Including Student Case Projects in Integrated Product and Production Development Research – Methodology Description and Discussion

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Abstract

Within integrated product and production development research, case studies need to be performed for data gathering purposes. Today, there are two commonly used ways to perform this research; observing industry projects or having the researchers perform the projects themselves. The first option can pose data access and IPR issues, and the second option comes with biasing risks. Another approach is to work with student case projects, giving students interesting projects and finding a solution to mediate both data gathering opportunity and biasing risks. This approach has been tested at Linköping University, with students performing projects in the Vinnova funded Production 2030 – Large Scale Production in Mixed Materials project. Two larger student case projects have been performed on the topic of material substitution and mixed material solutions within the automotive industry. In this paper, the method used to include student projects is presented along with identified benefits and drawbacks. Including student case projects in research have shown to be beneficial in research on processes, projects and methodology, but needs to be complemented by data from industry projects and the researcher´s own work within integrated product and production development in order to create a more reliable analysis with high level of detail.

Keywords: Case studies, Integrated product and production development, mixed material solutions.

1. Introduction

Integrated product and production development is a fairly new field in research, trying to integrate the vast knowledge in product development and production development into an integrative way of product realization.

Within the field of integrated product and production development research, larger development project studies often need to be performed in order to gather data for analysis. Today, there are two commonly used ways to perform this research; one is using industry projects (observing an already existing project at an industrial partner) and the other is having the researchers perform the projects themselves, with or without help from industrial partners.

To do the research within industry projects can pose issues, due to IPR sensitivity clashing with the Swedish principle of public access to information [1, 2] and business case secrecy complications. There is also an unknown factor in what material is released to the researcher, if the project is not set up with full transparency. Since projects studied are often already existing or planned projects at an industrial partner, the researchers might observe projects not well-suited for the research.

For the researchers to perform the projects themselves comes with biasing risks and the risk of limited knowledge; the researchers might not have experience in all engineering activities needed to perform the project themselves, and becomes reliant on either industrial partners or colleagues for specific tasks.

Another approach is to work with student projects, in order to give students interesting projects and find a solution to mediate both data gathering opportunity and biasing risks.

A lot has been written on the product development process [3, 4, 5, 6, 7, 8, 9], and on material selection processes [10, 11, 12, 13, 14], but new materials and subsequent manufacturing processes can affect the process since products can be viewed as a compromise between material, geometry and manufacturing processes [15]. Therefore, it is relevant to research how decisions regarding new materials are taken in integrated product and production development.

This paper aims to present a methodology on how to use student projects to investigate decision-making regarding introduction of new materials in existing production systems, discuss the benefits and drawbacks of this methodology and present possible solutions to manage these drawbacks. The authors have set up to case projects within engineering design projects at Linköping University, in cooperation with a Swedish vehicle manufacturer, to investigate how this approach can generate useful results.

2. The setting: Production 2030 – Large scale production in mixed materials

Produktion 2030 is the current Swedish strategic programme for production research and innovation [16], and one project within this programme is the Large scale production of mixed material products project [17]. This project involves academic and industrial (automotive industry) partners, and investigates the challenges when introducing new materials in existing manufacturing processes, looking at demands on the manufacturing system, materials and products in order to enable maximum ROI on introduction of the new materials.

Produktion 2030 – Large scale production of mixed material products is an attempt at discovering the new challenges following the trend of including lightweight materials in products [17], challenges that have been highlighted within the automotive industry in recent years [18, 19, 20, 21]. These new materials can sometimes demand new manufacturing and assembly technologies [15] that in turn affects the product development process due to the interdependency between product development and manufacturing [3, 22].

While these new materials and manufacturing technologies are being introduced, engineering design education (including product development and mechanical engineering) is not developed to the same pace, and many experienced engineers in industry does not get the professional development needed to fully grasp the new possibilities and challenges. This makes for a strong case to further investigate what happens when selecting materials in products or components, to further understand and develop new tools for industry.

