Journal of Industrial Engineering & Management	Purchasing	Supplier selection	Excluded Mathematical model. Practical use of the model not discussed.
Di Giuseppe et al	2017	Probabilistic Life Cycle Costing of Existing Buildings Retrofit Interventions Towards nZE Target: Methodology and Application Example	Energy & Buildings	Civil Engineering	Energy in buildings	Challenges are addressed Thorough sensitivity analysis

Search result

The table below shows the number of sources found and selected for each search phrase are shown.

Search phrase	Search field	Number of matches				
		Total	Pot. relevant	1 st selection	2 nd selection	3 rd selection
Total Cost Analysis	TITLE or ABSTRACT	134	134	94	39	21
Total Cost Calculation	TITLE or ABSTRACT	19	19	15	5	2
Total Cost Concept	TITLE or ABSTRACT	55	55	33	14	6
Total Cost Model	TITLE or ABSTRACT	158	158	109	27	23
Total Cost Approach	TITLE or ABSTRACT	67	67	38	16	8
Minimi*ing Total Cost	TITLE or ABSTRACT	309				
Total Cost Minimi*ation	TITLE or ABSTRACT	202				
Total Cost Minimi*ation	TITLE	20	20	8	3	2
Total Cost Optimi*ation	TITLE or ABSTRACT	26	26	18	2	1
Total Cost of Ownership	TITLE or ABSTRACT	>7000				
Total Cost of Ownership	TITLE	>1000				
Total Cost of Ownership [and] Model	TITLE	36	36	29	7	5
TCO	TITLE or ABSTRACT	>24000				
TCO	TITLE	>4500				
TCO [and] Model	TITLE	19	19	14	2	2
Total Cost of Care	TITLE or ABSTRACT	>800				
Total Cost of Care	TITLE	86				
Total Cost of Care [2013 --]	TITLE	30	30	23	6	4
Cost of Poor Quality	TITLE	46	46	27	4	2
Landed Cost	TITLE or ABSTRACT	26	26	14	6	4
Life Cycle Costing	TITLE	862				
D:o + "Challenge"	ABSTRACT	21	21	19	9	7
Cost estimation	TITLE	>9000				
Cost estimation [and] Method	TITLE	640				
Cost estimation [and] Method [2016 --]	TITLE	86	86	34	13	7
Cost estimation [and] Method [and] Challenge	ABSTRACT	6	6	5	3	3
Total			749	480	156	97

Complementary literature

In addition to the sources identified through the database search, additional literature was inspected because of either of the following reasons:

- Interesting reference found in one of the included sources
- Recommended by colleagues
- Previously known by me

These sources were assessed according to the procedure described above.

In addition, some logistics textbooks were examined (see Appendix 4). In total, the number of sources examined and selected are shown in the following table.

Examined sources	Total matches	Pot. relevant	Read	Selected
Logistics textbooks	41	41	28	28
Database search	749	480	156	97
Additional literature	52	52	52	46
Total	842	573	236	171

Appendix 4 – List of logistics textbooks

Textbooks published 2010 or later with ‘logistik’, ‘logistics’, or ‘supply chain’ in the title were examined to see how they addressed TCA.

Author(s)	Title	Edition (Latest)	Year	Publisher	Reviewed
Blanchard	Logistics Engineering & Management	6	2013	Pearson	Inspection copy requested, no response from publisher
Bowersox et al	Supply Chain Logistics Management	4	2013	McGraw-Hill	x
Chopra & Meindl	Supply Chain Management: Strategy, Planning, and Operation	6	2016	Pearson	x
Christopher	Logistics & Supply Chain Management	5	2016	Pearson	x
Coyle et al	Supply Chain Management: A Logistics Perspective	10	2017	Cengage	x
Crocker et al	Inbound logistics management	1	2012	Harlow	x
Glennsner & Femmerling	Logistics: Basics - Exercises - Case Studies	1	2013	Springer	x
Grant	Logistics Management	1	2012	Pearson	Inspection copy requested, no response from publisher
Grant	Logistics, Supply Chain and Operations Management Case Study Collection	1	2016	Kogan Page	x
Grant et al	Sustainable Logistics and Supply Chain Management: Principles and Practices for Sustainable Operations and Management	2	2017	Kogan Page	x
Harrison et al	Logistics Management and Strategy	5	2014	Pearson	x
Huang	Supply chain management for engineers	1	2013	CRC Press	x
Jacobs & Chase	Operations and Supply Chain Management	15	2018	McGraw-Hill	Inspection copy requested, no response from publisher
Jonsson & Mattsson	Logistik	3	2016	Studentlitteratur	x
Lumsden	Logistikens grunder	3	2012	Studentlitteratur	x
Mangan & Lalwani	Global Logistics and Supply Chain Management	3	2016	Wiley	x
Manners-Bell	Introduction to Global Logistics: Delivering the Goods	2	2017	Kogan Page	x
Mattsson	Logistik i försörjningskedjan	2	2012	Studentlitteratur	x
Murphy & Knemeyer	Contemporary Logistics, Global Edition	12	2018	Pearson	x
Myerson	Supply Chain and Logistics Management Made Easy: Methods and Applications for Planning, Operations, Integration, Control and Improvement, and Network Design	1	2015	Pearson	x
Oskarsson et al	Modern logistik - för ökad lönsamhet	4	2013	Liber	x
Richards & Grinstead	The Logistics and Supply Chain Toolkit	2	2016	Kogan Page	x
Rushton et al	The Handbook of Logistics and Distribution Management	6	2017	Kogan Page	x
Sanders	Supply Chain Management: A Global Perspective	2	2017	Wiley	x
Schönsleben	Integral Logistics Management	5	2016	Routledge	x
Storhagen	Logistik - grunder och möjligheter	4	2011	Liber	x
Wang & Gupta	Green Supply Chain Management: Product Life Cycle Approach	1	2013	McGraw-Hill	x
Waters & Rinsler	Global logistics / new directions in supply chain management	7	2014	Kogan Page	x
Wisner et al	Principles of Supply Chain Management: A Balanced Approach	4	2016	Cengage	x

Appendix 5 – Textbook protocol

Each logistics textbook was examined using a protocol. An example of a protocol is shown below.

Author(s)	Coyle et al (2017)	
Title	Supply Chain Management - A Logistics Perspective	
		Relevant pages
Overall - how is total cost considerations covered?		
Explicitly/implicitly; Thoroughly/superficially; Repeatedly/solitarily		
Cost considerations and cost/service trade-offs are influencing the text throughout the book, and a lot of examples are given. However, no chapter is specifically dedicated to the application and pitfalls of total cost calculations		
Are costs related to other aspects?		
Service; Environment; Others		
Cost-service trade-off		
Costs vs product value, weight density etc		
Supplier selection: costs vs other aspects		
Cost vs service (Lambert's model) (including cost of stockout - a "costification" of poor service)		
Distribution costs vs service		
Transportation costs vs service		
Transportation mode selection - cost vs performance		
Performance categories; SCOR model etc.		
Is a total cost model presented?		
Cost factors; How to calculate; Formulas		
Inventory management - cost trade-offs		
Plant logistics costs (example including a model)		
Sourcing: Landed cost - example of cost factors		
TC of manufacturing		
Lambert's TC model		
Trade-off between transportation and inventory		
Inventory management - cost factors, calculation models		
Distribution cost trade-offs		
Is the scope/context discussed?		
Defining alternatives to compare; Defining system boundaries; Time perspective		
Short run / Long run perspective		
EOQ under various circumstances		81-83 358-369
Is case-specific adaptation discussed?		
Relevant costs; Needed data; How to get data; How to handle bundled costs		
ABC costing referred to bundled costs (although case-specific adaptaion not discussed)		
Required data is not always available in the desired form		239-245 555
Is critical analysis discussed?		
Lack of data; Reliability in data; Effect of assumptions; Sensitivity analysis		
A number of pitfalls are listed (e.g. level of detail, accuracy of costs)		
An example of sensitivity		
Specific aspects of interest		
Motive for TC considerations (p. 13)		
List of pitfalls (p. 111)		

Appendix 6 – Protocol for total cost challenges

Tentative challenges found in the selected literature were documented in a spreadsheet protocol. The categories of challenges were successively developed during the research. The extract from the protocol shown here comes from the final version. Text in *italic* are quotations, the non-italicised text was written by me.

Source	Year	Title	1. Defining alternatives to compare	2. Defining the system	3. Making time considerations	4. Identifying other aspects of importance	
Asiedu & Gu	1998	Product life cycle cost analysis: state of the art review	An important step is the classification of the analysis objectives and the bounding of the problem such that it can be studied in an efficient and timely manner	In general: System boundaries The life cycle cost of a product is made up of the costs to the manufacturer, user, and society Different actors are interested in different parts of the TC.	The longer the time period (future), the more uncertain are the figures		
Sands et al	2017	Urine circulating tumor DNA (ctDNA) detection of acquired EGFR T790M mutation in non-small-cell lung cancer: An outcomes and total cost-of-care analysis			Life-time cost: Discounting of future costs. (short time horizon may ... disadvantage pollution prevention projects which often provide savings in the long term.	Medical effect	
Wildem & Isaacs	1998	Total Cost Analysis of Lead-Free Automotive Electrocoating			Life-time cost: Discounting of future costs. (short time horizon may ... disadvantage pollution prevention projects which often provide savings in the long term.	Revenue Benefits	
Source	Author	5. Selecting cost categories to include	6. Selecting calculation methods	7. Defining required input data	8. Retrieving input data	9. Processing input data	9. Processing ...
Asiedu & Gu		The cost categories considered will depend on the stage we want to use the model, the kind of information to be extracted ..., the data available as input ..., and the product ... Costs often vary from one setting to another ... gathering of specific ... data ... is encouraged.	Different approaches for estimating costs are presented		Lack of data/estimations	Monetization	Bundled costs The drawbacks of traditional accounting / overhead allocation is discussed. A.B Costing presented as a tool
Sands et al					Different sources might render varying data There was great variability in published data for the rate of little data available on liability cost savings	Averages, or weighted averages, used when input data vary. Historical data + indexing -> estimated current data	The goals of cost allocation are subjective and difficult to quantify. Statistics on past liabilities and predictive modeling techniques may be used to estimate liability costs for TCA.
Wildem & Isaacs		(some) costs are difficult to quantify and are usually excluded in traditional analyses, although they may be significant to decision making.					
Source	Author	10. Identifying uncertainties	11. Analysing the effect	12. Selecting presentation format	Interrelations between challenges	Comments	
Asiedu & Gu		Addressed, connected to the time horizon for which the costs are to be estimated			The cost categories considered will depend on the stage we want to use the model, the kind of information to be extracted ..., the data available as input ..., and the product ... See also comment to Challenge #1.		
Sands et al			Univar. S.A. for 15 parameters, Multivar. S.A.: 1000 simulations where all parameters were varied across their pre-protocol distributions	Useful diagrams illustrating S.A. Fig 2 and 4.			
Wildem & Isaacs			Discussed and performed A good presentation of the results on basis of the S.A.			"Although this TCA does not provide one absolute answer, it does provide important information to assist the decision maker in making a choice which is financially sound for the company."	

Appendix 7 – Literature review on education about total cost analysis

The procedure and the outcome of the literature search are described here.

Database search

Search engine and search procedure

UniSearch (available via Linköping University's library services) includes a large number of relevant databases (ASP, BSP, Scopus, Web of Science, etc.).

Various total cost phrases were tested in combination with various educational phrases (see search result table below). The phrases were applied in the 'Title' and 'Abstract' fields in combinations that rendered a manageable number of matches.

The option 'Peer reviewed only' was selected. Except for this option, there was no limitation concerning the type of source.

Selection procedure

First selection – removal of duplicates and non-understandable sources

Since UniSearch include several databases, the same source can be found in more than one of these. Moreover, a specific source may be found using different search phrases. For example, an article with 'Total Cost of Ownership' in the title and 'Total cost model' in the abstract will render a match for both these search phrases.

Moreover, those sources not written in a language I understand (English, German, Swedish, and other Scandinavian languages) were excluded.

Second selection – reading abstracts and checking availability

The abstracts were read to check if the source was matched at least one of the following inclusion criteria:

- Difficulties/challenges with learning about TCA,
- Teaching and learning activities connected to TCA, and
- Curricular aspects concerning TCA.

Third selection – reading the full text

The full text was more thoroughly examined to confirm the above inclusion criteria were satisfied.

Search result

In the table the number of sources found and selected for each search phrase are shown.

Search phrase 1	Search field	Search phrase 2	Search field	Number of matches				
				Total	Pot. relevant	1 st selection	2 nd selection	3 rd selection
Total Cost	TITLE or ABSTRACT	Educat* OR Teach* OR Pedagog* OR Learn* OR Student* OR Didactic* OR Understand*	TITLE or ABSTRACT	11 225				
Total Cost Analysis	TITLE or ABSTRACT		TITLE or ABSTRACT	25	25	14	1	0
Life Cycle Cost*	TITLE or ABSTRACT		TITLE or ABSTRACT	2 558				
Life Cycle Cost*	TITLE		TITLE or ABSTRACT	451				
Life Cycle Cost*	TITLE		TITLE	87	87	59	0	
LCC	TITLE or ABSTRACT		TITLE or ABSTRACT	2 187				
LCC	TITLE		TITLE or ABSTRACT	172				
LCC	TITLE		TITLE	41	41	25	0	
Landed Cost	TITLE or ABSTRACT		TITLE or ABSTRACT	152				
Landed Cost	TITLE		TITLE or ABSTRACT	4	4	2	0	
Landed Cost	TITLE or ABSTRACT		TITLE	4	4	3	1	0
Total Cost of Ownership	TITLE or ABSTRACT		TITLE or ABSTRACT	902				
Total Cost of Ownership	TITLE		TITLE or ABSTRACT	145				
Total Cost of Ownership	TITLE		TITLE	16	16	12	0	
TCO	TITLE or ABSTRACT		TITLE or ABSTRACT	1 517				
TCO	TITLE		TITLE or ABSTRACT	137				
TCO	TITLE		TITLE	33	33	23	1	0
Total					210	138	3	0

Appendix 8 – Essential aspects in constructivist teaching approaches

Based on literature previously known to me, recommended by colleagues, or found using a backward snowball search, 40 sources addressing constructivist approaches to teaching were examined to extract the essential aspects of constructivist teaching.

	Total considered	Pot. relevant	Selected after reading
No. of sources	81	41	40

Each source was entered into a spreadsheet protocol, and essential aspects were noted, and categorized. An extract from the protocol is shown below.

Author	Year	Learning approach	Authenticity	Familiarity	Ill-defined problems	Open-ended		
Leimings	2002	Case-based Consultancy Action	A case need not reflect a complete or accurate rendition of actual events (656)					
Palmer & Hall	2011	Project-based	Real world practical applications; Exposure to aspects of professional engineering (383)					
Perkins	2006			Problem solving with connection to the learner's world (38)				
Savery	2006	Problem-based Case-based Project-based Inquiry-based	Activities carried out must be those valued in the real world (14)		Problems in the real world are ill-structured. A key skill is the ability to identify the problem and then solve (13)	Complex problems without a single correct answer (12)		
Rein et al	2004	Authentic	May be 'real' or 'staged' (239) Designed to protect from elements that might impede learning (240) (which opposes to 'ill-defined...') Authentic for the learner and to the community of practice (241)	Authentic learning experiences should be personally relevant for the learner (235)				
Author	Year	Collaboration	Reflection & creation	Systems thinking	(Consultancy) projects	Business simulation	Role-playing	Teaching cases
Leimings	2002	Colleague supporting and challenging each other (538)			Problem situations within organizations; Learning arising through problem solving and the process (656)			Develop understanding of concepts and situations, then theory to practice (656)
Palmer & Hall	2011		Reflective skills are enhanced (358)	Project-based learning exposes students to the systems nature of engineering problems (358)	Realistic problems can be posed (358)			
Perkins	2006	Knowledge and understanding is co-constructed in dialogue with others (34)	It is not enough to be active. Learners need to create or recreate knowledge (34) Confront students with discrepancies in their initial theories (39)				To make students get into mindsets different from their own (40)	
Savery	2006	Essential reflects working life (13)	Challenge reflection to consolidate learning (14)					
Rein et al	2004	Gives opportunities to wrestle with ideas and understanding (249)	Reflective tasks to make students notice the knowledge they are developing (252)					

Appendix 9 - Case Descriptions

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1 Introduction

This appendix describes the four investigated cases. Sections 2-5 are dedicated to each of the four case universities. The first section provides general information to help the reader understand the structure used to present the cases. For details about methodological considerations about collection and processing of data, the reader is referred to Chapter 2 in the main text.

The case descriptions are divided into four sections, as shown in Figure 1. *The first section* gives general information about the case. First, information is presented about the logistics education provided at each university. Next, the logistics programs, profiles, specializations (or which label is suitable for the different cases) are presented, followed by short presentations of the course content. Finally, how Total Cost Analysis (TCA) is addressed in the courses are described, e.g., if students are actively working with cost calculations, or if costs are discussed more generally in relation to other decision factors.

