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Scenarios for Resource Efficient Rail Infrastructure- Applying Integrated Product Service Offerings

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Abstract

The rail infrastructure in Sweden, with its long lifetime, large amounts of materials used and traditional procurement, has escalating maintenance costs. What would occur if the infrastructure is instead procured as an Integrated Product Service Offering (IPSO)? This paper discusses scenarios for increased resource efficiency and more value for the money spent by applying an IPSO perspective to rail infrastructure. The best option depends on the conditions at the construction site as well as how much the availability of the tracks is valued.

Keywords: rail infrastructure, maintenance, availability, product service systems

1. Introduction

It has been stated in previous research that a large part of the greenhouse gas emissions from railway transport in Sweden comes from material-related energy use of the infrastructure [1]. This is because hydro and nuclear power is used for railway transport, but large amounts of material are involved when building and maintaining the infrastructure [1]. At the same time, industry has low motivation to innovate, rarely uses new products and methods, and the lowest price is the main driver for selecting a tender [2, 3].

Previous research has shown that using integrated contracting for infrastructure projects including design, construction and maintenance has resulted in lower life-cycle costs as well as faster completion [4]. Furthermore, using a product-service mix with more durable materials and other designs may prolong the lifetime of the product and potentially optimize maintenance and operations [5].

Every year the need for transports is increasing in Sweden, and at the same time the transport system is deteriorating [6]. There is an aggregated need for maintenance, causing errors in the infrastructure that subsequently affect the train traffic. During 2012, this caused 22,000 delay hours for trains in Sweden [6]. The train traffic also has major issues regarding availability and punctuality [7]; a third of all delays were related to the infrastructure and caused by signal systems, tracks and switches [8]. It has been concluded that there is a need for more proactive maintenance to create a robust system that causes less disturbance to the traffic due to an increased need for error correction [6]. It has also been shown that the corrective maintenance is increasing, and not the preventive [9].

There is an increased focus from the government side on transferring transports from road to train traffic [10]. In a proposition concerning the national transport plan for the coming 10 years, major infrastructural investments are planned including a new high-speed railway in the south of Sweden (Ostlänken), combined with a large sum for maintenance and reinvestment for the existing tracks [6].

The concept of the Integrated Product Service Offering (IPSO) has proven to be a way to potentially reduce the environmental impact of products and services, as well as to...
act as a driver for change and increase cost efficiency and quality. If the provider has control over the whole life-cycle, this would create incentives to realize more economically and environmentally-sound development [11]. Compared to the concept of Product Service Systems [12], the integrated development of the product and service is emphasized in the IPSO term. A performance-based IPSO contract where the availability is in focus could be a way of decreasing the problems the Swedish rail infrastructure is facing at the moment. There is a lack of publications of IPSO for rail infrastructure and in combination with interest from the industry in the field this implies that there is a gap in the area where research is needed [13].

Currently, the Swedish rail infrastructure is not built with a life-cycle perspective, and the standard procedure is that the Swedish Transport Administration (STA) already has decided how to build or maintain when a contractor is chosen for the project. The infrastructure has a long lifetime spanning several decades, making the life-cycle perspective very relevant since maintenance is needed continuously during this time. IPSO contracts provide a holistic life-cycle perspective and incentives for dematerialization, which could result in a more resource-efficient and durable infrastructure. This implies that the provider needs to be in charge of the design phase, since it is there where materials are selected and most of the environmental impacts are set [14]. By involving the contractors in the design phase their knowledge could be used in a better way, creating a feedback loop from practice to design [15].

The majority of the environmental impact from the infrastructure, i.e. not rolling stock included, can be contributed to three products: steel rails, concrete ties and ballast material, that is steel/iron, concrete and crushed rocks [1]. It would therefore make sense to study what changes can be made concerning these materials in building and maintaining rail infrastructure to decrease this impact. The infrastructure has a long lifetime and use phase, from 40-60 years, implying that ways of decreasing maintenance in cost, material and energy use have a significant potential for improvement. If the railway could be built and maintained in such a way that for every SEK spent more railway would be built and maintained, it would definitely create more value for the tax money, considering Sweden has 11,000 km of railway.