3. Why case studies?

While quantitative studies are vital for integrated product and production development research, two important questions that are hard to answer via quantitative methods are "how?" and "why?". Why decisions are taken, how tools and methods are being used or why information is valued in certain ways are questions very much relevant for integrated product and production development, and questions well-suited for a case study approach to research [23].

If one decides to go for a case study, the choice of respondents is one of the main decisions when deciding the study. In an academic setting, two different possibilities are selecting a project team in industry or selecting a student project team. There are arguments for both choices; observing a professional team in industry eliminates many uncertainties in qualifications and project relevance, while selecting student projects to observe might enable multiple cases since university courses are comparatively short (seldom more than half a year in timespan), and being able to fine-tune the project specification to the research focus. Other reasons for having student respondents might be to have almost total control of information, and therefore being able to tailor data gathering to a larger extent than when studying an industrial project. It is also easier to focus on early phases of product development; simply cutting out parts of the detailed design phase not beneficial for analysis.

On the other hand, there are also arguments for not using both options. Looking at using industrial cases, there is a challenge to ensure that all relevant data is shared due to IPR challenges, and with student cases questions regarding biasing risks emerge. Also, is there a risk that the researcher designs a student project so that the results are confirming earlier hypotheses while being untrue?

4. Case theory and earlier implementations

Case studies have been shown to be useful when the object or environment under study is hard to define or "messy" [24]. Combined with the suitability of case studies to investigate complex events [25], case studies have been popular in both product and production development research.

Why decisions are taken, how tools and methods are being used or why information is valued in certain ways are questions very much relevant for integrated product and production development, and questions well-suited for a case study approach to research [23].

Case-based approaches are framed by time and activities [26] and often investigates phenomena where the theory is weak [24]. Within case-based approaches, single-case and multiple case studies are two distinct categories of research designs [26].

4.1 Case studies in product development research

Since product development often is project based, case studies are common as a validation method for method or tool development. Examples are implementations of new development approaches [27] and validations of design tools [28].

Since product development problems are described as ill-defined [29], with no objectively correct answer [30] and often contradicting requirements [9], case-based approaches are very much relevant in order to study phenomena within the development process.

4.2 Case studies in production development research

Case studies in production development research have been used to investigate material efficiency [31], generate possible concepts for novel Human Robot Collaboration systems [32], data gathering regarding assembly flexibility [25], the effect of responsiveness and flexibility to customers on manufacturing [33] and comparing strategies for competitiveness in manufacturing companies between countries [34].

In production development, case studies can be very benefitial when looking at complex phenomena [25] where data gathering needs to be done via multiple mediums [25, 26].

5. Implementation

In order to generate enough data for analysis and being able to compare different product development processes, a multiple-case approach was selected. The number of cases in this first study was set to two, to keep the data set at a manageable size and to ensure the possibility to improve the research setup before continued work.

In this research set up, two larger case project have been performed in order to investigate certain aspects of including new materials in existing production systems. Both projects have been made as course projects in larger (18hp and 12hp) project courses at Linköping University, with help from industrial partners with base data, requirements and observational visits in manufacturing plants. Both courses were stretched over the whole semester they were conducted (one in spring, the other in fall).

The authors acted as project owners in both projects, having the project teams reporting to the authors and having regular (weekly) briefings during the course of the project. In case 1, an external steering committee (consisting of academics at the university, involved in the course) were used in collaboration with the project owner for the gate meetings, while both authors were responsible for gate meetings in case 2.

In both projects, the student project teams had weekly meeting with the corresponding author getting general supervision, following a Visual Planning-derived meeting layout. All students present were asked to answer three questions individually:

- What have you done since the last meeting?
- What will you do until the next meeting?
- Is anything worrying you right now?

After these questions had been answered, the corresponding author would address the topics mentioned as sources of worry, give general information, take general questions and have a short, open discussion. Meeting time started out around one hour per meeting at the start of the projects, reducing to half an hour during the middle of the projects and expanding to close to an hour again at the end of the projects.

5.1 Case 1

Case 1 was set up as an open-ended project focusing on lightweighting via material substitution on automotive roof structures. The project was set up to follow the Ulrich & Eppinger model of product development [8], with 4 main gates. The main restriction was that the assembly line would be as intact as possible, which was translated into a requirement of a possibility of implementing the solution with only one production cell added. Suggestions on how to improve the layout by making larger changes was encouraged.