A division is made between ‘core logistics courses’ and ‘logistics-related courses’ to limit the number of courses more thoroughly presented. Core logistics courses clearly deal with logistics management aspects (according to the CSCMP definition). This division has been made for each individual course, which implies that courses with similar names (but given at different universities) might be labelled as either ‘core logistics’ or ‘logistics-related’, depending on what is covered in the respective courses.

Figure 1. Sections in the case descriptions

The second section provides facts about the teacher respondents, to give the reader a sense of the teachers’ experiences:

- TCA-related practical experience from external organizations
- created TCA-related educational material
- (or have had) an overall responsibility for the logistics courses/programs.

Additionally, the teachers' experience teaching logistics is quantified. A division is made between short experience (up to 5 years), medium (5-10 years), and long (more than 10 years). After this, the teachers' opinions about challenges with planning and conducting TCA are listed. Here, the examples refer to teaching cases to better illustrate a challenge. However, aspects related to the teaching and learning of TCA are discussed in the concluding part of this second section.

In the third section, the student view is presented in a similar way as the teacher view. The information about the student respondents include a compilation of how many students took each course.

Section 4 presents information about how the master's theses addressed TCA challenges.

The ambition was to cover all four sections presented in all four cases. Due to problems in engaging student respondents at two universities, the third section is missing for these cases. In one of the cases, it turned out that TCA was not addressed in any of the examined master's theses, so the fourth section is missing for this case. Figure 2 shows the sections covered in each case.

Figure 2. Sections included in each case description

The first three cases have some similarities: they are all in Sweden and the logistics education described is given at technical faculties (i.e., to engineering students), mainly at the master's level. The fourth case is a Finnish university with business students working on a master's degree. Linköping University was chosen due to the good access to the respondents as it is the author's home university. The good access to information together with the author's pre-knowledge has made some parts of this case more thorough than the other parts.

2 Linköping University

Linköping University, based in Linköping, Sweden, has about 27 000 students, divided into four faculties, and four campuses. Logistics is almost exclusively part of study programs at the Faculty of Science and Engineering, where two departments offer logistics courses at Campus Valla (in Linköping) and Campus Norrköping. The case studied in this research is the logistics education at Campus Valla, provided by the Department of Management and Engineering, mainly by the Division of Logistics and Quality Management, which therefore is focused in the following text.

2.1 Logistics education – programs and courses

Logistics management courses are available for students following some of the 5-year engineering programs at Linköping University, which lead to a MSc degree¹. The first part of these programs focuses on mathematics, science, and various engineering subject. During the last two years of study, students are to choose a major track, a so called ‘master profile’. At two of these programs (Mechanical Engineering and Industrial Engineering and Management), Logistics Management is offered as a master profile. Some of the logistics courses may also be chosen by students following other programs, but in the following text the two master profiles are in focus. These two profiles are similar but not identical, due to different regulations from the program committees concerning size of the master profiles, and which courses are mandatory within the profiles. However, the available courses are more or less the same, and the profiles can therefore in practice be seen as similar. Below, these profiles, which together attract 50-70 students each year, are presented.

2.1.1 Mechanical Engineering program - Master profile in Logistics Management

At year 3 (i.e., at the bachelor’s level), the Mechanical Engineering (hereafter denoted M) students take a mandatory course focusing on production economy, including basic inventory management as well as an introduction to logistics. Another bachelor’s degree course of relevance here is Industrial Economics and Organization. The master profile at this program is on 90 ECTS² credits, consisting of 60 ECTS for courses, and a 30 ECTS

¹ Students are directly admitted to the complete 5-year programs: i.e., after having completed their bachelor’s thesis, they do not have to apply for the last two years at master’s level.

² ECTS is a European standard which stands for European Credit Transfer System. 60 ECTS equals one year of full-time studies.

master’s thesis³. In Figure 3 below, the courses included in the master profile are shown, together with other logistics-relevant courses.

Figure 3. Logistics Management master profile at the M program

All courses account for 6 ECTS credits, except the 12-credit course *Logistics Project*. As shown in the figure, the students take several courses in parallel. Each study year is divided into four periods, each one roughly 9 weeks long. To reach the 60 credits that in total is to be taken during a year, the students in average must take 15 credits each period, which in practice means two or three 6-credit courses each period. There are 14 courses included in the master profile, giving a total of 90 credits. Three of these courses are mandatory (bold framed in the figure), giving a total of 24 credits. Six additional courses must therefore be chosen within the master profile to reach the 60-credit demand of the profile. To complement the master profile and reach a total of 120 credits at the master level, the students can choose to take even more logistics courses.

2.1.2 Industrial Engineering and Management program

- Master profile in Logistics Management

Like the previously described program, the students at Industrial Engineering and Management (hereafter denoted I) follow a mandatory course in production economy at the bachelor’s level (year 2). This course includes basic inventory management, but no introduction to logistics. On the other hand, the students get a more solid management basis at the bachelor’s level compared to the M students, since they follow at least five courses in the area of Industrial Management.

The master profile at this program consists of 66 ECTS credits, including 36 ECTS courses, and a 30 ECTS master’s thesis. Figure 4 shows the courses included in the master profile, together with other logistics-relevant courses.

³ In addition to this, another 30 ECTS eligible courses must be chosen to reach the total of 120 ECTS required at master level.

Figure 4. Logistics Management master profile and logistics-related courses at the I program

9 courses (shaded grey) are included in the logistics profile, adding up to a total of 60 credits (*Logistics Project* is 12 credits, and all the others are worth 6 credits). At least 36 of these credits have to be taken to fulfil the profile requirements. Two courses (18 credits) are mandatory, and two are semi-mandatory, i.e. at least one of these two must be taken. In addition to the profile requirements, the students can choose even more logistics courses within the 120 credits that constitute the master.

2.1.3 Comparison between the master profiles

The Logistics Management master profile at the I program is smaller than the one at the M program (i.e., the I students are not forced to take that many logistics courses). However, the same courses are available for both groups of students and all these courses are given to a mix of students from both programs. At the I program, there are more program-mandatory courses during the final years of study, which means that the M students in practice have some more freedom in choosing some extra logistics courses. The number of students choosing Logistics management as their master profile has for some years been rather stable, between 60 and 80 students each year. Roughly 80% of these are I students, while approximately 20% belong to the M program.

2.1.4 Courses within Logistics Management

Short descriptions are here provided about the courses included in the master profiles (see Table 1 and Table 2). A division is made between Core Logistics Courses (in this case the ones included, mandatory or elective, in both Logistics Management master profiles, and Other Logistics-related Courses. In the coming sections, focus will be on the Core Logistics Courses, all of which are provided by the Division of Logistics and Quality Management.

Table 1. Core Logistics Courses in Linköping

Core logistics courses	
Basics in Logistics Management	Basic knowledge about important activities and processes within logistics. Mapping and analysis of relatively simple flows. Logistics contribution to an organisation's profitability. Focus on a single company.
Supply Chain Logistics	Deepened knowledge about logistics functions and from a supply chain perspective. Focus on supply and distribution structures.
Logistics Analysis	Training and application of analysing logistical systems. Quantitative and qualitative analysis for decision support.
Sustainable Logistics Systems	Logistics sustainability issues are introduced. Focus is on how logistics simultaneously can support a sustainable society and organisational profitability.
Logistics and Quality in Healthcare	Logistics principles and models are applied on flows and processes in the healthcare sector, to improve quality, efficiency and effectiveness.
Purchasing	Purchasing's role for an organisation's competitiveness. Strategy and organisation for effective supply of material.
Simulation in Production and Logistics	Basics about simulation, applied on production and logistics. Focus is on understanding the possibilities a simulation tool gives, and what is needed in form of pre-studies and input data in order to get a good output from a simulation.
Logistics Strategies	Logistics strategies, and their interplay with other business strategies. Models for strategic analysis of a company's total logistics operations.
Logistics Project	Application of theories, tools and methods from previous courses on real tasks in external organizations. Training in methodological logistics investigations.
Master's Thesis	Application and integration of knowledge from logistics courses and other parts of the program, mostly in collaboration with an external organization. Theoretical penetration in areas relevant for the project.

Table 2. Logistics-related courses in Linköping

Logistics-related courses	
Manufacturing Strategies	Manufacturing aspects connected to quality, delivery service, flexibility etc. Strategic choices concerning, e.g., capacity and production processes.
Lean Production	Principles of lean production. Lean tools and methods for mapping, analysis and evaluation, in order to improve the effectiveness in processes.
Operation Planning and Control	Principles and systems for materials planning and control. Methods for formulating, analysing and solving planning and control problems. The relation between production, planning and other functions in industrial companies.
Design and Development of Manufacturing Operations	Tools and methods for analysing manufacturing operations, with regard to lead times, inventories, customer orders etc. Value-based process improvement, e.g., with help from set-up time reduction.
Supply Chain Optimization	Planning, developing and realising optimization models of problems within logistics, production and supply chains. Common optimization models relevant for these areas. Advanced use of modelling tools.

2.1.5 Total cost analysis in the core logistics courses

TCA is present in all the core logistics courses, but to a varying extent. In some courses, TCA is clearly focused on and even is part of the expected learning outcome in official documents, while in other courses total cost considerations are something that come up in discussions even though they are not part of a major issue. This section describes how TCA is treated in the courses. Focus is on courses where TCA is a clear part of the course curriculum. The courses are presented in chronological order – i.e., the order that the students are supposed to take the courses. The information is gathered through informal discussions with the responsible teachers and by viewing course documents.

Basics in Logistics Management

Lectures introduce a basic logistics TCA model and the interplay between costs and customer service. These lectures are in line with the textbook used in the course as three of the teachers at the division are the authors of the textbook.⁴ In addition, a real application of TCA for a company's European distribution is presented. TCA is also discussed on a more general level, concerning total logistics costs in different industrial sectors.

In the major teaching case in the course, the students work in groups of 4-5 to solve a few tasks connected to a fictive bicycle producing company. One of the tasks concerns analysis of cost and tied-up capital effects from a suggested centralization of the distribution. Some assumptions are to be made by the students, but basically all relevant facts are available in the case descriptions. During seminars, teachers give guidance on how to work with TCA in a structured manner, and how to make the cost analysis in the specific tasks.

Another case deals with transportation route planning for a fictional assembly plant, where different routing options are combined with various delivery frequencies in a spread-sheet model. As part of the analysis, the total cost for each alternative is to be calculated.

A third case concerns a fictional pharmacy chain that is considering selling directly to consumers via internet and offering home-delivery. The focus is on delivery service, but as an add-on, the students should consider how their solutions principally will affect the company's total costs.

In a concluding seminar, some important issues (e.g., TCA) are repeated to help prepare students for the written examination.

⁴ Oskarsson et al. (2013), *Modern Logistik*.

Supply Chain Logistics

In a fictional case about sequencing incoming deliveries from suppliers to an assembly plant, students work in groups of 4-5. TCA is part of the task, but focus is rather on understanding the logistics system and the overall effect different solutions will have on the company's competitiveness. Cost data are readily available, so the cost part is not the major challenge for the students.

In another case, the students analyse different logistics solutions, first from a focal company's perspective and then from a supply chain perspective (i.e., with a widened system). Total costs are examined, but equally important is to regard the consequences on sales and revenue.

Logistics Analysis

In this course, methods and tools useful for performing logistical analyses are in focus. Concerning TCA in general, different TCA models are presented and discussed during a lecture. Two major theoretical areas associated with TCA are penetrated in the course. The first deals with Activity-Based Costing, a method for disseminating bundled costs, overhead costs, etc. and allocates them in a fair way to different objects (e.g., products or customers). Such allocation of bundled costs is sometimes needed to enable a proper TCA. After two lectures describing Activity-Based Costing, including concrete examples, the students work in groups of 4-5 students with a case where they use this method to allocate an aircraft engine manufacturer's materials handling costs to the different engines produced. Although adopted to fit a teaching case, all facts and data are provided by a real company. Literature is available as theoretical support⁵, and the students get help from teachers during tutoring sessions.

The second major theoretical area is inventory management, with a focus on modelling safety stocks. The interplay between service level and inventory costs then becomes a major issue. These issues are covered in the course literature.⁶ In a case about a fictional furniture producer, the students work in groups of 4-5 with the task to propose a suitable distribution structure, including whether to deliver directly to the end customers, where to locate the central warehouse, whether to outsource the warehousing activities, and which service level to offer the customers. The aim is to reach as high a profitability as possible, which means that revenues (depending on the service level), costs and assets should be considered. A problematic issue in this case is that there is an inevitable number of possible service levels, and therefore an inevitable number of cost (and assets and

⁵ Gerdin (1995), *ABC-Kalkylering*; Oskarsson et al. (2013), *Modern logistik*; Gunasekaran (1999) 'A framework for the design and audit of an activity-based costing system'; Stapleton et al. (2004), *Activity-based costing for logistics and marketing*.

⁶ Oskarsson et al. (2013), *Modern logistik*; Jonsson and Mattsson (2014), 'Lagerstyrning i hög- och lågpresterande företag'; Mattsson (2003), 'Några synpunkter på att reducera kapitalbindning'.

revenue) calculations that might be performed. The case is also designed to include some activities which do not really look like the typical ones shown in textbooks, in order to stress the fact that cost models must be adopted to the specific situation. Five seminars are given where the students present and discuss how to solve the task, with a teacher supporting the discussions. Three of these seminars are dedicated to the three most relevant cost factors in the case. Each group also gets individual tutoring during a specific session.

Sustainable Logistics Systems

The TC model is briefly discussed during a lecture. In small groups, the students work with a case where they are asked to recommend logistics solutions with a sustainability focus. The costs associated with the solutions should be properly addressed, but it is up to the students to decide how deep into TCA they go. The case as such is fictional, but they are supposed to make realistic cost assumptions, which leads many students to look for real data concerning e.g. investments in trucks, congestion taxes etc.

Purchasing

During lectures, the direct cost (i.e., the price) and the numerous indirect hidden purchasing costs are discussed. When dealing with supplier evaluation methods, Total Cost of Ownership (TCO) is one of the methods discussed, supported with literature⁷. As an introduction to the case described in the next section, the principles of TCA are introduced as the topic is novel for some students.

A case exercise, performed in groups of 4-5 students, specifically focuses on TCA. The fictional case company is about to select a supplier and has a few companies to choose from. The task is designed as a two-step exercise. In the case description, the decision situation as such is well described, but few much facts are provided. First, the students should consider which cost factors they find relevant to include in their analysis, how these are to be calculated, and which input data they need to make these calculations. In the first step, they hand in a compilation of the required data and receive a corresponding data set from the teacher (however, all requested data may not be available). During the second step, they use their data to perform calculations, analyse the results, and write all this in a report where they propose a suitable supplier. This exercise design creates a situation where all student groups have different data sets when performing their TCA. As a result of this design, the students will produce different results and therefore recommendations. This is supposed to reflect real TCA's, where it is often not obvious which cost factors to include and how to calculate the them. A follow-up lecture examines

⁷ Ellram (1995), 'Total Cost of Ownership – An Analysis Approach for Purchasing'; Kumar and Kopitzke (2008), 'A Practitioner's Decision Model for the Total Cost of Outsourcing and Application to China, Mexico, and the United States'.

the diversity of potential solutions and includes discussion as a form of collective feedback. In addition, every group receives specific written feedback on their reports.

Logistics Strategies

Strategical logistical decisions are discussed, including effects on cost. In a teaching case based on data concerning an outsourcing decision for a real company, students work in teams with qualitative analysis of the situation, including cost considerations.

Simulation in Production and Logistics

In one of the exercises in the course, the students build a simulation model of a logistic system. One of the aspects that is simulated is how the costs will be affected by changes in the logistics activities. It is rather clear which cost factors are to be included. A main challenge for the students is to make a good mathematical representation of the costs that reflect reality.

Logistics Project

In this course, the students work in groups of four to five members with a real task provided by an external organization. The students investigate a specific logistics task by mapping and analysing the present situation, designing possible solutions, and analysing these solutions, and presenting their proposed solutions to the organization. As the tasks assigned by the organizations span over the logistics field, the student groups might focus on different issues. In some cases, cost reduction is the main issue, while in others, costs are not in focus. However, in a majority of the projects, costs are considered in one way or another, for example, by evaluating the cost effects of different solutions.

The lectures focus on how to methodologically perform logistics investigations. As TCA is covered in previous courses, it is not addressed directly. However, for projects where costs are in focus, the students search for literature that deals with TCA to broaden their exposure to how the literature treats TCA. They also need to make active choices concerning how to perform TCA in their specific case such as how to choose which cost factors to include in their calculations. Each group has a faculty supervisor who supports the students along the project. In projects, where TCA is in the forefront, it comes natural that TCA discussions will be part of this supervision.

Master's thesis

The Master's thesis has many similarities with the Logistics Project course. In most cases, an external organization provides a task for the students to work with. The main differences are that the students work in pairs (sometimes individually) an increased demand of methodological rigor, and that the tasks are more complex and the investigations more thorough. No teaching is scheduled, but a faculty supervisor supports

the students. As in the Logistics Project course, cost aspects are dealt with in most projects, and rather frequently TCA is a central issue.

2.2 Teachers' thoughts concerning total cost analysis

A focus group discussion was held with five of the involved teachers and individual interviews with two of the teachers. Altogether, the research engaged six teachers, four men and two women, with thorough experience in the field. These respondents together cover most of the core logistics courses, however not all of them (see Table 3 and Table 4 for details).