This paper aims at discussing scenarios for increased resource efficiency and more value for the money spent, by applying an IPSO perspective to rail infrastructure. Actors in the industry were interviewed, the information synthesized and scenarios created to illustrate technical changes and possible improvement when applying an IPSO approach. This paper does not provide a detailed calculation of the environmental and economic changes by making changes in processes and technical solutions. Instead, it provides possible scenarios for change focusing on technical changes and work procedures. This derives the first research question.

**RQ1 – What potential scenarios can be used to exemplify the IPSO concept for rail infrastructure?** These scenarios are then discussed in a qualitative way to analyze how these changes would affect the use of material and energy as well as the cost for railway projects. This provides the second research question.

**RQ2 – How could the changes in the scenarios influence the life-cycle cost and the environmental impact of rail infrastructure?** By exemplifying the use of IPSOs for rail infrastructure and showing a different way of thinking through a life-cycle perspective, this paper serves as an eye-opener for the actors in the industry, as well as contributes to the research field with a practical potential implication.

This paper is structured in the following way. In Section 2 the research approach is presented, followed by a description of Swedish rail infrastructure management. The scenarios are presented in Section 4 and subsequently discussed in Section 5. The conclusions are presented in Section 6.

### 2. Research approach

Scenarios can be constructed in many different ways in various studies and should work as a catalyst for creative thinking and analysis [16]. The focus can be a single or a more complex development. It is important to provide information about assumptions made, sufficient detail for the specific study where the scenario is used as well as to be concrete enough to analyze in practical terms [17].

In this paper scenarios are used to describe possible changes that can be made in building and maintaining rail infrastructure by adding an IPSO perspective. Concrete options are illustrated and the assumptions are presented e.g. background information about the current procurement process, respondents involved and geological preconditions. By describing possible alternative design options the scenarios provide a foundation for a discussion concerning resource efficiency.

The scenarios were developed based on interviews with eight employees at the STA: construction site manager; maintenance coordinator; maintenance analyst; project leader investment; product developer; project leader operations control; head of section for specialists in technology and environment; and head of department for technology and management in investments. The respondents were chosen because they work close to the actual construction and maintenance of the infrastructure. This means they have competence about the technical solutions currently used in the projects.

The respondents were asked to think outside the confines of current practice, using separate contracts for construction and maintenance as described in Section 3, and instead apply a life-cycle perspective. The changes the respondents identified could be either other types of technical solutions, changes within the organization or the work processes. This paper focuses on the technical changes. More specifically, the respondents were asked to “Consider the possibility of the contractor having the responsibility to design, build and maintain the infrastructure for a longer period of time; what would they do differently in terms of technical solutions?” Questions such as “what affects the lifetime of the infrastructure and why” as well as "what type of impact factors for this exists" were asked. Examples of impact factors could be geological conditions such as swamps and rocks as
well as the length of the line and organization. Complementing information has also been retrieved from various scientific papers and reports.

Most of the respondents did not identify any real concrete changes when asked during the interviews. They had a difficult time to think outside of the current procedures applied within the STA. This was clearly also hindering several of the respondents to think in a different way. The scenarios discussed in this paper are the product of innovative thinking from three of the respondents that had the ability to apply the IPSO perspective.

Employees from the contractor organizations, the providers, were asked to participate but never responded to the request. In some scenarios, additional information about price has been retrieved from a material catalogue published on the STA’s homepage [18] as a tool for the contractors.

3. **Swedish rail infrastructure management**

The life-cycle of the rail infrastructure is divided into several different contracts, with different actors involved in each phase. There is no continuation between building and maintaining since these are separate contracts. The STA is divided into two divisions, where the Investment Division is responsible for the design and construction phase, while the Traffic Division is involved in the maintenance phase. The current procurement practice is seen as resource-demanding from both sides. The procurement is seen as inefficient; an example is the design results that are delivered by consultants that are not optimal for actual building. These quality issues are noticed by the contractor during the building phase, and result in lost time and money when the design has to be redone.