This, along with a restriction on added cost (see exerpt below) set up the main framework for the requirements.

”... design and construct a lightweight roof solution for Volvo Car Group, and develop and demonstrate an assembly sequence that can be implemented with little to no increase in manufacturing cost” / Exerpt from project start-up documents, translated from Swedish to English.

The project team were given CAD data in form of the body sides and roof of a mid-size station wagon for their project, along with basic requirements on the end product along with study visits and filmed material of specific processes.

The project team consisted of eight third-year students in Design and Product Development, these students also wrote their bachelor thesis on specific topics within the project (see table 1).

Table 1: *Specializations within case 1*

No. of students	Topic	Thesis title
2	Product development	Technical Opportunities and Limitations for Lightweight Materials in the Automotive Industry
2	Industrial design engineering	Design concepts for car roofs made of carbon fiber composite
2	Production	Create a more efficient assembly process for car roof structures when introducing lightweight materials
2	Product development	Opportunities and limitations in the manufacturing of body components in lightweight materials for the automotive industry

Information was gathered via the four gates, the final project report, the four bachelor theses and an unstructured group interview at the end of the project. The objective in this case project was to investigate how the product development process was applied in the case of integrated product and production development projects, and how decisions regarding material selection were taken.

In the case project, concepts were ranked and selected via concept screening [8] and concept scoring [8], as well as discussions to cover aspects difficult to quantify.

5.2 Case 2

Case 2 was set up as an open-ended product and production development project on lightweighting via material substitution on automotive roof structures. The project was set up to follow Cross’ model of product development [9], with 8 main gates corresponding to two full iterations of the project. One major difference between case 1 and 2 was that the material in the final product in case 2 was restricted to be an aluminium derivative, while the material in case 1 was unrestricted with regards to material type.

The project team were given CAD data (body sides, roof and roof structure) from a large SUV in order to recreate a real-world realistic project set up, along with basic requirements on the end product along with study visits and filmed material of specific processes.

Table 2: *Team setup within case 2 project.*

No. of students	Program
4	Design and Product Development
1	Mechanical Engineering masters program

In case 2, the project team consisted of five fifth-year students, from the Mechanical Engineering masters program and the Design and Product Development program (see table 2). This project team was also set up to collaborate with another student team from another university, them focusing on production system changes and production system simulation [35].

Information was gathered via the 8 main gate documents, as well as two unstructured interviews (one at half time and one at the end of the project) and individual reflection documents mandatory for the course grade.

The objective in this case project was to investigate how an iterative product development methodology would affect material selection, and how decisions regarding materials were taken when material type and parts of the production system were clearly restricted.

In the case project, concepts were ranked and selected via concept screening [8] and concept scoring [8].

6. Findings and analysis

The lack of restriction regarding material in case 1 proved to be a minor challenge for the students, and forced the team to develop a visualization of the interdependency between cost, environmental aspects and lightweighting possibilities at a certain time for a material. From this, the students found that additional information regarding time for implementation was needed.

The result from case 1 has potential for further development, mainly in structural design, due to the students’ lack of experience in computational analysis such as Finite Element Analysis.

The respondents in case 1 identified possibilities for production sequencing changes following the material change and initial design, showing a number of secondary effects of changes in integrated product and production development.

In the final interview, the respondents in case 1 emphasized on the issue of implementation vindow within their process. While they could estimate costs and effects on product qualities with reasonable fidelity, it proved difficult to appreciate when a certain solution could be seen as viable from an industrial point of view.

Initially in case 2, the student team was restricted to only use existing production cells to join the roof to the body side. This resulted in an extremely small design space, where only one concept was deemed to be viable. Upon realization, the authors decided to rework the restriction to allow for one added or modified production cell, which opened up the design space significantly; more than five significantly different concept became viable solutions.

Comparing the project results, case project 2 is more refined despite the project being smaller in time and having fewer team members. At the moment, it is not possible to say whether this difference should be contributed to the difference in experience, the project setup or a combination of the two.