Table 3. Number of Linköping teacher respondents with certain experience

Teaching experience	< 5 years	0	5-10 years	1	> 10 years	5
Overall responsibility for the logistics courses (director of studies, program director or similar)						2
Practical experience from TCA in companies/organizations						3
Have created educational material about TCA						4

Table 4 - Number of Linköping teacher respondents with experience from the respective courses

Course	Examiner / responsible	Actively participating
Basics in Logistics Management	3	5
Supply Chain Logistics	1	3
Logistics Analysis	2	3
Sustainable Logistics Systems	1	3
Logistics and Quality in Healthcare	0	0
Purchasing	0	5
Simulation in Production and Logistics	0	1
Logistics Strategies	0	0
Logistics Project	4	6
Master's Thesis	4	6

The term *TC Analysis* caused some debate during the group discussion. Does it refer to the comparison of costs between alternatives, the wider analysis based on such comparisons, or the more complete process from defining the situation to be analysed until suggesting a recommended solution? However, looking beyond the term TCA, the teachers seemed to share the views about important aspects of logistics investigations, and the role of cost considerations in such investigations.

In the following sections, the essence from the discussions and interviews are compiled. Challenges with TCA are addressed and some thoughts regarding teaching TCA are presented.

2.2.1 Challenges with conducting total cost analysis

One teacher suggested that the major challenge with TCA, as with logistics in general, might be connected to application of knowledge, rather than with knowledge per se:

“[The difficulties are] not the theories and models, but to go out in a reality-like setting and apply these models.” (Linköping teacher 1)

However, a number of more specific challenges came up during the focus group discussion and the individual interviews. In Figure 5 a concept map shows a compilation of the challenges discussed during the focus group session, where the ones in black were mentioned spontaneously, while the red ones came up after some extent of prompting from the moderator.

Figure 5. TCA challenges mentioned during focus group discussion with Linköping teachers

The challenges raised during interviews and discussions are briefly described below. The headings used are in line with the challenges defined in this thesis (which do not fully correspond to the labels used in the concept map).

Defining alternatives to compare

In most of the teaching cases, the alternatives are given from the start; however, there are exceptions. In the Sustainable Logistics Systems course, the students are asked to come up with their own scenarios, and in Logistics Analysis course the number of alternatives is infinite, so the students have to decide which ones their analysis should focus on. When working with real problems, in the Logistics Project course and in the master's thesis, it is often up to the students to define alternatives, for example, to suggest some possible

distribution structures for a company, and then analyse the cost effects of implementing these solutions. Sometimes the relevant alternatives are obvious, but more frequently defining the alternatives is challenging. The alternatives generated should significantly impact the major cost factors, a variable many students ignore early in their work. As the students normally lack experience with these issues, they will have a difficult time selecting an alternative that will significantly affect the major cost factors.

Defining the system

The system boundaries limit what to include in an analysis. Therefore, system boundaries are important, but hard to define. A large system is difficult to manage; a too small system will not incorporate all relevant aspects that are affected.

One teacher stressed that in real settings, time pressure makes the investigators rush through the TCA and therefore not 'wanting' to make the system big enough. There might also be a lack of incentive for individuals to take a holistic view, since they will not get a reward for saving money somewhere else in the company, if there are no immediate savings in their own department.

Another issue raised was the question of how to handle different actors affected by a logistics change. Making a separate TCA for each actor will result in an outcome unlike a joint TCA. That is, TCA outcomes depend on how the system is defined or from whose perspective the system is viewed. With several actors involved, it will also be a matter of how to divide costs and revenues between them.

Making time considerations

The change-over costs (i.e., the 'investment' needed to switch from one state to another) were discussed. These costs might in some cases be rather big, and therefore important to consider for a decision maker. However, since most cost categories in a TC analysis are on a yearly basis, the inclusion of change-over costs requires choosing a time horizon over which the cost is spread out.

Identifying other aspects of importance

There is a consensus among the teachers that costs alone should not be the basis for a decision. In one way or another, the output of the logistics system is important. However, students tend to neglect other aspects unless they are guided to do otherwise.

Customer service was raised as an almost inevitable aspect to consider, either by setting the service level to a certain value and then calculating the cost effects, or by evaluating costs as well as service effects of the different alternatives. Certain logistics solutions might lead to cost effects as well as service effects, which in turn might affect sales, and

ultimately the revenue. These contingencies are rather complex to model as clear connections between service and costs are often hard to quantify.

Environmental aspects connected to the logistics solutions are another aspect to consider alongside a TCA. Like revenues, these aspects are often difficult to quantify. However, models for quantifying environmental costs do exist and are used in teaching cases in one of the courses. A certain challenge here is that such costs are societal rather than organizational, which raises the question of how to handle this from a company perspective.

During the discussion, it was suggested that rather than focusing on TCA, teachers should talk about TCA as part of evaluating a 'logistics solution'. Perhaps it would be more appropriate to talk about 'Total Value Analysis', including costs, revenues, as well as future competitiveness.

Selecting cost categories to include

As mentioned above, selecting relevant cost categories for a specific case is challenging, as it requires a good understanding of the system. A specific issue brought up in the group discussion was that costs that are not expected to change between the alternatives can be excluded if the purpose is to investigate how the alternatives differ.

In addition, when deciding which alternative to recommend, it is often unnecessary to include each and every cost that will change. It might be sufficient to focus on a limited number of cost factors (the big ones), since the minor ones in reality will not have any impact on the outcome of the TCA. This way an analyst more efficiently reaches a sufficiently good answer. However, this requires an ability to roughly judge the magnitude of different cost factors, which might be difficult, especially for a novice TC analyst.

Identifying calculation methods

Inventory carrying cost is mentioned as being rather problematic for the students to understand, since it includes real costs as well as opportunity costs. Especially when connecting a change in this cost factor to the profitability with help of the DuPont model, this creates problems. When doing this, it is not enough to have a carrying cost percentage; you must also know how it is built up by different components.

Sometimes costs must be calculated on different 'levels', which students often find hard to handle. As an example, the cost for picking goods in a warehouse might partly depend on the number of orders and partly on the number of order lines. Weight and volume of the goods are other factors that might also influence the cost.

Defining, retrieving, and processing desired input data

In the teaching cases, data are most often available, although these data might not match what is needed to 100%. In one of the courses, however, the students have to create a case-specific TC model and ask for the necessary data, something they find difficult. When performing company-based projects, the students must define required data as well as collect this data. Retrieving good data at companies can be a very cumbersome task because of insufficient measurement, lack of accessible reliable data etc. One teacher addresses this issue by telling students that:

"[You] must be 'total cost detectives' at the company when you get out. It's not enough just to ask. You must actively work with it yourself to get to know."

(Linköping teacher 3)

If starting with system-generated data and not understanding these data very well, there is a risk that these data will not reflect what is sought. Understanding what happens in the processes gives students and professionals a better chance to understand how to use the available data.

A challenge regarding data collection is to decide upon the extent of data to collect for a certain parameter. Single measurements rarely provide a representative value. It is common to use averages from a certain period, but this neglects variations, which leads to an underestimation of costs. The time period from which data is taken is also of interest, since different periods of time might be more or less representative and relevant for the TCA.

Another challenge is how to treat bundled costs. Transportation costs are given as an example where companies often only have overall costs, but do not know the cost of e.g. specific products. Activity-Based Costing is suggested as a tool for 'disassembling' bundled costs to create useful input for TCA.

Critical review

The way insecurities are dealt with is by making a sensitivity analysis or a 'what if' analysis. As these tools investigate the effect on the TCA result by changing input parameters, the focus should be on the significant and most uncertain parameters. Sensitivity analysis is seen as an important add-on or complementary tool to TCA.

Some other aspects were also mentioned concerning critical review: to check whether the models/formulas used are valid; whether the calculations are correctly performed; and how uncertain the result is, given the uncertainty in various input values. This latter point is a kind of 'numerical analysis' which requires a certain level of mathematical modelling.

How much effort critical review should be given is another issue. For big cost factors it is probably crucial, but for small ones, probably not.

2.2.2 Aspects on teaching and learning total cost analysis

TCA vs. logistics understanding – where to start?

To make reasonable cost calculations, the students must have an understanding of the logistics operations and activities.

The teachers express that especially when the students have a poor understanding, they tend to focus too much on the costs as such. They look for and stick uncritically to cost models and formulas presented in lectures or in textbooks without critically considering the system they are analysing. One teacher expressed that:

“[The students] go too quickly into costs, without really considering how the system works. ... Their result is ‘the cost difference is...’, instead of saying ‘this is a better system, because... and the cost difference between them is...’ “
(Linköping teacher 2)

Students who understand the principles of TCA and have a good understanding of the system to be analysed, might not need a TC model at all. However, the students’ general pre-understanding of logistics activities when entering the introductory course is regarded to be rather low, which makes it difficult to teach by applying TC discussions to real logistics systems. This ‘system understanding’ – i.e., the understanding of the logistics activities and their interrelations– is regarded to be more difficult for the students to learn than the TCA per se:

“I think this is a major threshold. I feel that standing in front of a hundred students I might scare them away if I’m too abstract. ... They don’t visualize it the way I do when two different logistics systems are to be compared. ... They have a hard time understanding what a logistics system is.” (Linköping teacher 3)

With ‘logistics understanding’ as a potential threshold for learning TCA, it was discussed whether enough logistics understanding could be reached before TCA is introduced in the courses. At present, TCA is introduced very early in the introductory course during lectures and in teaching cases. When working with these TCA-related teaching, the students get the opportunity to practice TC calculations and in parallel improve their understanding of the logistics system, activities, and operations, as these are things that must be discussed in connection to the cases.

Focusing on TCA, there is a risk that the students do not reflect on the system they are to analyse. If costs are the priority for the students, the system and interrelations have lower priority and might receive insufficient attention. Moreover, as costs are principally rather easy to quantify, the students tend to rely on the result as being ‘the answer’. Although this result might be based on assumptions, they tend to regard it as robust:

“They feel that this cost they have calculated, there is some truth in it. That the sales might increase, that the assortment might change, that there might be obstacles that might crash this solution, I think they regard such aspects too vague to abandon the solution. So, the fact that they reach a concrete figure, might create a ‘false robustness’.” (Linköping teacher 2)

During the group discussion, the issue was raised that it might be wrong to start with teaching TCA, as this takes the focus away from understanding the logistics systems that are to be analysed and compared. It was argued that focusing on logistics understanding from the start also would limit this kind of over-reliance on cost figures expressed in the quotation above. As expressed by another teacher:

“The cost is a consequence of having used a resource, which is a consequence of having performed an activity. And this is done because we have taken something through to a process, a flow etc. ... So variable costs occur because of what we do. Therefore, it’s crucial to focus on what we do in order to understand how things work and are connected to each other.” (Linköping teacher 1)

However, other teachers believe that working with logistics costs is a way of making students interested in the activities connected to the costs and that TCA in several courses is discussed in combination with other things, like system definition. In the introductory course, logistics activities are explained in lectures to give the students a pre-understanding, which hopefully helps them when they analyse the costs of the activities. One teacher noted that in the course Supply Chain Logistics there is a case where TC calculations are important but where the learning is about logistics mechanisms rather than costs as such. In a case in another course, an understanding of the relevant activities is necessary for proper allocation of the logistics costs to different products.

The TC model vs. more general TC understanding

The TC model by Oskarsson et al. (2013) (consisting of five cost categories) is used as a basic tool, a starting point to describe and discuss TCA with the students. As the students pass through the courses, more and more complexity is added to the TC discussions. At the end of their studies, the students are supposed to be able to create cost models fitting the specific situation they are facing. When students are working with projects and master’s theses, the teachers expect them to search the literature for alternative presentations of TC models and relevant cost categories.

TC models are seen as helpful tools for performing TCA. However, as with any tool, the tool is only as good as the user of the tool – i.e., the TC model is only a starting point for a TC analysis. There is a consensus among the teachers that a general TC *understanding* is more important than mastering a TC *model*. The teachers also agreed that a pre-defined

TC model has too defined ‘cost boxes’, and that the students tend to regard these boxes as ‘the truth’, thereby limiting their critical thinking. As one teacher expressed:

“If viewing it principally, as a way of thinking, we’re interested in the total cost, no matter how we label these costs.” (Linköping teacher 1)

Another teacher noted that as a student he/she regarded cost factors as abstract constructions to be memorized rather than understood. These models and concepts (like warehousing costs) might be necessary, but they might also act as a filter against understanding the TC thinking. According to another teacher, students do understand the logic that a proper TC understanding is necessary for adopting a certain TC model to a specific case, but they nevertheless stick to the model because it is easier and gives them a sense of comfort and security.

However, there is not a consensus on how to tackle this problem. While some argue that teaching focus should be more on principal understandings of how to work with TCA (combined with understanding of logistics systems), others argue that the TC model is a good way to enter into TC thinking. Two “model first” voices from the group discussion:

“It’s difficult to show them everything. There’s so much you’d have to describe to make them grasp it all. The TC model is a tool to view the world, to trigger thinking about ‘What have we got here?’. I still think it’s a point with it - ‘this is the tool which we use to view the world’. It might be a bit more boring, but still it helps them on their way towards understanding.” (Linköping teacher 4)

“It’s when using this tool, you really reach this understanding of reality.” (Linköping teacher 5)

Another teacher expressed a more “understanding first” view:

“What is important? It is to stress the understanding, that it is about total cost analysis, it’s a principal way of viewing it. It will by definition be situation specific, and therefore you need to make a flow description to understand which parts that really are crucial to consider. ... A risk with models is that they might lock in the students and make them miss this step [of understanding].” (Linköping teacher 1)

Connected to the students’ work with TC-related teaching cases, the importance of discussions is stressed by the teachers:

“I would say that it’s during discussions [we can make them learn TCA]. The thing is that the students must work with it, face different problems and challenges.” (Linköping teacher 6)

Yet another teacher reports on having tested different ways over the years, starting with TC model, or with more general TC discussions. From his/her experience, for students

with low logistics pre-understanding, it is preferable to start the teaching with the TC model.

Principal reasoning vs. correct calculations

The teachers agree that good principal understanding and reasoning is more important than getting the figures exactly correct. Correct calculations, of course, are important when performing TCA, but the teaching is more focused on reasoning, as this forms the ground for the calculations to be based on proper assumptions, relevant data, etc. A consensus also exists that the students in general put much more focus on the calculations as such. According to the teachers, the reason for this is that the students from previous courses are used to working with cases and exercises where correct calculations can produce ‘the correct answer’ and where the answer as such is more important than the process leading to that answer. Teachers also noted that students tend to calculate everything, ignoring the relative importance between different costs. It is understandable, however, that students want to include everything – they want to show what they have learned. One teacher raised the issue that it is also a matter of how we assess their work:

“Say that seven cost factors can be calculated, and correct calculations on all factors gives a score of seven. But if you’ve made a prioritization that ... three factors the important ones, and you only calculate these three, could you then be awarded with seven points? You’ve only calculated three. Is the prioritization worth four points?” (Linköping teacher 1)

This teacher concluded that of course we could hand out seven points, provided that the prioritization is well performed. Another issue is that the students must know and trust the teacher’s intentions. Otherwise, they might still think that they had better include everything. The same teacher continued:

“This is connected to how the task is designed. ... If we want them to calculate all seven, the parameters should be set in a way that all seven factors are relevant. If we want them to make prioritizations, then the parameters should be set to support this.” (Linköping teacher 1)

Another teacher expressed that ‘we might not really live as we learn’:

“We do stress the reasoning, that they will have to make assumptions, and that solutions can be reached in different ways. But when the students ask for feedback on [calculated] figures, we do review these ... and after all, this review tends to be rather cost focused.” (Linköping teacher 4)

This is a trap that teachers may fall into. However, quantitative data and calculations are viewed as important as they are concrete characteristics to base discussions on.

Another issue raised is that there are ‘levels of correctness’. In some situations, rather rough cost estimates are sufficient, whereas in others more detailed calculations are necessary. In this context, critical review was raised as important, with the opinion that this is not really taught in a structured way in the courses.

Yet another thing brought up as a challenge (see section 2.2.1 in this appendix), and which the teachers admitted is more or less neglected in the courses, is the change-over costs when switching from one state to another.

TCA vs. other important aspects

Costs are not treated as the single important decision factor in the courses, but it is more focused in some courses than in others. One teacher expressed that in the course Logistics Analysis several aspects are connected – e.g., costs, service/revenue, and profitability. The learning progression is then not specifically about TCA, but a progression from a wider logistics understanding perspective.

While cost calculations in e.g. master’s theses often are concrete and quantitative, the effects on service are often restricted to qualitative assumptions. However, in some of the teaching cases, the service is made quantifiable, to enable students to calculate the effects on the revenue. Another aspect that is difficult to quantify is environmental impact. However, in the course Sustainable Logistics, a model for quantifying environmental costs is used in one of the teaching cases.