Construction contracts, or Design-Bid-Build contracts, are the most common for building rail infrastructure in Sweden. The technical solutions and how much of each material is needed are specified by the procurer, the STA, and the winning tender is normally the one with the lowest price. Construction contracts do not create any incentives for a more efficient process; instead, the contractor benefits from reaching the maximum roof for the price set [19]. A newer type of contracting is the Design-Build contract, where the contractor is responsible for construction as well as the more detailed design phase [20]. This type of contract has not shown any benefits in terms of efficiency so far [21].

When maintaining the infrastructure, detailed contracts spanning a maximum of seven years are used, which is a short period of time compared to e.g. the lifetime of the tracks lasting 40–45 years.

3.1. **Geology creates fundamental preconditions**

The choice of structural support needed for the railway is very much affected by the geological preconditions in each particular area. Different types of soil require more or less support depending on their characteristics, and this consequently affects the cost of the project. Structural support is used to avoid instability and subsidence, and the need for structural support depends on the thickness of the layer of soil, the strength of the soil, the load from the traffic on the tracks and the load on the banks next to the railway. This choice of structural support is a very complex topic, and will therefore not be studied as one of the scenarios in this paper.

4. **Scenarios**

This section presents five scenarios for change. All the information comes from the respondents unless otherwise indicated. The scenarios are illustrated in the end of the chapter.

4.1. **Scenario 1: Choice of track type**

This scenario presents the choice between ballasted track and ballast-free track, or slab track, as shown in Fig 1a. Slab tracks are built by fixating the tracks in concrete, compared to traditional tracks where ballast is used. For traditional tracks, the ballast material causes problems when it deteriorates and causes drainage problems and geometrical irregularities [22]. This means regular maintenance is required to keep the quality of the infrastructure. For high-speed trains another problem is added as well; the ballast particles swirl when the trains pass, for example causing damage to the wheels [22].

Even though the tracks are fixated and cannot cause any variation in geometry causing problems for the trains, the concrete foundation requires structural support to avoid cracks. Slab track requires less maintenance and thereby provides higher availability than ballasted tracks [22, 23]. Different studies have shown cost-saving potential over the life-cycle of slab tracks compared to ballast tracks. The initial cost for building slab tracks is significantly higher than for ballasted tracks, but the savings over the life-cycle is greater than the initial construction cost [24]. The reason why slab track is more expensive to build is for instance a longer building process that requires more measuring and increased accuracy, since the structural foundation is of extreme importance [25]. Not everything in the construction phase is more expensive; for instance, less digging is needed since no ballast is used [25].

4.2. **Scenario 2: Choice of number of tracks**

This scenario presents the choice between double and single tracks, as shown in Fig 1b. In Sweden, the standard is to build single tracks with meeting points for the trains to pass. If more capacity is needed, the cheapest way is then to add more meeting points. Every meeting point requires switches, however, and these are expensive as well as maintenance-heavy. Double tracks, on the other hand, provide better flow for the traffic and fewer switches but cost much more to build. Obviously, more material is needed but also more land needs to be acquired, adding to the costs and the land use. Switches are expensive and require a substantial amount of maintenance during their 40-year lifetime. If compared, the cost of one of the cheapest switches equals around 3 km of track.
4.3. **Scenario 3: Choice of steel quality**

There are different steel qualities to choose from when building railways, as seen in Fig 2a. Mostly two standard qualities are used, one for curves and one for straights. The wear on the curves is significantly higher, and therefore a better steel quality is used for curves. The outer part of the rail, which is most affected by the wear, is changed every 10-20 years depending on the radius of the curve - the smaller the radius, the greater the wear. For straight stretches, the load is less and thereby the rail is less worn, and these rails are changed in the interval of 40-45 years. The cost of the premium steel tracks is 25% higher, which indicates a 25% decrease of the maintenance cost is required for this scenario to be feasible. The cost of the reconstruction, that is changing the rail, also has to be taken into account.