When examining the end result of the project in case 2, industry experts identified process requirements that were not managed in the process. This was concluded to be due to too restricted case, and the lack of context knowledge in the student team. An activity downstream of the studied area was identified as a factor creating design requirements, which was excluded from the case and not mentioned in the observational visit. This resulted in a faulty requirement specification.

In the final interview with the respondents in case 2, it was mentioned that the project team felt obliged to deliver at every gate meeting, something that restricted creativity in order to reliably get useful results. When asked about what the team would like to have done differently, this was again mentioned as a possible venue for improvement.

7. Discussion

In both case projects, it became apparent to the authors that while the students made reasonable and rational decisions, information and holistic knowledge of the manufacturing process of a vehicle sometimes lacked. Also, some gaps in analysis capabilities were identified early by the students in both projects. These were both a result of infrastructure (access to assembly line, software access) and experience gaps.

In the second project, the authors found that what had initially seemed as a minor restriction impacted the design space heavily. Also, the data gathering methods for the study seems to have impacted the project result.

While the authors designed the projects to use different product development methodologies (Ulrich&Eppingers' and Cross'), the respondents in case 2 (following Cross' model) did not see the methodology as different to the Ulrich & Eppinger model they had earlier experience in. At the same time, the respondents in case 2 pointed out that the number of gates had influenced their concept selections, which points at the opposite.

The difference in experience between students and engineers in industry is a factor that can affect results, this difference falls under the challenge of context knowledge. While this can be partially managed by providing data, setting up the project and selecting respondents, the transition from data to knowledge or experience regarding the context cannot be controlled. This needs to be taken into consideration.

There is also a possible difference in willingness to respond from the diffrerent types of respondents. In industry, knowledge can be seen as a factor of power and is not necessarily something that respondents want to share indiscriminantly. In the case of student projects, on the other hand, there is incentives for the student to provide all information and knowledge that has been accumulated, since this might affect their grading. This incentive can work as in favor for researchers investigating how data and knowledge is being used. On the other hand, industry respondents might be more willing to admit decisions being made ad hoc, while students might try to find basis for their decisions afterwards to give the impression of structured decision making; since they might feel that their grading would be affected.

8. Conclusions and future work

While case studies are suitable for questions regarding how decisions are made, there are some challenges when using students as respondents in case studies while attempting at examining industrial challenges. The four main ones identified in this research are: context knowledge, research questions, project boundaries and data gathering methods (see figure 1). Context knowledge implies the students'context knowledge regarding the industry in reference to what the regular design engineer in said industry knows. This could be experience or knowledge about downstream activities either in the development process or for the product itself.

Research questions and project boundaries needs thorough consideration, to make sure that the research questions are suitable for project teams with lower levels of context knowledge and that the project boundaries allow work that addresses the research questions. The data gathering methods should be designed to minimize the effect on the project team and their work.

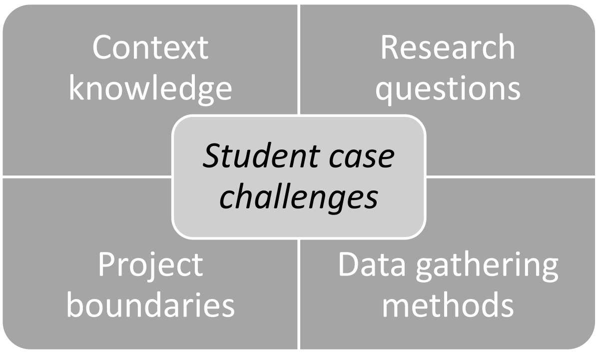

Fig. 1: *Student project case challenges.*

The conclusion from this research is that student case projects are beneficial to case-based research on integrated product and production development due to the possibility to create an explicit and specialized framework, focusing on specific decisions and the data availability, but this type of project cannot be the only way of gathering information regarding phenomena such as material selection or introduction of new materials in existing production systems. For this, the amount of tacit knowledge available and used in industry is too large and the student cases cannot fully predict how why decisions are made. Student case projects should be complemented with industry case studies and the researchers' own work within integrated product and production development in order to gather enough data for a sufficient analysis.