Students sometimes emphasize costs but neglect other aspects because the teachers focus on TCA. One teacher expressed a self-critical view concerning this:

“... not enough time [is devoted to] on the continuation, sensitivity analysis ... how to combine quantitative and qualitative results. It’s rather that you don’t continue and develop, like ‘Ok, now we’ve done a total cost analysis, how do we proceed?’” (Linköping teacher 2)

One teacher wanted to offer students a palette of tools related to TCA where sensitivity analysis is one of these tools. An understanding of such a ‘mega-model’ containing TCA and other important aspects would help the students advance their understanding. The idea is not to actually construct a mega-model, but to foster holistic thinking. It was suggested that these mega-model aspects are probably addressed when the complete master profile is considered, but that these aspects are not integrated. To encourage deeper, more integrated understanding, one teacher suggested that teachers summarise TCA to the students at the end of their studies and show them how TCA have been addressed issues throughout the courses and how TCA connects to other kinds of analyses they have experience with.

Cases as a pedagogical tool

Teaching cases are used to a high extent. The general idea among the teachers is that the cases are realistic enough to give an authentic feeling even though they are fictional or adapted to fit a teaching situation. Almost all cases used are performed in teams, which encourages discussions between students. The cases are supposed to be challenging, forcing the students to face different difficulties associated with TCA, where the teacher's role is both to put them in problematic situations and help them out again:

“At first, [the problem] might look rather simple, but when getting deeper down it becomes more complex, but this is where we lead them. ... and then all these questions come. But then you must somehow get up again, and that's when we [discuss] assumptions, estimations etc., that it's OK.” (Linköping teacher 4)

The teachers' view is that this way of working encourages the students to be more autonomous, taking responsibility for their work and their learning. One risk, however, is that ambitious students will go too far in wrong directions while working a lot between tutoring sessions.

Someone expressed concern that this case-focused way of working might not be appropriate for those students with poorer pre-understanding. However, the teacher responsible for the second course in the master profile reported that the students from the introductory course in general have a good understanding of TCA, and approach new cases in a good manner, e.g., when discussing relevant costs in specific situations.

Another issue brought up was that students should be aware of how parameters/input data are designed in teaching cases. If teachers want students to make good choices concerning what to include in the analysis, this should be rather clear from the data, that some factors are less relevant than others. It is also important to guide them, so they understand they are expected to do this kind of prioritizations.

2.3 Students' thoughts concerning total cost analysis

A focus group discussion was held with six students, three men and three women, following the master profile in Logistics Management. Each of these students had taken between six and eight of the core logistics courses, and each of these courses is covered by at least two of the respondents, as shown in Table 5.

Table 5. Number of student respondents having followed the core logistics courses

Course	No of students
Basics in Logistics Management	6
Supply Chain Logistics	6
Logistics Analysis	6
Sustainable Logistics Systems	3
Logistics and Quality in Healthcare	2
Purchasing	3
Simulation in Production and Logistics	5
Logistics Strategies	6
Logistics Project	4

The following sections describe the relevant parts of the discussion, starting with various challenges connected with TCA, followed by aspects regarding teaching and curriculum.

2.3.1 Challenges with conducting total cost analysis

Several challenges were discussed during the session. The concept map below (Figure 6) illustrates these challenges. The black boxes and lines indicate ideas spontaneously mentioned, and the red ones indicate ideas to some extent prompted by the moderator.

Figure 6. TCA challenges mentioned during the focus group discussion with Linköping students

The challenges mentioned during the discussion are briefly described below. One student found it difficult to plan for everything that might happen. This is a general problem for

investigations about TCA or any other topic. However, some of the challenges discussed below certainly have to do with planning.

Defining the system

The students agree that defining system boundaries is both important and difficult. To make a case-specific TCA and to choose relevant cost factors, students must understand which parts (stocks, activities, etc.) of the total system will be affected and decide which parts should be within the boundaries. Since it is difficult to understand how big the effects will be for all the parts, it is also hard to decide what to include. No matter how the boundaries are drawn, there will always be some effects outside these boundaries.

Identifying other aspects of importance

Several aspects in addition to costs were mentioned as being relevant: customer value, time reduction, sustainability, and congruence with the organization's strategic directions. It was argued that profit (built up by costs, sales, service, etc.) always should be in focus rather than costs. Someone objected that for non-profit organizations, this is certainly not true. In such cases, sustainability or social consequences might be more relevant decision factors. All agreed, however, that costs are an important aspect to consider in almost all organizations. However, cost might not be the aspect that should be in focus:

"You often reach a cost figure and then run a discussion about other aspects. But it could be the other way around, that other aspects are the important ones, and then you say that costs might be discussed." (Linköping student 1)

Selecting cost categories to include

This challenge was the one most discussed by the students. The need to choose relevant case-specific cost categories was identified as was the difficulties in doing so. Some aspects to consider concerning inclusion of costs were suggested:

- estimated size of the cost factor
- estimated effect the cost factor has on the decision
- time available for the investigation
- availability of necessary cost data

The students assumed that in real situations there probably never will be time for making a 'perfect' TCA. One student talked in terms of effectiveness:

"For the company it might be a small cost. It might be more costly to investigate this cost, than the 'revenue' this work will lead to." (Linköping student 1)

In connection to this it was discussed whether TC models with pre-defined cost categories are helpful or if they limit the perspective. The students felt that such models are

supportive, but that in the end the total cost must be covered no matter how specific costs are categorized.

The TC model in the textbook used in several courses includes the cost category ‘miscellaneous’, which some students see as somewhat problematic. If a specific cost does not fit into any of the pre-defined categories, it belongs to miscellaneous, which by definition is regarded as less important. Then this specific cost might be more or less neglected, even if this cost in a specific situation in fact is rather big. Other students replied that it is then necessary to step out from the pre-defined model and create new categories.

Some costs might be hard to quantify because of lack of measurement/information in the IT systems. Other costs are indirect and therefore hard to allocate to certain activities, products, etc. In such cases, it might not be possible to include these, at least not in a quantifiable manner and comparable with other costs. They might have to be excluded from the TC model and discussed more qualitatively instead.

Selecting calculation methods

Costs can be calculated in many ways, using different methods, making different assumptions etc. One student reported about cases in the courses taken:

“Everyone reaches different results. ... No one has ever got the same result, despite everyone has exactly the same data.” (Linköping student 2)

An issue in any TCA is to decide in which detail the cost calculations should be performed. Identifying cost factors to include it is partly a matter of input (time spent) and outcome (quality of the result). Even less detailed calculations might produce useful results. Although the exact cost might be wrong, the calculations might uncover how the alternatives differ.

All costs are not equally easy to deal with. Inventory carrying cost was given as an example. As some products might have higher scrap rate than others, using a general inventory rate for all products (which is normally done) will actually give an incorrect cost for several products. On the other hand, calculating product-specific inventory rates would in most cases require much work.

Defining, retrieving, and processing desired input data

Scrutiny in defining necessary data is regarded important in order to achieve a good result from the TCA, but also to save time, avoiding retrieving data that later proves not to be necessary. Referring to a teaching case (i.e., a rather regulated setting) where the students were to define which data they needed for their TCA, one student noted that even though data were carefully scrutinized for relevancy, they failed to consider several aspects. In a

real setting (i.e., less regulated), determining relevancy of data is probably even more difficult.

The fact that desired data are often unavailable must also be considered. Either there are no figures available at all, because of lack of measurement, or the quality of data is questionable: Should these data be used despite its shortcomings? Should estimations be made and, if so, how? In addition, do the data accurately represent the situation being analysed? For example, are data from a previous year representative when predicting the following year? How should outliers be handled? Should they be dismissed, or should they be included because the deviation is relatively normal?

Critical review

Uncertainty in input data and assumptions could indicate a sensitivity analysis is needed. How to do this is not clear although focus should be spent on the factors that are most questionable.

Another way of handling uncertainty is to avoid presenting too detailed figures but round them off because of the uncertainty. One student gave a more holistic view, concluding that one cannot replace a non-critical view during an investigation by merely applying a sensitivity analysis afterwards:

“Not just making an analysis at the end, but critically reviewing it while working.”
(Linköping student 1)

2.3.2 Aspects on teaching and learning total cost analysis

Course interfaces and learning progression

The students experienced good interfaces between the courses in the master profile and the TCA learning progression to be effective:

“Similar things have been treated [in different courses], and teachers’ assessment in these courses have been fairly consistent each time. This has made you dare to step away a bit [from the basic models]. Today, it feels natural to exclude cost factors you see won’t change, but in the beginning, you were more thoughtful: ‘Is it really OK to do this?’.” (Linköping student 3)

Another student noted that different examiners have a slightly different focus, which means the students were exposed to different perspectives. This student compares their situation today with the introductory course in the master profile:

“You feel more comfortable today. You dare to have a free rein, knowing that it usually works out well in the end. In the beginning, it was more about learning a

method from step one to five. Having made some TCA's, getting some experience ... we've learned that if we don't find certain cost data ... we might skip it and continue. We've starting to find our feet." (Linköping student 4)

Moreover, the students feel that the TCA principles they have learned with some adaptations can be applied to areas other than logistics.

The TC model vs. more general understanding

To perform a logistics TCA requires, according to the students, an ability to visualize the situation, which depends on a good understanding of logistics in general as well as of the specific situation or system studied. Such understanding enables the case-specific adaptation of available TC models. However, even though they understand the need for adaptation, they argue that in educational settings they can be unsure of how they are expected to proceed. For example, according to one student, excluding a pre-defined cost category because is irrelevant in the specific case feels better than adding a new cost category. The students' hesitation is connected to how they think they will be assessed:

"In the introductory course, it was outspoken that all factors in the TC model not always had to be included, and that it should be adapted to fit the situation. Whether you [as a student] dare to rely on this is another thing..." (Linköping student 5)

"In educational settings I think it's hard to know when it's alright to trust my own ideas and knowledge and what I feel is reasonable and right, and when I'm supposed to stick to the given models." (Linköping student 2)

Although the students think that a certain TC model to some extent might be limiting, they believe that it would be confusing if the TCA principles were taught without a TC model as support. Even if several TC models are available in the literature, they feel that to avoid confusion it is sufficient to focus on one of these in the courses.

Principal reasoning vs. correct calculations

As described in the section about challenges with cost calculations, there is a trade-off between time required to reach 'perfect' calculations and the supposed value of such perfection. Voices were raised that even though this is a reasonable consideration, students are prepared to dig deeper and this might be due to the pressure of assessment:

"taking the school perspective ... we should calculate it, it feels right to do so, but for the company it might be a small cost ... If I had been only in a working situation, I would never have considered this cost factor..."
(Linköping student 1)

"... but as a student you feel you should." (Linköping student 5)

"If I am to be examined on a TCA and investigate 3 of the 5 cost categories [from the theoretical model], I feel like I've only done 60%, even if these 3 represent 95% of the total cost. It feels like I don't show what I can." (Linköping student 1)

But it might also be driven by a true desire to learn:

"When studying I want to go through all parts [of a TCA] in a structured way, and maybe include factors that are relatively unimportant. ... As a student, it's important to learn all parts in detail, so even if it's a small cost factor I want to go into it and understand how it works. The size is not important, but the connections between all aspects." (Linköping student 1)

"You kind of hoover the information sources on everything you might possibly want to include, and try to check off it all, not to miss out anything." (Linköping student 6)

"And you might learn until next time what should be included ... it is in the back of your mind what's relevant to look at." (Linköping student 5)

Cases as a pedagogical tool

There is a consensus that working with teaching cases is a favourable way of learning. A major reason for this is that the application needed in cases forces you to think about how things work:

"What I think I've gained from the cases is ... thinking deeper, or from a different angle on it all. Things I might not have considered before." (Linköping student 6)

However, good teaching cases should reflect reality. The more realistic they are, the more fun students have and the more time they spend on the cases as a result of this interest. It is not obvious, however, that the time spent correlates with the level of learning achieved. Some support along the road is considered important. This support might come from the literature, lectures, or tutoring.

There was a discussion about how much support should be given to students before they start working on a case. Perhaps, for example, the most effective pedagogy is to throw them into the deep end of the pool before teaching them how to swim. Although thorough early support might help students solve a case, most of the students argued that they learn more when you encounter problems which you must tackle, even if they do not really succeed to solve the case. That is, the students believe good feedback and debriefings of their experience provide the best learning opportunities. However, when being assessed on the performance on a case, the support before and during the case work have to be sufficient enough to enable the students to solve the case in a good way.

2.4 Total cost analysis-related aspects addressed in master's theses

To see how TCA is covered in master's theses, 54 theses performed during 2017 within logistics management and closely related areas were scanned. In 16 of these, TCA-related challenges are addressed, although mostly not explicitly described as a challenge or a problem. All these theses deal with tasks initiated by external organizations – i.e., they deal with applications of TCA in one form or another. Predominantly, TCA is used to evaluate specific alternatives, but in one case (Hamparsomian and Milesson, 2017), the purpose was to create a TC model the organization could use. The following discussion presents the challenges addressed.

Defining alternatives to compare

In seven theses, the authors had to define the alternatives to evaluate, at least to some extent. For most cases, the alternatives were given to the students but not elaborated upon. An example where a structured approach is used is given by Sjöberg (2017), who uses a number of parameters to evaluate potential alternatives to select the ones to include in their TCA. In some of the cases, such as Lundell and Nilsson (2017), the authors describe that alternatives were decided in collaboration with the host organization. In other cases, major alternatives were given by the external party, while the more detailed options were defined by the authors such as alternative types of freight consolidation (Freyschuss and Hallenberg, 2017).

Defining the system

System boundaries are discussed and defined in almost all theses, but problems and challenges related to boundaries are seldom mentioned. In a few cases, there are explicit reflections, however. Claesson and Rehme (2017) express a need for a clear system definition to enable fair comparisons between alternatives, and Calmfors and Werdin (2017) highlight that their rather narrowly defined system influences the result. Freyschuss and Hallenberg (2017) conclude that because they take the perspective of a specific company this necessarily affects system boundaries (as the supplier's activities are excluded).

Making time considerations

In two of the theses, the authors discuss complexity related to the time perspective. Evaluating warehouse set-ups (equipment, layout, etc.), Sjöberg (2017) concludes that the expected lifetime must be estimated and therefore uses the Net Present Value method to make fair comparisons of different alternatives. Claesson and Rehme (2017), when estimating costs for future distribution structures, face problems determining future sales volumes as it is hard to know where customers will be situated ten years ahead.

Identifying other aspects of importance

In 50% of the studied theses, delivery service is emphasized as an important decision factor, sometimes specified as lead time or stock availability and sometimes treated more vaguely. There are examples where costs are evaluated with the service kept at today's level (Lundqvist and Stenström, 2017), at a certain specified level (Claesson and Rehme, 2017), and concerning how costs as well as service are affected (Freyschuss and Hallenberg, 2017).

Other aspects are considered in a few theses. Among these are flexibility, safety issues, risks, and possibilities for future expansion.

Selecting cost categories to include

With one exception, the choice of cost factors is clearly described. Several authors stress that the most important cost factors are to be focused. How this is practically handled differs, though. In some cases, only the biggest cost factors are included (Hamparsomian and Milesson, 2017; Olsson, 2017). In other, the factors supposed to be most affected by changed conditions are regarded (Wallin and Westberg, 2017), and in yet other case-relevant factors are focused (Asklund and Johansson, 2017). The clarity in motivations for the selected cost factors differ significantly between the theses.

Selecting calculation methods

Calculations as such are not reported as being a problem. However, in many cases uncertainty or impreciseness in data forced the authors to make adjustments in formulas used before calculating.

Defining, retrieving, and processing desired input data

Mäkinen and Runér (2017) specifically point out the definition of needed data as a specific 'process step' in their investigation, but most authors do not explicitly present a compilation of desired data. Some of the theses are more mathematically oriented, and in these cases formulas and calculation models are clearly presented. This implicitly indicates which data were needed to enable calculations and comparisons. Freyschuss and Hallenberg (2017) address the issue of how much data are needed and based on this they decided to collect data for a one-year period.

Since data collection methods are presented in the theses, on a general level it is clear where data are collected. However, the more detailed connection between specific data and specific sources of information is often lacking. There are exception, however, e.g., Olsson (2017) clearly describes how observations, interviews, historical data, and regression analysis are used to collect and process the various data used.

Lack of data is mentioned by several authors as a problem they encountered. Lundqvist and Stenström (2017) state that data were available, but lacking the desired level of detail. Hamparsomian and Milesson (2017) found that the information they received were not transparent enough to reveal the desired data. Mjörne and Patel (2017) had the intention of using historical stock levels, but these data were unavailable in the organization's IT system.

In many cases, uncertainty or imprecise data forced the authors to adjust the data. For example, Wallin and Westberg (2017) found that interview respondents had different opinions concerning required time for certain activities. Therefore, they had to make assumptions about which figures to use. Connected to field observations, Olsson (2017) faced a similar problem: because the time needed to perform a certain activity differed, it was difficult to make reliable calculations. Olsson also encountered some unreasonable figures extracted from the organization's ERP system, which necessitated closer analysis and elimination of outliers. In one case (Askund and Johansson, 2017), uncertainty in information was regarded too big to allow a quantitative cost evaluation. Instead, a qualitative analysis was performed.