4.4. **Scenario 4: Choice of space between tracks**

When constructing tracks the space between them can differ, as Fig 2b illustrates. When double tracks are chosen, the distance between them is as a standard 4.5 meters. This means that when maintenance is carried out on either of the two tracks, the train speed on the other track has to be reduced to 70 km/h or less. This equals a double disruption for the traffic, on the track that is maintained as well as on the other track due to speed limits. Instead, the tracks can be built with a distance of 6.0 meters between them to reduce the traffic disruptions. This is sometimes done, but it is more expensive due to more land use and more processing of the land that is needed, for instance if more rock needs to be cut through.

4.5. **Scenario 5: Choice of shape for embankments**

On each side of the track or tracks the surrounding soil has been affected by the construction in one way or another. When the infrastructure is built in hilly or rocky terrain there are different ways of shaping these surroundings, as shown in Fig 3. One way is to keep steep hills, while another is to cut and transport rock and soil away from the site. The latter is more expensive due to labor and transport, which also causes a higher environmental impact due to diesel use. However, keeping the surroundings flat generally decreases the maintenance costs. Steep cuts, especially in rocks, can be very expensive too cut if the quality of the rock is bad and requires nets, bolts and extra reinforcement. The flatter cut does cost more to construct, but requires less maintenance. It all comes down to the quality of the surrounding macadam/crushed rocks and if they can be reused. If there is a shortage of macadam along the railway line, the cost of shaping has to be related to the cost of purchasing macadam from somewhere else and vice versa. Sometimes a steep surrounding might be needed to protect for instance a road on the other side.

5. **Discussion**

Due to the fact that a railway system is interconnected, an interruption on the main line will affect not only that section, but also have a great impact on the train traffic in other areas. In Sweden, the track system runs at near full capacity in many areas [8], and there are many areas with only single tracks. This means that there are little or no margins for delays and interruptions. On the main line, an interruption is very expensive for the actor responsible for the infrastructure since compensation has to be paid to the train operating company. Passenger transportation and freight traffic use the same tracks today, contributing to bottlenecks in capacity in some areas. At the same time, the Swedish government has an increased focus on transferring transports from road to rail traffic [10].

The scenarios present different choices for the construction of the rail infrastructure, but they all have in common the fact that they affect the maintenance and reconstruction need and the availability of the track. Higher availability means an increase in trains, making it possible for instance to realize the shift from road-based to rail-based freight transport. Increased use of the railway system would also increase the income for the STA as well as decreasing the environmental impact from transport. Availability is a critical factor in the Swedish railway system, and is strongly coupled to the maintenance.
Track designs that require low maintenance are increasing in Europe, but so is traffic intensity, making it more difficult to find slots for maintenance work [22]. This is why availability is one of the main issues in this discussion. If the infrastructure can be built in a more durable way, less maintenance is needed and the availability may increase. The five scenarios presented in Section 3 are not revolutionary, but could still contribute to a more resource-efficient infrastructure. The parts affected in these scenarios are mainly ballast, rail and switches. They contain two (steel and crushed rocks) of the three materials that contribute most to the environmental impact from the infrastructure [1]. This fact makes these scenarios relevant in the discussion concerning resource efficiency for the rail infrastructure.

The slab track option requires less maintenance than the ballasted tracks, but since it is more expensive to build, a long perspective is required to reach the point where it is profitable. This point in time will be reached faster the more availability is valued, and the maintenance during the use phase needs to be avoided. In Scenario 2, the option of using more double tracks is presented. This increases the land use as well as the material use, but the availability is also increased. The need for availability is the factor that will determine which option to choose.

Scenario 3 presents the options of steel quality. The question is whether a more expensive steel quality would be worth using on the straight to make the rail last longer and minimize the maintenance and reconstruction. In this case, it would save material and labor costs over the life-cycle. Less maintenance decreases the number of times the track has to be closed for traffic; hence, the availability increases. This scenario is very closely related to Scenario 4 concerning the space between the tracks. Using a wider space would facilitate the maintenance process and not affect the availability of the other track. On the other hand, more land use is required, which can be a problem in highly populated or rocky areas due to lack of land or high cost connected to the construction. The choice between the widths of the space can be adjusted to the conditions and surroundings along the rail track. Finally, the shape of the embankments in Scenario 5 also affects the maintenance. Generally, the steeper the cuts, the more maintenance required, which in turn affects the availability of the track. A nice synergy is if the cut macadam can be used along the track and thereby minimize the transports. This scenario very much depends on the conditions for the specific construction site.