There are possible ways of managing the students' lower level of context knowledge, or improving the students' context knowledge within the project. Preparing the students to maximize the outcome of observational visits [36] is one, building virtual factories [37] is another. But both these, on their own, would be challenging to validate and demand large investments in time from researchers. A combined approach, along with very well-defined research topics and projects, might enable more reliable results.

The respondents identified a shortcoming in the methods used, not being fully able to incorporate non-quantifiable parameters or hard-to-quantify parameters. This meant that the decision support functionality of the concept selection tools used lost some impact. This should be further investigated in future research.

Due to the data transparency, it is possible that student case projects can highlight design decision challenges with regards to information sequencing and information availability. In these cases, the limited context knowledge of the project team could work in favour for the researchers since there should be a clear sign of lack of information before decisions are made.

An iterative approach, using student case projects as explorative projects to be evaluated by industry experts and to identify questions and topics for industry case projects, is a promising approach in order to create effective and efficient research on integrated product and production development. The authors would like to investigate this further, and develop and describe a method for enabling a "win-win-win" situation where academia, industry and students gain from the work being done within research on integrated product and production development.

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References

[1] K. Rivette, H. Nothhaft and D. Kline, "Discovering New Value in Intellectual Property," *Harvard Business Review,* Vols. January-February, 2000.

[2] Regeringskansliet, "Offentlighetsprincipen," Regeringskansliet, 01 04 2015. [Online]. Available: http://www.regeringen.se/sa-styrs-sverige/det-demokratiska-systemet-i-sverige/offentlighetsprincipen/. [Accessed 08 08 2016].

[3] J. Herbertsson, Holistic Design for Manufacture - A Theoretical Analysis, Linköping: Linköping University, 1995.

[4] C. W. Elverum and T. Welo, "The role of early prototypes in concept development: insights from the automotive industry," in *CIRP 24,* Milano, 2014.

[5] M. Derelöv, On Evaluation of Design Concepts - Modelling Approaches for Enhancing the Understanding of Design Solutions, Linköping : Linköping University, 2009.

[6] P. Hallberg, Low-Cost Demonstrators - Enhancing Product Development with the Use of Physical Representations, Linköping: Linköping University, 2012.

[7] V. Hubka and W. E. Eder, Engineering Design - General Procedural Model of Engineering Design, Zürich: Heurista, 1992.

[8] K. T. Ulrich and S. D. Eppinger, Product design and development, Singapore: McGraw-Hill, 2008.

[9] N. Cross, Engineering Design Methods - Strategies for Product Design (third edition), Wiltshire, Great Britain: John Wiley & Sons Ltd., 2003.

[10] S. Sapuan, "A knowledge-based system for materials selection in mechanical engineering design," *Materials and Design,* no. 22, pp. 687-695, 2001.

[11] S. Sapuan and H. Abdalla, "A prototype knowledge-based system for the material selection of polymeric-based composites for automotive composites," *Composites Part A,* vol. A, no. 29, pp. 731-742, 1998.

[12] P. Chatterjee, V. M. Athawale and S. Chakraborty, "Selection of materials using compromise ranking and outranking methods," *Materials and Design,* no. 30, pp. 4043-4053, 2009.

[13] M. Ashby, “Multi-objective optimization in material design and selection,” *Acta Materialia,* no. 48, pp. 359-369, 2000.

[14] A. Jahan, F. Mustapha, S. Sapuan, M. Y. Ismail and M. Bahraminasab, “A framework for weighting of criteria in ranking stage of material selection process,” *International Journal of Advanced Manufacturing Technology,* no. 58, pp. 411-420, 2012.

[15] F. Henriksson and K. Johansen, “An outlook on multi material body solutions in the automotive industry – possibilities and manufacturing challenges,” in *SAE World Congress 2016*, Detroit, Michigan, USA, 2016.

[16] Produktion 2030, “Vision and challenge,” 09 05 2016. [Online]. Available: http://www.produktion2030.se/en/vision-agenda/.