Critical review

As mentioned in the previous sections, many authors are aware of the effect lacking and uncertain data have on the credibility in the result and discuss potential effects of assumptions and delimitations. Most of the theses perform some kind of sensitivity analysis where selected parameters are varied to check the effect on the total cost. However, why a parameter is chosen is rarely explained. Lundqvist and Stenström (2017), however, chose the parameters that had the highest impact on the result to test.

Presentations

The theses present the TCA results in different ways. Most authors use tables to present the costs for the alternatives in various detail, but charts are also common. A few examples are presented in this section.

In their thesis, Lundell and Nilsson (2017) investigate three alternatives for distribution of spare parts for a manufacturer of heavy machinery. They use various formats to present the results. They use a table to present the total cost for each scenario divided into costs for distribution centres (DC) and customer centres (CC) (Figure 7) and a bar chart to present how the total cost for the scenarios from different cost factors are calculated (Figure 8).

Total costs								
Scenario 1			Scenario 2			Scenario 3		
DC	CC	TOT	DC	CC	TOT	DC	CC	TOT
3 947 240	20 607 258	24 554 497	2 518 034	17 321 028	19 839 061	2 448 630	7 187 621	9 636 250

Figure 7. Total costs in table format (Lundell and Nilsson, 2017), p. 75

Figure 8. Total costs in bar chart format (Lundell and Nilsson, 2017), p. 76

Claesson and Rehme (2017) also investigate alternative distribution structures, but in their case for a wholesaler. They use the same kind of bar chart as Lundell and Nilsson to show how the different cost categories vary for the alternatives. When showing the contribution of each warehouse location to the total cost for the different scenarios, they use another kind of bar chart (Figure 9), where colours are used to increase the visibility.

Figure 9. Bar chart showing how different locations contribute to total costs (Claesson and Rehme, 2017), p. 74

Hamparsomian and Milesson (2017) also use colour coding. In their thesis project, they created a TCO model for a company. Based on the literature, they made a tentative model consisting of 38 cost factors. This model was tested using data from three cases – purchases which the company previously had performed. Different subsets turned out to be relevant for each of the cases. Cost compilations for two of these cases are shown in pie charts (Figure 10 and Figure 11). Although colours are helpful when comparing these two charts, in the second one (case 2) it is more difficult to see the details because more cost categories are included so many of these are relatively small.

Figure 10. Pie chart showing total costs divided by cost category for case 1 (Hamparsomian and Milesson, 2017), p. 54, slightly modified for readability of text

Figure 11. Pie chart showing total costs divided by cost category for case 2 (Hamparsomian and Milesson, 2017), p. 76, slightly modified for readability of text

3 Lund University

Lund University, based in Lund, Sweden has eight faculties and three campuses serving approximately 29 000 students. Logistics is almost exclusively part of educational programs at the Faculty of Engineering, mainly at Campus Lund, which is in focus in this research. The logistics courses are provided by the Packaging Logistics Division (belonging to the Department of Design Sciences), and the Department of Industrial Management and Logistics (where the Engineering Logistics Division as well as the Production Management Division are engaged).

3.1 Logistics education – programs and courses

Logistics courses are offered to Swedish students following some of the 5-year engineering programs at Lund University, leading to a MSc degree.⁸ The first part of these programs focuses on mathematics, science, and various engineering subjects. During the last two years of study at the programs Industrial Engineering and Management and Mechanical Engineering, students choose a major track, a so-called ‘specialization’. There is also an international 2-year MSc Program in Logistics and Supply Chain Management. Each year, approximately 20 students are enrolled in each track.

Some of the courses are also available to students following other programs, but the following text focuses on the programs mentioned above. These programs are very similar, and almost all courses are given in English to a mix of students from these programs.

3.1.1 Master program in Logistics and Supply Chain Management

This 2-year 120 ECTS credit program consists of 90 ECTS courses and a 30 ECTS master’s thesis. Figure 12 displays the courses, including information about which ones are mandatory.

⁸ Students are directly admitted to the complete 5-year programs, i.e. they do not have to apply specifically for the last two years at master level.

Figure 12. Courses at the Logistics and Supply Chain Management program

The study year is divided into four periods, each one roughly 9 weeks long. Since all courses are on 7,5 ECTS credits, each period corresponds to 15 credits. As shown in the figure, the courses in each period run in parallel. There are 16 courses available in the program. Eight of these are mandatory, giving a total of 60 credits. Another four must be chosen to reach the 90 course-credit requirement. The program is completed with a 30-credit master's thesis.

3.1.2 Industrial Engineering and Management program - Specialization in Supply Chain Management

Students following the 5-year Industrial Engineering and Management program (hereafter denoted I) take an introductory course in logistics during their second year. At the master's level (i.e., year 4-5), the students can choose to specialize in Supply Chain Management. The specialization is 120 ECTS credits, where 90 credits are courses and 30 are for the master's thesis. As shown in Figure 13 below, the similarities with the MSc program are great. The courses are the same, except for the introductory course 'Fundamentals ...', which is included in the MSc program (corresponding to the course 'Logistics', which the I students follow at bachelor's level). However, a few of the courses are switched between the study years. The main difference is that in the specialization, no courses are mandatory. It is up to the students to pick a suitable combination of twelve courses.

Figure 13. Supply Chain Management Specialization at the I program⁹

3.1.3 Mechanical Engineering program - Specialization in Logistics and Production Management

During the second year of this 5-year program the students take an introductory course in logistics. The logistics specialization is almost identical to the one at the I program, although labelled differently. The only difference is that the course Packaging Logistics is offered year 4 to the Mechanical Engineering (M) students instead of year 5.

3.1.4 Courses within Logistics Management

Short descriptions are here provided about the courses included in the master program and the specializations. A division is made between the core logistics courses (Table 6) and the logistics-related ones (Table 7).

⁹ The course Humanitarian Logistics is not formally included in the specialization, but eligible for the students, and selected by approx. 50 students from the I- and M-programs each year.

Table 6. Core logistics courses in Lund

Core logistics courses	
Logistics	Basic knowledge about the logistics system within a company. Fundamental skills in analysing, designing and selecting logistic solutions.
Fundamentals of Logistics and Operations Mgmt	Principles used to plan, organize, coordinate, develop, control and manage the flow of material from supplier through the company to its customers; How logistics and op. management can affect the profitability within an organization.
Warehousing and Materials Handling	Design and the management of a warehouse; Techniques and tools required to analyse and improve the efficiency in warehouses.
Industrial Purchasing	General understanding of issues related to industrial purchasing and supply management; Methods and models supporting the strategic, tactical and operational purchasing work.
Production and Inventory Control	Formulate, solve, and use relevant basic quantitative models for analysis and control of production and inventory systems.
International Physical Distribution	The entire distribution network is considered, focusing on key aspects such as infrastructure, transport modes, transport market, and design/planning of distribution operations.
Mgmt of Production and Inventory Systems	Knowledge and understanding of methods for management of production and inventory systems, both from a theoretical and applied perspective.
Supply Chain Management	Principles and methods used to produce an effective and efficient flow of material and information throughout the supply chain; Methods and tools for the analysis, design and development of supply chains.
Project and Research Methodologies in SCM	Knowledge and insights into research methodologies and project management; Skills in how to organize projects and scientific studies within a logistics context.
Simulation of Industrial Processes & Logistics Systems	In-depth studies in quantitative methods for simulation of production systems; Practice and development of the ability to formulate and solve an industrial project in simulation.
Humanitarian Logistics	Design, management and measurement of supply chains in the humanitarian context; Disaster relief as well as logistics in developing countries will be covered.
Packaging Logistics	Packaging system components and the impact of packaging on supply chains; Analysing, designing and choosing packaging system components
Master's Thesis	Knowledge and skills from previous courses are applied on an individual project, often performed in collaboration with an external stakeholder.

Table 7. Logistics-related courses in Lund

Logistics-related courses	
Business Process Management	Tools and methods as well as principles, concepts and visionary perspectives within the subject area Process Orientation and Development.
Operations Strategy	The strategic role of the production system and the infrastructure in the company's performance.
Packaging Technology and Development	Packaging development and innovation; How packaging affects sustainable development in society; Practical project work with a relevant industry.
Supply Chain Information Systems	How to assess, select, implement and use information systems for supply chains.
Quality Management	Overview and understanding of Quality Management (QM); Fundamental principles and concrete tools for analysis and improvement; Quantitative and qualitative tools in QM.

3.1.5 Total cost analysis in the core logistics courses

The presence of TCA differs between the logistics courses. In a few courses, it is more in focus, and in some case even mentioned in the official course syllabus, while in others total cost considerations come up in discussions even though not as a major issue. This section describes in what way TCA is part of the different courses. Focus is on those courses where TCA is a clear part of the course curriculum. The courses are presented in chronological order based on the specialization at the Industrial Engineering and Management program (i.e., the order that the students are supposed to take the courses). The information is gathered through interviews, informal discussions, and e-mail conversations with the responsible teachers and by viewing course documents.

Logistics

In the textbook used¹⁰, a chapter is dedicated to logistics costs. During lectures, costs are highlighted as one important measure when evaluating logistics. The total cost model by (Lambert, 1975) is introduced, and some of the cost elements in this model is elaborated upon. Following this, the students work with minor inventory management exercises, where total cost minimization is the focus.

In ChainSim, a larger case, the students are to manage logistics decisions in a fictional company in order to improve efficiency and reduce the total costs.

A subsequent lecture discusses a TC model applied on distribution¹¹ and this is related to further examples from real cases where TCA plays an important part.

¹⁰ Jonsson & Mattsson (2016), *Logistik – Läran om effektiva materialflöden*

¹¹ From Abrahamsson (1993), *Time Based Distribution*

Industrial Purchasing

Total Cost of Ownership is highlighted during lectures and covered by the literature¹². In one of the cases in the course, the students evaluate the offers from four different suppliers from a total cost perspective.

Supply Chain Management

The first lecture introduces logistics trade-offs between cost factors as well as between costs and other measures and a later lecture provides real-world examples of such trade-offs.

A major part of the course is devoted to The Fresh Connection, which is a web-based business simulation game that deals with sales, operations, supply chain, and purchasing issues. The students' decisions in these four areas affect costs as well as other performance measures that ultimately affect the profitability of the company. Therefore, analysing the cost effects is an important part of the students' work as good analyses will support good decisions.

Master's thesis

The content differs from project to project. However, many projects contain an evaluation of alternatives, where costs often are an included parameter. In some cases, TCA is the main issue, where the goal could be to create a total cost model for an organization.

3.2 Teachers' thoughts concerning total cost analysis

A focus group discussion was held with six of the involved teachers, three men and three women, who collectively have extensive experience in the field. Individual interviews were performed with three of these teachers; one of these teachers was also observed during a teaching. These respondents collectively cover most of the core logistics courses, however, not all of them. (See Table 8 and Table 9 for details about their experiences).

Table 8. Number of Lund teacher respondents with certain experience

Teaching experience	< 5 years	0	5-10 years	2	> 10 years	4
Overall responsibility for the logistics courses (director of studies, program director or similar)						3
Practical experience from TCA in companies/organizations						2
Have created educational material about TCA						2

¹² Ellram (1993), 'Total Cost of Ownership: Elements and Implementation'

Table 9. Number of Lund teacher respondents with experience from the respective courses

Course	Examiner / responsible	Actively participating
Logistics	1	3
Fundamentals of Logistics and Operations Mgmt	2	1
Warehousing and Materials Handling	0	0
Industrial Purchasing	2	2
Production and Inventory Control	0	0
International Physical Distribution	0	1
Mgmt of Production and Inventory Systems	0	0
Supply Chain Management	1	1
Project and Research Methodologies in SCM	0	1
Simulation of Industrial Processes & Logistics Systems ¹³	2	2
Humanitarian Logistics	0	0
Packaging Logistics	2	2
Master's Thesis	4	5

In the following sections, the essence from the discussions and interviews are compiled. First, challenges with TCA are addressed, and then some thoughts regarding teaching and learning TCA are presented.

3.2.1 Challenges with conducting total cost analysis

During the focus group discussion and the individual interviews, several challenges were discussed. The concept map in Figure 14 shows a compilation of the challenges discussed during the focus group session; the black boxes and lines indicate ideas that were mentioned spontaneously, and the red ones came up after some extent of inference from the moderator.

¹³ The two teachers noted here were actually not involved in this specific course, but a similar one, Applied Logistics Simulation.

“You’ll handle this package 50% less times, so the handling cost per product unit will be half. You have to base your calculations on the product, even though you’d like to say something about the packages.” (Lund teacher 1)

In this example, the system cannot be based only on the packaging, but must catch what happens when the product is handled during the different steps in the chain. Another teacher added that what is cost efficient for a specific product might not be cost efficient for the whole range of products, so the system might have to be further expanded.

Defining system boundaries “once and for all” might not be possible. For example, in many master’s theses, the students draw a map of system and set boundaries for the study, but as the study proceeds, these boundaries might have to be modified.

Identifying other aspects of importance

It was rather strongly argued that costs are just one out of many aspects to consider when designing, analysing, or evaluating logistics systems. A question that was raised is whether costs were more in focus in older logistics textbooks, while in newer ones, costs are a bit muted, since many other aspects have received increased attention.

Several factors were mentioned as being relevant to consider, such as environmental issues, social sustainability, and tax effects. It was argued that focus should be on profitability, which is built up by costs as well as revenues and assets. The interplay between costs and revenues might be rather complex, as illustrated by the following case from an e-commerce company in the fashion business:

“The big revenue comes from customers who return a lot. If you only consider the costs, the return costs for these customers are very, very high ... What happened was that when they made it hard to return, these customers stopped buying. Then you lose in profitability. And it’s hard to understand this, that’s clear, ... that the profitable customers are the ones with many returns.” (Lund teacher 2)

Selecting cost categories to include

One of the teachers argued that more and more aspects are included in TC thinking, but that it is not easy to put a price on all these aspects. Environmental costs, for instance, have received more attention during the last 10-20 years, but it is not easy to put a price on the environment. Social sustainability is another factor – what cost should be allocated for the risk of getting bad publicity? Even the fairly ‘easy’ costs can in practice be hard to decide correctly, and this affects the choice of cost factors to include.

According to the teachers, it seems to be challenging for the students to understand which cost factors are more important than others. For example, it is common that they dig deep into EOQ calculations in situations where other costs are much more relevant to consider. A reason might be that when certain data are available, they choose to calculate costs that

are supported by this data and forget about other cost factors, which are then excluded albeit not deliberately. The ‘wrong’ things might then be measured with high precision, while ignoring the ‘right’ things. Although available data in practice influence which cost factors are investigated, measures should be taken to identify which ones are most important, such as by asking the stakeholders to give their opinions (AHP¹⁴ was mentioned as a possible method for considering different opinions) or by collecting and analysing raw data.

Selecting calculation methods

With certain cost factors selected, these costs should somehow be calculated or estimated. However, it is often difficult to allocate costs at the right ‘level’ or unit of analysis.

“When comparing one packaging system with another, it’s a challenge to identify the ‘lowest common denominator’, which kind of is the single product. ... it’s a challenge to understand how to kind of cut down a number of costs to a specific product.”

(Lund teacher 1)

An associated problem that was addressed is how to handle fixed costs. Will a certain change lead to a *real* cost reduction? If not, how should this be handled? If we, for example, own a car, our costs for insurance and depreciation will not increase if we drive another kilometre. How should we then price additional use of the car – 0,4 SEK/km for the diesel cost or 3,5 SEK/km, including all costs spread out on the total distance travelled?

Defining, retrieving, and processing desired input data

The challenge gaining most attention during the group discussion was data retrieval. According to the teachers, in almost every case, it is hard to retrieve reliable data. Sometimes data do not seem to exist or are time-consuming to catch and sometimes it is ‘politically impossible’ to retrieve the required data because the organization is not willing to share data.

One of the teachers referred to the concept of Total Cost of Ownership (TCO)¹⁵, which principally should be based on Activity-Based Costing¹⁶ (ABC). However, since companies normally do not use ABC as an accounting method, performing TCO in a correct way will be difficult. Using readily available ‘standard costs’ from the company’s systems in such situations might give a false picture of the true costs. A great deal of work

¹⁴ AHP, Analytical Hierarchy Process, is a multi-criteria method for decision support. See Nydick and Hill (1992) for an overview.

¹⁵ Total Cost of Ownership is described in section 1.3 in the main text.

¹⁶ Readers interested in Activity-Based Costing are referred to e.g. Kaplan and Anderson (2007).

might need to be done to catch the data needed to calculate the costs correctly. Having experience performing time studies, this teacher knew they are time-consuming and that such studies often are met with mistrust from the people being observed. Less time-consuming would be to interview selected people about the times required for certain operations, but this is less reliable as estimations of average values for ‘standard orders’ might miss important information. Another issue is that different respondents sometimes give different answers, either because they are not well enough informed or because they mistrust each other or because their opinions are biased for one reason or another.

Because of the problems of retrieving data, it is important to try to identify which data are the most important:

“Where should we have detailed data? We might not be able to have it everywhere, ‘cause then we would never reach an end. [The reasoning should be] ‘Here are most probably our challenges, and this is probably where we should dig down deep for data.’ ... It is kind of a trade-off analysis. Look at the whole package, view the complete system and then see where the trade-offs are important, and which data is needed there in order to reach some result.” (Lund teacher 3)

An issue raised related to the calculations was how to handle outliers – i.e., values/measures outside a certain range. One standpoint was that outliers should be washed from data sets, since they are not representative. Another teacher replied that if you wash data too much, it might result in a too optimistic result. For example, if all exceptionally long times are eliminated, it might give a false impression that the time is always short.