5.1. Adopting a life-cycle perspective

All of the scenarios have options where the maintenance could be decreased, cutting cost and environmental impact from material and energy use. However, these options add to the construction costs, and given the way the management of the infrastructure is handled today, it is not an option. A life-cycle perspective is needed to see the positive influence on material and energy use as well as availability. It is generally known that it is in the design phase that materials are selected and most of the environmental impacts are locked into a product [14]. This is why it is so important to have the whole lifetime of the infrastructure in mind when choosing technical solutions.

Which option is the best very much depends on the conditions at the construction site: if it is a rural or an urban setting, if it is a regional train track or a track for high-speed trains, etc. The aim of this paper is to show how to change the current practice and achieve more value for the money spent on the infrastructure by applying a life-cycle perspective. This goes hand-in-hand with previous research, which states that a competitive IPSO provider is required to use a minimum input of resources for a maximum utilization of the elements in the offering [26].

There are regulations that hinder the development of the infrastructure. For example, the land use is an important issue for several scenarios, since building with a larger space between the tracks or building a double track requires more land. A reason supporting the current practice could be an interpretation of the law of building railways, which states that “the location and the purpose of the railway should be obtained with the least amount of intrusion and inconvenience and with an acceptable cost” [27]. Using single tracks is for instance the option that is the least invasive on the land surrounding the infrastructure, but is it realized with an acceptable cost? One disadvantage that affects the societal costs is the total stop that is created when there is only a single track; at least a double track could keep the traffic flowing on a limited basis. When only taking into account the initial building cost a single track is cheaper, but when including the maintenance and the societal costs over the life-cycle of the infrastructure, the answer might be different.

In this discussion it is also important to add that the profitability of the different options in the scenarios depends on which lifetime that is used for calculating the life-cycle cost. Expensive investments normally take a substantial time period to recoup, but this depends on the value that is set for availability of the tracks. However, it can be concluded that no matter how long the calculated lifetime is set for, it is important to actually take it into account and adopt a life-cycle perspective in the construction process.

5.2. A hindering organization

The fact that the organization needs to undergo changes when transitioning to IPSO thinking is well-known and documented in the literature. Mont [28] states that if buyers have a traditional mindset, they might lack the knowledge about life-cycle costs and therefore be unable to evaluate or understand the offering. Additionally, it is necessary to work in a cross-functional way to design an IPSO [29]. Previous research has shown that the way the STA is organized today, with separate construction and maintenance phases, is a major hurdle, and the organization has an internal reluctance to change and develop the process of contracting as well as lacks a long-term overall perspective [15].

An interesting aspect of this case is that strong public support is needed to create incentives for major economic and environmental innovation [30]. Also, demands from public procurement can serve as a driver or a barrier for IPSO from a provider’s perspective [12]. In the case of the Swedish rail
infrastructure, this creates a dilemma. The STA provides contracts for the public procurement market of rail infrastructure, but is also the buyer of the solutions provided by the contractors. This makes the situation complex, since the same organization that can accelerate the innovation process can also hold it back.

6. Conclusion

With a railway system already using a major part of its capacity, the availability of the tracks becomes very important. This paper has explained why the rail infrastructure industry would benefit from a life-cycle perspective, and how the technical solutions could be altered using IPSO thinking. The situation is complex, since one dominant actor has the potential to hinder or facilitate the development.

A natural step for this research would be to explore the scenarios even further, and to perform life-cycle assessment and life-cycle cost analysis to more thoroughly investigate the changes and potential. Additionally, with the help of geotechnics the importance of and the potential for the structural support could be a focal point in future research.

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