[17] Produktion 2030, “Large scale production of mixed material products,” 09 05 2016. [Online]. Available: http://www.produktion2030.se/en/projects/storskalig-tillverkning-av-produkter-i-flera-material/.

[18] BMW AG, “BMW 7 series: Driving dynamics and efficiency,” [Online]. Available: http://www.bmw.com/com/en/newvehicles/7series/sedan/2015/showroom/driving_dynamics_and_efficiency.html. [Accessed 22 02 2016].

[19] Mercedes-Benz Australia, “The C-Class Sedan - Lightweight Construction,” [Online]. Available: http://www.mercedes-benz.com.au/content/australia/mpc/mpc_australia__website/en/home_mpc/passengercars/home/new_cars/models/c-class/w205/facts/lightconstruction.html . [Accessed 22 02 2016].

[20] M. Pfestorf and J. van Rensburg, “Improving the Functional Properties of the Body-In-White with Lightweight Solutions Applying Multiphase Steel, Aluminium and Composites,” *SAE Technical Paper Series,* 2006.

[21] SAE, “Cadillac pursues aluminum/steel mix for new CT6 luxury sedan,” 01 04 2015. [Online]. Available: http://articles.sae.org/13986/ . [Accessed 13 08 2015].

[22] A. Kampker, P. Burggräf, C. Deutskens, A. Maue and R. Förstmann, “Integrated Product and Process Development: Modular Production Architectures Based on Process Requirements,” in *Second International Conference on Ramp-Up Management*, Aachen, 2014.

[23] R. K. Yin, Case Study Research - Design and Methods (5th ed.), SAGE Publications, 2014.

[24] A. Harrison, “Case Study Research,” in *Essential Skills for Management Research,* Beverly Hills, Sage, 2002, pp. 158-180.

[25] B. Diffner, Combining Flexibility and Efficiency in Automotive Assembly - Preparing for New Powertrain Vehicles, Linköping: Linköping University, 2001.

[26] P. D. Leedy, Practical Research - Planning and Design, USA: Prentice-Hall, 1997.

[27] P. Tuli and R. Shankar, “Collaborative and lean new product development approach: a case study in the automotive product design,” *International Journal of Production Research,* vol. 53, no. 8, pp. 2457-2471, 2015.

[28] M. Tarkian, “Design Automation for Multidisciplinary Optimization - A High Level CAD Template Approach,” Linköping University, Linköping, 2012.

[29] D. G. Ullman, The Mechanical Design Process, Singapore: McGraw-Hill , 2010.

[30] K. S. Hurst, Engineering Design Principles, Bristol, Great Britain: Arnold Publishers, 1999.

[31] S. Shahbazi and M. Kurdve, “Material Efficiency in Manufacturing,” in *Swedish Production Symposium*, Gothenburg, 2014.

[32] V. Gopinath, K. Johansen and Å. Gustafsson, “Design Criteria for a Conceptual End Effector for Physical Human Robot Production Cell,” in *Swedish Production Symposium*, Gothenburg, 2014.

[33] H. Skipworth and A. Harrison, “Implications of form postponement to manufacturing: a case study,” *International Journal of Production Research,* vol. 10, no. 42, pp. 2063-2081, 2004.

[34] C. Soosay, B. Nunes, D. J. Bennett, A. Sohal, J. Jabar and M. Winroth, “Strategies for sustaining manufacturing competitiveness,” *Journal of Manufacturing Technology Management,* vol. 27, no. 1, pp. 6-37, 2016.

[35] P. Denzler and M. Wiktorsson, “Maximizing product possibilities while Minimizing process change: A case of introducing Light Weight Material in Automotive Manufacturing,” in *26th CIRP Design Conference*, Stockholm, 2016.

[36] E. R. Goodson, “Read a Plant - Fast,” *Harvard Business Review,* pp. 3-11, 2002.

[37] T. Tolio, M. Sacco, W. Terkaj and M. Urgo, “Virtual Factory: an Integrated Framework for Manufacturing Systems Design and Analysis,” in *Forty Sixth CIRP Conference on Manufacturing Systems*, Setubal, 2013.