Critical review

The teachers believe that students tend to rely too much on their calculated results. One teacher observed that students are a bit unsettled by the fact that finding ‘the solution’ is impossible and that they must critically evaluate their results. This includes questioning the quality of collected data as well as reviewing formulas used and assumptions made during the process. If something is found to have a large effect on the result, this has to be clearly announced and analysed:

“... an estimation, which you in hindsight is aware of, and if it has a great effect, you’ll perform a sensitivity analysis.” (Lund teacher 1)

Concerning sensitivity analysis, one teacher talked about statistical methods such as Monte Carlo simulations, while another suggested making scenarios where certain parameters are changed to test the sensitivity of the cost model. Which method to use is a matter of what is desired. Is it a 95% confidence in the result or rather a ‘general feeling’ of how reliable the result is? In many real cases, a rather reliable indication on how to act is more important than statistical confidence.

3.2.2 Aspects on teaching and learning total cost analysis

The TC model vs. more general TC/systems understanding

There is a consensus among the teachers that a total cost *thinking*, and a general understanding of systems, is more important than knowledge about specific TC models.

“It’s the system view that’s important, not the total cost model. Total cost is a way of illustrating a system view that is classical within our field.” (Lund teacher 3)

Therefore, the teachers do not always explicitly use the term total cost analysis when such analyses are being made. However, in some courses, TC models are presented and discussed, and such models are found to be good for highlighting trade-offs and systems understanding. One teacher uses the classical TC model (Lambert 1976) not to focus on costs as such, but to highlight interfaces and trade-offs. If e.g., using the EOQ formula, the TCA is limited to two cost factors, but there might be other relevant things to add. Profitability is more important than costs in themselves.

One teacher argued that a TC model could be viewed as a ‘formula’ or as a conceptual model. Engineering students tend to search for formulas that will lead to the correct answer but find conceptual models more difficult to grasp. The big value for students, however, is to learn the TC *thinking* by using a conceptual model. However, another teacher highlighted that there is a problem with conceptualised models, since they give a false sense of triviality:

“There is a sense of triviality in this total cost model: ‘Hey, that’s not strange, it’s obvious that we should add costs. Really easy!’ Our point is: ‘No, it’s rather difficult.’ The difficulties are in the details, to get the hands on those and include them and choose which trade-offs to make. It’s a lot of work with this, but conceptually it’s a trivial model.” (Lund teacher 3)

Retrieving desired input data

The fact that it is difficult to retrieve data is addressed in the start-up phase of the master’s theses. When supervising students, one teacher warns the students not to underestimate the time and effort needed to catch and analyse the data. To discuss the system with the students, the relevant trade-offs, and the required data, was mentioned as important.

Progression in TC learning

TCA is introduced and practiced in the introductory course (Logistics). Some subsequent logistics courses (e.g., in the Industrial Purchasing course) explicitly deal with TC aspects, while other SCM courses implicitly deal with TC aspects. However, Swedish students specialising in SCM at the master’s level do not have any mandatory courses but can choose courses freely from the ‘course smorgasbord’. Added to this, a significant majority

of the Swedish students spend half a year studying abroad, making it even harder to know what they have learned in their courses. Therefore, deliberate progression is difficult to achieve and the actual progression in TC learning is difficult to grasp, since progression depends on the individual course choices. If students choose to take the Industrial Purchasing and Supply Chain Management courses, they are exposed to content that will improve the TC skills they acquired in the introductory course.

The students who follow the two-year master's programme have a different experience. With one exception, the first year of the program consists of mandatory courses so these students share a common base. However, the teachers admit that they do not really know what happens with respect to TCA in courses other than their own.

Despite this lack of 'controlled' progression concerning TCA, the teachers believe students are prepared to tackle a TC-oriented master's thesis project. These students have a systems understanding as this is a theme in the logistics courses. This systems understanding helps them address TC problems even though the practical issues of applying and using TC models remains problematic for them.

Critical review

The need for critically reviewing the rigidity in data is discussed with students. The basic EOQ formula was given as an example. The formula seems simple with rather easy components, but in practice, all these parameters are to be debated – e.g., future demand must be estimated, and the inventory rate is often a policy-decision. Students need to be made aware of the importance of these assumptions and insecurities. When students work with tasks and cases with more than one correct solution, they have to evaluate the robustness in their results, something they regard as challenging. Although the students train this during the courses, they still express insecurity when entering the master's thesis, a reaction the teachers regard to be natural.

How to conduct a sensitivity analysis is not explicitly taught in the logistics courses. One teacher was previously involved in a simulation course where tools such as by using Tornado diagrams and basic Monte Carlo simulations¹⁷ were described to show the effect of variances. The teachers assume their students are exposed to sensitivity analysis that uses statistical tools in previous math courses; however, the teachers have no direct knowledge of whether this assumption is valid. One teacher stressed that sensitivity analysis does not have to be based on statistics. In master's theses, the students are sometimes encouraged to create scenarios where the robustness in the result can be tested against different values on certain parameters.

In addition, teachers raised the issue of usability. In master's theses, students sometimes create a TC model for an organization. Of course, the correctness in calculations is

¹⁷ See e.g. Robert and Casella (2004) for a presentation of Monte Carlo analysis

important, but it is also crucial that the model is understandable and easy to use. Moreover, the output of the model should support decision making. These aspects must also be critically evaluated.

The use of cases to facilitate understanding

Teaching cases are appreciated by the teachers to be a good way of getting students to think more critically and reach a better understanding. The courses use several cases to address TC aspects in different ways. In some of these cases, costs are a minor issue; in other cases, a major one. Finding good teaching cases is considered difficult. In the introductory course, teachers used a case a few years ago that was regarded suitable, but having changed the course literature, this case no longer is a good fit. After having tested some alternatives, teachers introduced a new case, ChainSim, which hopefully will work out well. The problem is to find a case that accurately shows the complexity; most cases are too basic.

“The challenge is to make it complex enough to make it relevant, but not too complex, they really must understand ... I think rather much follow-up and discussions are required to make them really get it ... You sort of have to get the feedback face-to-face.” (Lund teacher 2)

This quotation indicates that case teaching might be a rather demanding activity for students as well as teachers. In an example given from one course, the students were asked to use a specific TC model presented during a lecture as a way to describe the system and structure the problem. However, the students were rather poor at using a conceptual model this way. They headed right to solutions without structuring and analysing properly. In another case, students tend to get stuck on specific cost calculations without realising that these costs may not be the most important ones. Teacher support seems to be crucial in order to make the students gain a deeper understanding of how to tackle TC problems. The more complex the case, the more is required from the teachers.

The Fresh Connection is a simulation game running over some weeks in the Supply Chain Management course. In this case, the complexity is successively increased. There is a huge number of parameters that can be changed, a lot of performance measures to consider etc. The students get a response on their actions in form of changes in various cost categories (and other measures) which is a good starting point for fruitful discussions that hopefully helps them to understand better, get a more holistic view, collaborate more etc. During feedback sessions, one teacher asks the students specifically to explain aspects where the team's performance is poor. This opens up for discussions where they are receptive to the teacher's hints and advice. The teacher normally does not talk specifically about TCA during the tutoring sessions, although in almost all cases cost trade-offs, including trade-offs between costs and customer service, are evident. However, during every supervision sessions, the teachers try to discuss these trade-offs in relation to Return On Investment (ROI).

A trick used in a case in another course is to open the students' eyes by 'fooling' them to go in the wrong direction. By writing the case in a certain way, highlighting certain information etc., the students almost without exception tackle the problem in a certain way. However, this kind of solutions are not in line with what the lectures address. When encountered with this, the students understand that their solutions are sub-optimizations, and they (hopefully) learn to take a more holistic perspective when stumbling into new challenges.

3.3 Students' thoughts concerning total cost analysis

A focus group discussion was held with three students, one man and two women, from the I and M programs following the logistics-oriented specialization at these programs. Each student took between six and seven of the core logistics courses, and together these courses covered a majority of the core logistics courses (see Table 10 for details). At the time of the discussion, they were about to start their master's thesis projects¹⁸.

Table 10. Number of student respondents having followed the core logistics courses

Course	No of students
Logistics	3
Fundamentals of Logistics and Operations Mgmt	0
Warehousing and Materials Handling	2
Industrial Purchasing	1
Production and Inventory Control	2
International Physical Distribution	3
Mgmt of Production and Inventory Systems	1
Supply Chain Management	3
Project and Research Methodologies in SCM	0
Simulation of Industrial Processes & Logistics Systems	0
Supply Chain Information Systems	3
Humanitarian Logistics	1
Packaging Logistics	0

The students' spontaneous response to what TCA is, was that it is about including as many costs as possible. One of the students saw a strong connection to investment calculations. In the following sections relevant parts of the discussion are described, starting with various challenges connected with TCA, followed by aspects regarding teaching and curriculum.

¹⁸ As an introduction to the master's thesis project, the students following the 5-year programs are offered seminars about research methodology. Therefore, many of these students do not choose to take the course 'Project and research methodologies in SCM', which is mandatory for students in the 2-year master program.

3.3.1 Challenges with conducting total cost analysis

Several challenges were discussed during the session. In Figure 15 a concept map shows a compilation of these challenges, where the black boxes and lines indicate spontaneous ideas and the red ones came up after some extent of inference from the moderator.

Figure 15. TCA challenges mentioned during the focus group discussion with Lund students

The challenges mentioned during the discussion are briefly described below.

Defining the system

When defining system boundaries, it is important to make clear what is inside and outside the system and which input and output is linked to the system. From a supply chain perspective, a rather large system is preferred, at least theoretically. In reality, however, defining the system is difficult. A help to set the boundaries could then be to consider what is possible to affect, and what is not.

Making time considerations

The difficulties of estimating future costs were noted. When considering investment alternatives, future costs and savings must be taken into consideration, something the students consider a challenge. (How to do this is briefly discussed in a later section).

Identifying other aspects of importance

Although the students regard costs to be of major interest for companies, other relevant decision factors were mentioned. One point made was that profitability rather than costs is most important. Higher costs could be acceptable if the costs contribute to

customer satisfaction and loyalty. Shorter lead times and higher flexibility were mentioned as examples of factors contributing to customer satisfaction.

During the discussions, the students also noted that decisions are influenced by sustainability and risk factors and they discussed how to monetize these aspects (i.e., allocating a cost). Although such monetization is done in some situations (i.e., putting a value on a human life when planning for disaster help), the students agreed that such figures will be rather unreliable estimations, so it might be better to handle these aspects separate from the costs.

Selecting cost categories to include

A way to find out which cost factors to include is to map the physical and administrative flows and processes. Having done this, you could reason about the steps in the value chain, identify costs connected to each step, and spot the differences. Focus should be on those costs that significantly affect alternatives. However, the students regarded this as self-evident and this kind of separation of costs was not raised as something that would be problematic.

Selecting calculation methods

As mentioned above, estimating future costs is considered challenging. Methods for fair comparison of the investment alternatives were suggested, like the Net Present Value method and the Annuity method. However, the calculation methods as such do not solve the problem of getting good input data.

Retrieving and processing desired input data

It was stated that it might be time-consuming to collect data needed for cost calculations, and that it can be difficult to retrieve exactly what you're after. This means that you often must stick to more limited information than desired.

One specific problem is that some costs are shared between functions or activities, which makes it difficult to know how big part a specific product should bear. Examples were given concerning overall administration (where the activities cannot be easily connected to specific products, even though some products might demand more administration than others), and transportation (where the charge e.g. could be for a complete pallet, containing several different products). Activity-Based Costing was mentioned as a method for dividing the costs and allocating suitable proportions to each product.

Critical review

Since it is difficult to find exact data, input parameters must be estimated. With uncertainties at many stages, the incorrectness escalates. The more estimation and

assumptions made, the more important it is to critically review these. By making a sensitivity analysis the impact of change in parameters could be revealed.

Although critical reflection using sensitivity analysis is helpful, the students have the impression that in reality sensitivity analyses are rarely used. Organizations might know that TCA and sensitivity analysis should be used, but due to limited capacity and knowledge they are overlooked.

3.3.2 Aspects on teaching and learning total cost analysis

Course interfaces and learning progression

According to the students, there is no clear progression over time concerning TCA in the course package. From the basic course, Logistics, they do not recall TCA as part of the course curriculum, but in several other courses, there is rather much focus on relevant costs, and the problems with calculating these costs. In the Industrial Purchasing course for example, the costs associated with buying from a certain supplier are discussed. Different warehousing solutions are evaluated in a case in the Warehousing and Materials Handling course. A third example is the course Supply Chain Management with the case 'Fresh Connection', where cost is one of the important parameters.

A general critique presented (not specifically connected to TCA) was that most courses focus on how things should work, but not really reveal that much of these ideas are 'utopian', because it does not work this way in real companies.

Cases as a pedagogical tool

Teaching cases are used in many of the logistics/SCM courses, spanning from rather simple cases to more complex ones. An example of a complex case including TC considerations is 'Fresh Connection'. The complexity of this fictional case makes it hard, close to impossible, to foresee how the parameters would be affected by certain decisions, something that is regarded difficult by the students, but which also makes the case more realistic.

That cases are realistic is considered important. Authentic cases are however not necessarily positive. On the contrary, fictional cases could be easier to work with and more rewarding, as long as they are realistic.

"You can make learnings points clearer ... it can be more spot-on the specific subject if you can make things up a little." (Lund student 1)

3.4 Total cost analysis-related aspects addressed in master's theses

To see how TCA is addressed in master's theses, 115 theses performed within logistics and supply chain management between 2012 and 2017 were examined. Nine of these, address TCA-related challenges, although mostly not explicitly described as a challenge or a problem. All these theses deal with tasks initiated by external organizations, i.e., they deal with applications of TCA in one form or another. Predominantly, TCA is used to evaluate specific alternatives. The challenges addressed in the theses are presented below.

Defining the system

Most theses identify system boundaries. Some theses explicitly discuss system boundaries. For example, Eriksson and Sterner (2016) describe a system where costs are considered, but they also declare that when analysing the drivers of all these cost parameters, factors outside this system were taken into account. Similarly, Dahlström and Peterson (2013) stressed that the choice of system boundaries affects the total cost figures.

Making time considerations

Harrysson and Landin (2015) conclude that even though their TCA is performed for the as-is state, the result might be affected by future changes in the business.

Costs vs other aspects of importance

This is something hardly not mentioned explicitly. The exception is Berg and Karlström (2017) who add reliability, transit times, and implementation issues as decision factors together with total costs.

Selecting cost categories to include

The challenge of selecting cost factors is addressed in roughly 50% of the theses. Bodehed (2008) notes that choosing cost factors can be difficult. When creating a TCO model for an organization, she asked several respondents to rank cost factors according to their importance, and this input guided her choice of cost factors. As argued by Dahlström and Peterson (2013), the relative size of cost factors should guide this decision, so they checked the size of different costs on a general level as an input for their cost model. Another guiding factor mentioned by Bäckström and Magnuson (2015) is to: “... *include only costs that are manageable to identify and calculate*” (p. 57).

Selecting calculation methods

Formulas for cost calculations are presented in most cases. Adelfar and Beythien (2017) conclude that all relevant aspects may not be possible to catch in a single model, so they

reformulated the problem to make it possible to analyse from a mathematical perspective. This is in line with how Bäckström and Magnuson (2015) approached selecting calculation methods: “[A] cost model cannot be complex and should not be time-consuming to calculate” (p. 57).

Defining, retrieving, and processing desired input data

Which data that are needed to perform TC calculations is either not discussed at all or implicitly given from formulas presented. Bodehed (2008) chose to use both historical data and actual (current) data, instead of relying on figures from a too limited period. Bäckström and Magnuson (2015) report that cross-communication in the organization was needed to retrieve the desired data. Similarly, Berg and Karlström (2017) used different sources of information because of problems in retrieving good data. Another They also had to use average cost data instead of specific, an issue they share with Eriksson and Sterner (2016).

Lack of data for certain cost aspects is reported by several authors. This led Bäckström and Magnuson (2015) to exclude these cost aspects, while Adelfar and Beythien (2017) handled it by making estimations. Bundled costs are mentioned in some cases, where it is desired to divide these and allocate them to specific products. Bodehed (2008) argues that this is problematic if the organization does not use Activity-Based Costing (ABC).

A specific challenge for an external investigator (not belonging to the organization where data is collected) is that data access may be restricted. Harrysson and Landin (2015) experienced this problem, as they were not allowed direct access to the organization’s databases.

Critical review

Cost analyses are compromised by estimations and unreliable data. To check the reliability of results, Berg and Karlström (2017) and Hagberg and Daadooch (2017) used a kind of sensitivity analysis by changing values of some input parameters.

Referring to the impossibility to get access to data (see previous paragraph), Harrysson and Landin (2015) report: “*The result of this thesis depends heavily on the information The Company has agreed to share with the authors.*” (p. 95). They conclude that they therefore had: “*no opportunity to examine neither accuracy or trustworthiness*” (p. 96).

Presentation

A way of showing each cost factor’s share of the total cost is given by Eriksson and Sterner (2016), who use colours to highlight cost factors, see Figure 16.

Figure 16. Cost factors' proportion of total cost (Eriksson and Sterner, 2016), p. 123

Hagberg and Daadooch (2017) present their sensitivity analysis in graphs to help the reader to interpret their findings. Two examples are shown in the following figures.

Figure 17. Total cost effect of changing inventory holding rate (Hagberg and Daadooch, 2017), p. 53

Figure 18. Cost dependence on various factors (Hagberg and Daadooch, 2017), p. 70

4 Chalmers University of Technology

Chalmers University of Technology, based in Gothenburg, Sweden, has approximately 10 000 full-time students. The university has two campuses and 13 departments. The Department of Technology Management and Economics is the main provider of logistics courses. Within this department, two divisions are responsible for different courses: The Division of Supply and Operations Management, and the Division of Service Management and Logistics.

4.1 Logistics education – programs and courses

Compared to the two universities previously described, Chalmers has chosen to focus on separate bachelor programs (3-year) and master programs (2-year), and do not provide 5-year engineering programs.

A common feature for all the bachelor's programs at Chalmers is that there is an emphasis on mathematics and engineering subjects. However, there are also introductory courses in logistics available at bachelor level. For students following some programs, the introductory course is compulsory, while it is elective for other students.

At the master's level, approx. 60 students each year follow a MSc program in Supply Chain Management which has a core of courses within logistics, supplemented by several courses directed to other areas of supply chain management. Some of the courses are available also to students from other MSc programs.

4.1.1 Master program in Supply Chain Management

This 2-year 120 ECTS credits program consists of 90 ECTS courses, and a 30 ECTS master's thesis. The study year is divided into four periods, each one roughly 9 weeks long, and each period corresponds to 15 credits. As shown in Figure 19, the courses in each period run in parallel. There are 28 courses available in the program. Eight of these are mandatory, and six are semi-mandatory (i.e. two of these must be selected). Figure 19 shows the courses and information about which courses are mandatory.¹⁹

¹⁹ During the research project, the MSc program was updated. Some courses were replaced, others slightly modified, and yet others were moved in the sequence. The structure shown in the figure is in line with the structure is for the study year of 2017/18, since this is what the respondents could base their experiences on during the main interviews.

Figure 19. Courses in the Supply Chain Management program. ‘Semi-mandatory’ indicates that two of these six courses must be selected.

4.1.2 Courses within Logistics Management

Short descriptions of the introductory course and the logistics-related courses included in the Supply Chain Management program are provided below. A division is made between core logistics courses (Table 11) and logistics-related courses (Table 12). Some courses in the program are left out, due to their weak connection to logistics.

Table 11. Core logistics courses at Chalmers

Core logistics courses	
Logistics	Fundamental understanding of logistics terminology and concepts. Basic models and methods for analysing and controlling material flows.
Supply Chain Management	A holistic view of Supply Chain Management, including perspectives, concepts, and methods to analyse, organize and improve supply chains.
Purchasing and Supply Management	Principles, theories and practices of purchasing and supply management (PSM). The role of PSM in the organization, in relation to SCM processes.
Operation Planning and Control	Knowledge about design and practical use of planning and control processes and methods, both in manufacturing and supply chain contexts.
SCM Seminars 1	Insight from host companies' specific supply chain contexts. Strategies are matched with theoretical concepts and perspectives on SCM.
SCM Seminars 2	Supported by lectures and seminars, an individual paper is written focusing on a specific theme within the SCM area.
Freight Transport Systems	Overview of freight transports systems. Matching transport demands with appropriate transport services. Quantitative tools for freight transport analysis.
Management of Physical Distribution	The physical distribution is viewed from different perspectives. Distribution structures, coordination and control, and resource utilization.
Production Flow Management	Models and principles for production flows and materials handling systems. E.g. warehouse layout, picking processes, packaging, and performance measurement.
Sustainable Logistics	State of the art knowledge in the field of environmental aspects of logistics and freight transport.
Projects in Supply Chain Management	Problem analysis, problem solving, and research method, connected to projects about logistical, marketing or purchasing issues in organizations.
Master's Thesis	Knowledge and skills from previous courses applied to an individual project, often performed in collaboration with an external stakeholder.

Table 12. Logistics-related courses at Chalmers

Logistics-related courses	
Lean Management	Concepts, strategies and principles of lean management. Various lean methods and tools.
Customer Relationship	Features of customer relationships and distribution networks. Links between customers and internal functions such as marketing, sales and logistics.
Quality Management	Quality management and its principles. Quantitative and qualitative methodologies to improve processes, products, and organizations.
Service Management	Key principles, frameworks and theories of developing, delivering and improving services in contemporary organizations.
Shipping Contracts and Finance	In-depth knowledge about the main transactions and contracts that govern shipping and ownership activities.
International Business Rel.ships	How international business relationships create possibilities and challenges for firms such as global marketing and supply strategies.
Sustainable Transportation	Potential and challenges of alternative fuels, innovative vehicle technology, alternative transport modes, and transport policy measures.

4.1.3 Total cost analysis in the core logistics courses

The logistics courses address TCA in variety of ways. A few courses focus on TCA and in one case TCA is even mentioned in the official course syllabus; other courses address total costs only when it comes up in discussions. This section describes how TCA is covered in the different courses. Focus is on those courses where TCA is a clear part of the course curriculum. This section presents the courses in the sequence they are to be taken. The information is gathered through interviews, informal discussions, and e-mail conversations with the responsible teachers and by viewing course documents.

Logistics

In the textbook used²⁰, a chapter is dedicated to logistics costs. Logistics-relevant cost factors are discussed during lectures. In a case in the course total cost is one of the aspects considered.

Supply Chain Management

Costs and performance in supply chains are covered in the course.

Purchasing and Supply Management

This course discusses how an organization's cost efficiency depends on the way purchasing processes are organised and on the relationships with suppliers. The concept of Total Cost of Ownership is introduced.

Management of Physical Distribution

Various total cost issues are covered, such as trade-offs between transportation costs and material handling costs, cost comparisons between performing logistics services in-house or buying them, including transactions cost connected to the change-over from 'make' to 'buy'. In the teaching case 'Apelsin', the students work with cost aspects when comparing new distribution set-ups with the present one.

Sustainable Logistics

The interplay between costs and environmental effects is highlighted. A supply chain perspective is applied to get a complete picture of emissions and external costs assigned to society due to transports.

²⁰ Jonsson & Mattsson (2016), *Logistik – Läran om effektiva materialflöden*

Projects in Supply Chain Management

Since student groups work with individual projects, these projects differ with respect to whether the project focuses on cost issues.

Master's Thesis

The content differs from project to project. However, several projects contain evaluation of alternatives, where cost often is an included parameter. In some cases, TCA is the main issue, where the goal could be to create a total cost model for an organization.

4.2 Teachers' thoughts concerning total cost analysis

A focus group discussion was held with two of the involved teachers. Another teacher was individually interviewed, i.e., all in all three teachers participated, all of them men with significant experience in the field and insight in all but two of the core logistics courses (see Table 13 and Table 14 for details).

Table 13. Number of Chalmers teacher respondents with certain experience

Teaching experience	< 5 years	0	5-10 years	0	> 10 years	3
Overall responsibility for the logistics courses (director of studies, program director or similar)						1
Practical experience from TCA in companies/organizations						2
Have created educational material about TCA						3

Table 14. Number of Chalmers teacher respondents with experience from the courses

Course	Examiner / responsible	Actively participating
Logistics	2	3
Supply Chain Management	1	1
Purchasing and Supply Management	0	0
Operation Planning and Control	1	1
SCM Seminars 1	1	1
SCM Seminars 2	0	1
Freight Transport Systems	1	1
Management of Physical Distribution	1	0
Production Flow Management	0	1
Sustainable Logistics	0	0
Projects in Supply Chain Management	1	2
Master's Thesis	3	3

The following sections present information gathered during the discussions and interviews. First, challenges with TCA are addressed and then some thoughts regarding teaching and learning TCA are presented.

4.2.1 Challenges with conducting total cost analysis

During the focus group discussion and the individual interviews, several challenges were discussed. The concept map in Figure 20 shows a compilation of the challenges discussed during the focus group session. The black boxes and lines indicate ideas mentioned spontaneously. The red ones came up after some extent of inference from the moderator.

Figure 20. TCA challenges mentioned during the focus group discussion with Chalmers teachers

The following sections briefly describe the challenges raised during interviews and discussions.

Defining alternatives to compare

When working with real cases, the alternatives are not necessarily given from the start. One of the first tasks is then to describe the present state and come up with alternatives to investigate. Although this is the case for many master's theses, teachers are confident the students can handle this complexity.

Defining the system

Although system boundaries were not explicitly mentioned during the discussions, the teachers expressed that it is relevant to consider from whose perspective the system is viewed. For products in transport, for instance, there is a cost for tied-up capital for the one who owns the goods, but the TCA might be performed by another (e.g., a transport company) that is not affected by this cost. Another example could be an organization using internal payments between departments. From a certain department's view, a

specific activity might lead to a cost, whereas from an overall perspective, the activity is just a transfer of money, not a cost.

Identifying other aspects of importance

In addition to costs, some other aspects relevant in decision-making were mentioned. Some of these might be possible to translate into costs, for example, poor quality represented by the cost of re-making or environmental emissions costs estimated using the NTM²¹ database. More often, these other aspects cannot be monetized and therefore are handled as separate decision factors such as environmental concerns and how customers are affected by shortages and poor quality.

Selecting cost categories to include

The more experience one has with selecting categories, the easier it is. That is, this task requires a good understanding of how things work, something students do not have especially when entering the first courses. For example, it is not obvious to the students that buying from a Chinese or a Swedish supplier might render a difference in inventories as each supplier might imply different delivery times and order quantities, conditions that will affect stock levels. It takes time for students to understand these details. In other words, cost selection is challenging for students.

A TC model, e.g., the one in a textbook used at Chalmers²², could be used as a kind of checklist. However, some costs might be difficult to include because of the difficulties putting a figure on it, such as the cost of shortage. The teachers doubt that shortage costs are included when most organizations perform cost analyses.

Selecting calculation methods

An example raised was that the value of products might change during a process, which makes it reasonable to use an average product value in cost calculations instead of a fixed value (which is more correct in other cases). The calculations must fit the specific situation, and this case-specific adaptation is something that some students find difficult.

Small improvements can cause some headache, because they might not necessarily lead to a real cost reduction. If, for example, 10% of a full-time employee's time is saved, will this lead to a real cost saving? Maybe not in the short term, but it creates a potential that together with other actions might affect the total number of employees needed. It can be debated whether to include this time reduction and to what extent to include the TC calculations.

²¹ NTM stands for the Network for Transport Measures, who among other things offers a calculation method for transport emissions (NTM, 2019). (<https://www.transportmeasures.org/en/about-ntm/> 2019-02-05)

²² Jonsson & Mattsson (2016), *Logistik – Läran om effektiva materialflöden*

Defining, retrieving, and processing desired input data

One issue the teachers discussed was how to evaluate the relevance of data and what data are redundant. Students tend to believe, mistakenly, that all available data should be used when evaluating teaching cases and solving exercise problems. The teachers observed that students need to learn how to critically scrutinize data.

In reality, retrieving desired data is often problematic as securing the desired data depend on the complexity of the task, the willingness of the organizations and stakeholders to share data, and whether the company has a good IT system that stores data in a useable format:

“You shouldn’t think that just because you say that you would like data about something from a company, they will be able to get it for you. This data is not always available, at least not in the format you would like it to be.” (Chalmers teacher 1)

Some data might be available, but it could be questioned how good it represents reality. For example, a student group found that a company was using an outdated ordering cost. When a student group examined it, it turned out that when the IT system was installed ten years ago, an ordering cost was entered into the system by an external consultant without knowing if the value was correct, just because a figure was needed, and the ordering cost had never been changed since then. In such a case, identifying the real cost could require a lot of time. Concerning set-up times for production, the time needed for specific products might be easily measured, but for administrative ordering costs, such as purchasing-related tasks, might be more difficult to ascertain. Such activities are often shared, which makes it hard to separate how much to allocate to each specific product. Activity-Based Costing was mentioned as a method to reveal the real cost for certain products, but the teachers thought this method requires too much work to make it practically useable.

Another example of tricky input data is the inventory holding rate. Since the risk factor might differ significantly between products, the inventory rate should principally be specifically defined for each individual product. In reality, the same rate is used for all products in an organization. Moreover, most organizations do not have a person assigned to retrieving figures for calculating the inventory rate. In addition, in many organizations, the inventory rate is not set to reflect the real costs, but as a management mechanism to drive inventory levels in a certain direction.

In situations where data are needed from more than one organization, another problem is added. Due to different IT systems, data storage routines, performance measures etc., the risk increases that the different data sets are not easily comparable.

Because of these complexities, finding the perfect input for the cost calculations is very difficult. Therefore, it is important to decide the ambition level concerning which data are needed and what detail is desired:

“How scrupulous is it? How much time is reasonable to put down to get it exact?”
(Chalmers teacher 1)

Critical review

When there are uncertainties in parameters, sensitivity analysis can be performed. For example, if the inventory rate is uncertain, it might be necessary to compare how changing levels of the inventory rate affects the result.

4.2.2 Aspects on teaching and learning total cost analysis

Progression in TC learning

In the introductory course, many logistics aspects are covered, and TCA is not prioritized over other things, but a basic understanding is given. Focus is on making the students understand the basic principles, that all costs that differ should be considered and calculated. Focus is on direct costs, such as transportation costs and inventory carrying costs, while the more diffuse costs are left aside. In the courses, there is no real discussion about challenges/problems with performing TCAs.

Some of the later courses, which focus more deeply and narrowly on specific subjects, focus on certain cost factors, although using very few calculations and mainly focusing on qualitative issues. However, in a new course, SC Analytics, there will be more quantitative analysis (including big data), and TCA will probably be considered in more depth.

The teacher responsible for one of the later courses, said that even though this course deals with TC issues, the teaching is not based on what the students learn about TCA in the introductory course.

The TC model vs. more general TC/systems understanding

In the textbook used in the introductory course²³ a TC model is presented. This model is used to some extent, but not in focus. General TC understanding is regarded more important, something students have some difficulties with, due to their lack of experience.

²³ Jonsson & Mattsson (2016), *Logistik – Läran om effektiva materialflöden*

Critical review

Engineering students often believe that a correct answer always exists. But logistics is not an exact science in that sense. Exactness is not possible; it is rather a matter of getting a 'good enough' solution. It is therefore important to help students understand that they should be able to value their solutions and consider how reliable they are. In the tasks they work with in the introductory course, the students are required to perform sensitivity analyses.

The use of cases to facilitate understanding

Different exercises and smaller teaching cases are used to facilitate understanding. For example, in the introductory course, students practice TC calculation (and other aspects within logistics) and present and discuss their findings. In the environmental part of the case, the students are provided with fictional environmental cost to simplify this part of the case, so they do not get lost among too many details. It could, of course, be discussed how large the costs should be, but the students mostly accept the costs as they understand the underlying purpose of the exercise.

In real situations, a crucial skill is to be able to go through large volumes of data and sift out the most important data. Cases are regarded a good teaching form to get students to practice this. However, students often find it hard to accept that case data are not adapted and arranged to fit their needs. Concerning the amount of information available to the students, the cases need to balance the need for realism against the risk of data overload. For example, the Distribution course includes a large amount of data for the students to evaluate. Previously, even more data were provided, but the amount has been reduced due to work overload – i.e., the students tended to get stuck in data processing and spend too little time on other important issues. Because reducing the amount of data makes the case less realistic, the teacher might add more data to a specific part of the case to make input data for the cost calculations more realistic.

A self-critical voice was raised that there is a tendency that best practice cases are shown at universities, and students tend to believe that this is a representative view of the world.

4.3 Total cost analysis-related aspects addressed in master's theses

To see how TCA is addressed in master's theses, 161 theses performed within logistics and supply chain management between 2015 and 2018 were examined. Eleven of these address TCA-related challenges, although mostly not explicitly described as a challenge or a problem. All these theses deal with tasks initiated by external organizations – i.e., they deal with applications of TCA in one form or another. Predominantly, TCA is used

to evaluate specific alternatives. The following sections examine the challenges addressed in the theses.

Defining alternatives to compare

Although alternatives to investigate in most cases were more or less given from the start, there are exceptions. When investigating effects of transport consolidation, Pezeshki and Wang (2016) had to design alternative ways of consolidation before evaluating them. More and Vu (2017) identified the best countries for sourcing direct material for a company. However, they first had to limit the number of interesting countries to consider.

Defining the system

System boundaries are most often not explicitly presented. In a few cases, a system perspective is indicated as each actor's perspective of the costs were discussed (Dönmez and Zemmouri, 2016; Alickovic and Behrman, 2017).

Making time considerations

An awareness of the time perspective's influence on cost calculations is shown by Alickovic and Behrman (2017). They discuss potential expansion, increase of volumes, and future efficiency improvements etc., before deciding not to regard them in their calculations.

Identifying other aspects of importance

In a majority of the theses, other aspects are put forward to complement costs. The most frequently addressed are delivery service in different forms (e.g., lead time and reliability in delivery time), flexibility, and environmental aspects. Other aspects mentioned are communication, political factors, and achieved 'value'.

Selecting cost categories to include

In most theses, there is no discussion about the costs included. However, some authors provide motives for their selection. Alickovic and Behrman (2017) clearly discuss which cost factors will be affected by the decision and include only these. Based on a similar reasoning, More and Vu (2017) when evaluating supplier countries, exclude the suppliers' raw material cost since it is regarded to be roughly the same worldwide. Two factors to consider are lifted by Blomgren and Eriksson (2016): the relevance for future cash flows; and the possibility to influence the costs.

Selecting calculation methods

Except for Cedulf and Andreasson (2017), who use a calculation tool, TrEXTool, to estimate costs related to environmental and social effects, calculations models and methods as such are not discussed in the theses.

Defining and retrieving desired input data

Axelsson and Skogum (2016) found that much of the desired data were hidden, which made it difficult to know how and where to catch the data. To increase the reliability in data, Alickovic and Behrman (2017) triangulated observations and data from the ERP system. They report some difficulties connected to the data collection, e.g. that the observation in itself may influence the observed persons' behaviour, and that information gathering takes time:

"It was quite difficult and time consuming to go through all sales data and transactions in the system..." (Alickovic and Behrman, 2017), p. 29

Halkjaer and Nybonn (2018) report that even though at an early stage they defined which data to collect, they had to revise this later on because of limitations of the IT system.

Critical review

Most authors comment on assumptions and estimations made due to lack of information. Both Pezeshki and Wang (2016) and Alickovic and Behrman (2017) highlight the fact that historical data were used to support decisions about the future. The risk for respondents giving biased information is mentioned by Halkjaer and Nybonn (2018). To handle the various uncertainties, different measures were taken, such as with a sensitivity analysis testing different values of certain parameters (Blomgren and Eriksson, 2016) or presenting the level of unreliability (using a certain scale) as a complement to the cost figure itself (Axelsson and Skogum, 2016).

Presentation

In their work on Cost of poor quality (CoPQ), Axelsson and Skogum (2016) state that the presentation is an important step in the investigation process:

"The presentation of CoPQ needs to be easy to understand and include figures." (Axelsson and Skogum, 2016), p. 57

They use two kinds of charts in their presentation, bar charts and waterfall charts (see Figure 21 and Figure 22).

Figure 21. Bar chart showing the cost of specific activities. (Axelsson and Skogum, 2016), p. 61

Figure 22. Waterfall chart showing the size of each cost factor in relation to total cost. (Axelsson and Skogum, 2016), p. 58

To show how costs relate to other important aspects, Pezeshki and Wang (2016) use a spider web chart (see Figure 23).

Figure 23. Spider web chart showing the performance on different decision parameters for a number of scenarios. (Pezeshki and Wang, 2016), p. 84

5 Hanken School of Economics

Hanken School of Economics operates at two locations in Finland, Helsinki and Vaasa, and has approximately 2 500 students. Logistics-related courses are offered to students in Helsinki at the bachelor’s and master’s level. Courses within logistics are provided by the Supply Chain Management and Social Responsibility part of the Department of Marketing.

5.1 Logistics education – programs and courses

Hanken offers three-year programs at the bachelor’s level and two-year programs at master’s level. Courses within the field of logistics and SCM are available at the bachelor’s as well as the master’s level.

5.1.1 Bachelor program in Economics

The 3-year BSc program ‘Economics’²⁴ includes a mandatory course in ‘Logistics Management’, and some elective courses in the logistics/SCM field. Some of the elective logistics courses are provided by Arcada, a university of applied sciences, with whom Hanken cooperates. However, since most students choose not to take logistics courses at Arcada, the following description focuses on courses provided by the Hanken faculty. The logistics-related courses at the BSc program are shown in Figure 24. All courses are five ECTS credits, except ‘Business sales...’ which is worth four ECTS.

Figure 24. Logistics-related courses at the BSc program in Economics (Arcada courses not included)

5.1.2 Master’s Program in Economics

At master’s level, a 2-year program in ‘Economics’ is offered. One of the available majors in this program is Supply Chain Management and Social Responsibility, with a number of logistics and SCM-related courses, see Figure 25 below. Except for the ten-credit

²⁴ There is no formal label in English for this program; in Swedish it is called ‘Ekonomie kandidat’. The label ‘Economics’ is used in this thesis since this corresponds to the label used for the MSc program.

courses ‘Project course ...’ and ‘Advanced ... II’, each course is worth five ECTS credits. The mandatory supply chain/logistics courses account for 30 ECTS credits, and the master’s thesis covers 30 credits. The complete program accounts for 120 credits (i.e. non-logistics-related courses (mandatory as well as elective) are included in the program). (This explains why the first half of year 2 in the figure below is empty – the students are taking non-logistics courses during this period).

Figure 25. Logistics-related courses at the MSc program in Economics, the SCM and Social Responsibility major

The same courses are also available for students following the Humanitarian Logistics track within the Business and Management major, however with some differences concerning which courses are mandatory (see Figure 26).

Figure 26. Logistics-related courses at the MSc program in Economics, the Humanitarian Logistics track

Together, these two tracks at the master’s level attracts approximately 20-25 students each year. Each course, however, might be taken by additional students, as these courses are also offered within other tracks.

5.1.3 Courses within Logistics Management

Short descriptions are provided about the courses included in the programs described above. A division is made between core logistics courses, and logistics-related courses, see Table 15 and Table 16.

Table 15. Core logistics courses at Hanken

Core logistics courses	
Logistics Management	Key logistics and SCM concepts. Basic logistics strategies and models with a focus on global supply chains. Trade-offs between logistical functions.
Operations Management	Operations strategies in manufacturing and services. The role of quality in process and product design.
Sustainable Logistics	A broad view of supply chain sustainability with a focus on sustainable transportation.
Supply Chain Management	SCM concepts, trade-offs, and principles. Focus on supply chain performance material and info. flows in the global supply chain.
Supply Chain Strategy for Sustainability	Principles and practices that facilitate responsible and sustainable SC strategies and operations. Sustainable sourcing, packaging, storage and transportation.
Humanitarian Logistics	Application of logistical concepts and principles in the humanitarian setting. Familiarity with the special problems of logistics and SCM in the humanitarian context.
Project Course in CSR and Hum. Logistics	Students work in groups with analysing and solving real-world problems (provided by case organizations) related to social and environmental responsibility.
Master's Thesis	Application and integration of knowledge from logistics/SCM courses and other parts of the program. Theoretical penetration in areas relevant for the project.

Table 16. Logistics-related courses at Hanken

Logistics-related courses	
Business Sales and Purchasing Management	Fundamentals of business-to-business sales and purchasing. How to analyse, evaluate, develop, and co-create value through strategic sales and purchasing.
Supply Chain Risk and Resilience	Knowledge of supply chain risks. Assessment and management of such risks, in order to make supply chains more resilient.
Advanced Internship in SCM and Soc. Responsibility I and II	A self-study course connected to practical work experience at an internship in an organization.
Emerging Issues and Challenges in SCM and Social Responsibility	Emerging issues and challenges in SCM at the time of the course. The topics may vary from year to year.
Current Topics in SCM and Social Responsibility	Current topics in SCM at the time of the course. The topics may vary from year to year.
Research Seminar in SCM and Social Responsibility	Research methods that support the master's thesis project.

5.1.4 Total cost analysis in the core logistics courses

TCA is not a central part in any of the courses. However, total cost issues are present in many of them, mainly through qualitative reasoning, while cost calculations are only peripherally addressed. Short descriptions of total cost-related content in the courses are given below. The information is gathered through informal discussions with the responsible teachers, and by viewing course documents.

Logistics Management

Trade-offs concerning costs and other aspects. The textbook²⁵ includes a section on ‘total landed costs’.

Sustainable Logistics

Economic aspects (where costs are a crucial part) are discussed in relation to the other aspects of sustainability.

Supply Chain Management

This course examines trade-offs in managing supply chain performance, which among other things includes cost trade-offs.

Supply Chain Strategy for Sustainability

This course discusses costs for different set-ups, connected to a teaching case.

Humanitarian Logistics

Cost efficiency is put in relation to other performance measures.

Project Course in CSR and Humanitarian Logistics

Depending on the projects performed, cost issues could be addressed to various extent.

Operations Management

This course focuses on trade-offs related to inventory management.

Degree Project – Master’s Thesis

Depending on the thesis topic, cost issues could be addressed to various extent.

²⁵ (Mangan and Lalwani, 2016), *Global Logistics and Supply Chain Management*

5.2 Teachers' thoughts concerning total cost analysis

A focus group discussion was held with four of the involved teachers, two men and two women, and all the teachers took part in individual interviews. The teachers' experience in the field is strong, and collectively they cover all the core logistics courses (see Table 17 and Table 18 for details).

Table 17. Number of Hanken teacher respondents with certain experience

Teaching experience	< 5 years	1	5-10 years	0	> 10 years	3
Overall responsibility for the logistics courses (director of studies, program director or similar)						1
Practical experience from TCA in companies/organizations						2
Have created educational material about TCA						2

Table 18. Number of Hanken teacher respondents with experience from the respective courses

Course	Examiner / responsible	Actively participating
Logistics Management	3	3
Operations Management	3	2
Sustainable Logistics	1	1
Supply Chain Management	1	1
Supply Chain Strategy for Sustainability	2	2
Humanitarian Logistics	1	1
Project Course in CSR and Hum. Logistics	0	2
Master's Thesis	1	4

In the following sections, the essence from the discussions and interviews are compiled. First, challenges with TCA are addressed, and thereafter some thoughts regarding teaching TCA are presented.

5.2.1 Challenges with conducting total cost analysis

The concept map in Figure 27 shows a compilation of the challenges discussed during the focus group session. The black boxes and lines indicate ideas mentioned spontaneously. The red ones came up after some extent of inference from the moderator.

Figure 27. TCA challenges mentioned during the focus group discussion with Hanken teachers

The challenges raised during interviews and discussions are briefly described in the following sections.

Defining alternatives to compare

The issue of defining the alternatives to investigate was not brought up in the discussion. However, one of the teachers stressed that there is always a cost of doing nothing, and that the ‘do nothing’ alternative therefore should be considered.

Defining the system

There was some debate concerning the word ‘total’ in TCA:

“In ‘totality’ I think I would consider everything. I don’t think you can set boundaries then.” (Hanken teacher 1)

However, the teachers agree that in practice one must decide how much and what to include in a study and therefore set the boundaries. This is something that is regarded as a main challenge, especially when one lacks experience. An example was given of a U.S. company that outsourced some operations to Mexico in order to cut costs. The company failed to consider that the inventory would be affected. In fact, the increased unpredictability in supply forced them to put up a big safety stock. In the end, it turned out that the total costs rose after the outsourcing, partly because they had not understood what to include in the system when estimating the costs.

In addition, some raised the issue of whether system boundaries are suitable depends on from whose perspective this is considered. Looking at the total cost of freight from shipping from one place to another, an issue is the costs of decarbonization, but this cost is a societal cost, not covered by a certain company. Therefore, from a company perspective, the system would be more narrowly defined than from a societal perspective. These issues are also present when considering transactions between companies. One teacher referred to a case in the Nordic reader case book by Arlbjørn et al. (2006), where Toyota by putting pressure on a supplier made the supplier's costs increase without this affecting the price Toyota paid. Another teacher argued that companies always end up paying in the end, but the opinions differed concerning this.

Making time considerations

A specific problem connected to calculations is that you're limited to the information available at the time. In a year's time things might have changed. That is, basing the calculations on present data, what is the TCA worth if the time perspective is extended?

Identifying other aspects of importance

There was a consensus that looking at costs only would be too narrow-minded, with the effect that strategically important issues might be neglected. Although costs often are important, there are trade-offs with other aspects, such as environmental impact and social impact. One of the teachers stressed that it is the whole set of parameters that should be considered. Outsourcing to a foreign supplier might look good from a monetary perspective, but there will be more pollution due to the longer transports and there is a risk of poor labour conditions.

Another aspect brought up was 'value'. As a customer, you would like cheap products, but you also want the products to contribute to an increased value for you. However, it was expressed that value is not always easy to measure. A similar problem comes with 'risk'. Although it is easily understood that costs might rise because of certain risks, it might not be possible to calculate the risk costs.

Selecting cost categories to include

Buying from China was brought up as an example where many companies might disregard the costs for inland transports, port expenses, duty, warehousing etc. Tightly connected to defining the system boundaries comes the issue of identifying which cost factors to include. The major challenge here is to understand the system and the processes well enough to see what is affecting the costs, and which the cost drivers are. Some less obvious cost factors mentioned during the discussion were costs for recycling of used products and costs for changing supplier.

Part of the discussion dealt with an observation that in companies the ‘wrong’ costs are frequently in focus. Much attention is often given to rather small expenses, like coffee, while the large expenses are ignored. A possible reason for ignoring large costs is that people find it difficult to grasp large numbers. Another explanation presented was that it is very tangible if the cost for coffee increases by 5%. When the complexity gets higher, it becomes more difficult to grasp and understand.

Selecting calculation methods

For the students, calculations can be a challenge due to limitations in mathematical skills. Although many TC calculations as such are simple, the students lack confidence in their calculation skills. The main problem, however, is that if they do not understand the algorithms used, they cannot see the possible shortcomings in the calculations made and formulas used. Concerning calculations, a warning was given that trying to be too exact will require too much effort compared to the outcome. One should try to find a suitable level of detail is:

“Some things are not worthwhile to calculate” (Hanken teacher 3)

Defining, retrieving, and processing desired input data

Something lifted as a major challenge is the problems of retrieving data for cost calculations. One teacher argued that students do not know where to find data, or what data they need. Another teacher then replied that the same goes for practitioners in companies. Furthermore, it cannot be assumed that desired data desired is readily accessible:

“Whatever you want to analyse, and what you have data for are to very different things” (Hanken teacher 2)

Sometimes, the lack of data is due to shortcomings in an organization’s IT system. It was argued that many companies do not really know what is in their systems and how these systems work. In other cases, there might be a reluctance to share information. One of the master’s students intended to perform a cost study, but the organization she set out to study denied her access to the data she needed.

Referring to a project performed within warehousing, one teacher described that the number of order lines can differ much from order to order. The order administration cost that each product should bear differs from case to case, which causes calculation challenges. Should this be considered each time or should the average figures be used?

Critical review

As stated in the previous sections, there are uncertainties associated with TCA, such as lack of data, limited knowledge about the future, and system boundaries that may be too

narrow. Part of TCA is the ability to modify and evaluate the TC procedure (inputs and analyses) to reach a better decision. Sensitivity analysis was highlighted by one of the teachers for its ability to test how variations in input, time considerations, probabilities, etc. affect the output. For example, if the price of oil falls to \$10, what would happen? What if it rises to \$110? What would it do to costs? How would it affect the price we have to charge our customers? Where are the thresholds when a certain alternative is better than another?

5.2.2 Aspects on teaching and learning total cost analysis

Cost calculations vs general understanding

The general opinion in the teacher group is that it is crucial that students have a basic understanding of operations, including the main costs, and what drives these costs. When cost drivers are known, different tools can be used to support the calculations (e.g., Excel). However, unless the analyst has a proper understanding of the system and the operations, the analyst cannot construct cost equations that suit the situation. Uncritical use of standard formulas might cause problems. For the educational context, one of the teachers recommends the ‘first things first’ principle – i.e., make sure the students understand the basic principles and relationships before going into calculations. In line with this, one of the teachers argued that at early stages in the logistics courses system boundaries should be set rather narrowly; only when the students have reached a better basic understanding, should teachers introduce larger, more complicated systems.

Referring to humanitarian logistics, where decisions often have to be made quickly, the issue was raised that there is not always time for detailed cost analyses. Quick cost estimates might have to be done, which then should be based on a proper principal understanding. Although the skill to make good estimations quickly is a kind of tacit knowledge acquired through experience, it is important to make students understand that this kind of decision-making sometimes is necessary.

Cases, games and other pedagogical forms

Especially at the master’s level, lectures are rarely used. Discussion seminars, assignments, and teaching cases are more common. The Humanitarian Logistics course, for example, is largely built on the use of teaching cases. An example of a case where cost issues are discussed comes from the Supply Chain Management course, where transport mode selection is made based on costs, volumes, time, and distances.

As a result of a student project, a teaching game about humanitarian logistics has been created. The game has so far only been used in external courses, but since it has been much appreciated, using it with the master’s students has been discussed.

Total cost analysis in the teaching

The courses do not explicitly focus on TCA even though cost issues are touched upon in many courses (see section 5.1.4). One thing that was discussed was that even though the teachers view sensitivity analysis as an important part of TC investigations, the courses generally ignore it. Using teaching games was suggested as a suitable educational form for learning such skills, since games can help students see the effects of making certain decisions. Major projects, such as the one in the Project Course in CSR and Humanitarian Logistics, is also regarded as potentially suitable for putting more focus on critical review and sensitivity analysis.

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