Continuous Improvements During Project Based Production

A Case Study Executed at Bombardier Transportation

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Edvin Ekblad
ABSTRACT

Bombardier Transportation in Västerås develops trains that are assembled in Hennigsdorf, Germany. Due to changes in the organization there are shortcomings in terms of processes for feedback from the production back to the engineering organization. Physical Integration is responsible for the design and industrialization of interior and exterior products. Product engineers at the department need to take part of improvements and lessons learned that can be made in the initial pre-series production phase. During the execution of the thesis Physical Integration developed products for the C30 project, a metro train for Stockholm subway.

The aim of the thesis is to achieve processes with continuous improvements so that Physical Integration can take part of feedback from the production in a structured way, in order to become a learning organization.

Data was collected with qualitative research through interviews, observation and documentation. Main takeaways was that engineers needs to be more involved in the production to gain experience and the process for problem solving has to be documented with focus on the cause of problems.

A comparison between theory and data analyzed the subjects of improvements & lessons learned, engineering involvement in production, standardization of problem solving and the staffing at Physical Integration. Solutions focus on the mindset needed for a learning organization and a new process for problem solving.

The research questions can be answered through a number of concluding remarks: Physical Integration needs permanent staffing that participate in problem solving in the production. Problem solving with the proposed process ensures documentation and identification of causes. Together, these two sources of experience and documentation create a base of knowledge for engineering and methods department to review projects and have input to upcoming projects.
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1 INTRODUCTION

Bombardier Transportation Sweden develops and manufactures railway solutions for the Scandinavian market, currently for AB Storstockholms Lokaltrafik (Stockholm Public Transport). C30 is a new metro for the red line in Stockholm that will have the ability to operate in manual, semi-automatic and unattended -train operation. Bombardier’s goal with the thesis is to get proposals for how communication between the engineering site in Västerås and the production site in Hennigsdorf, Germany can be improved.

1.1 Railway Industry

Today’s Railway Industry consists of manufacturers of rail supplies, system integrators, operators and infrastructure managers.

- Manufacturing includes infrastructure as tracks and electrification, rolling stock as trains and locomotives, signalling systems and components, services with engineering and consulting.
- System integrators are companies that use subcomponents, produces and sell finalized train sets.
- Operators drive trains, manage passengers, collect fares and handles goods.

The European railway industry account for almost half of the world’s rail products, employs nearly 400 000 people and sales of the EU rail suppliers amount to 47 billion euro, (UNIFE 2015) Rail manufacturers were earlier connected primarily to domestic markets, but since the 1990s, mergers and restructuring in Europe led to three dominant global manufacturers; Bombardier, Alstom and Siemens. In 2009 Bombardier was accounted as the leading Rail equipment manufacturer, Figure 1, (Renner and Gardner 2010).

![Figure 1. Leading global rail equipment manufacturers, by sales, (Renner and Gardner 2010)](image)

1.2 Purpose of the thesis

Bombardier Transportation has not applied necessary processes to ensure proper internal communication between sites and departments. The background is a big growth of the organization, reorganizations and long distances between sites. Thesis work is based on processes used in a contemporarily project that is being executed at Bombardier
Transportation Västerås. The purpose of this work is to propose processes and tools to be used for communication of production improvements and lessons learned between the production and engineering departments.

1.2.1 Background

Bombardier Transportation AB is world leading in rail industry and deliver a large range of products, including; complete trains, sub systems, maintenance system integration and signaling. Bombardier Transportation have more than 2000 employees in Sweden and the Vehicle Division based in Västerås develops, manages projects and deliver trains to, mainly, the Nordic market. This thesis work will be written at the department of Physical Integration, which is a part of the Vehicle division. This department produces all of the technical documentation and is the foundation for assembling instructions. Phases during product development for Physical Integration consist of Design and Industrialization, while Manufacturing and Assembly is placed at Bombardier in Hennigsdorf, Germany. Production of the C30 metro with driverless functionality for the red line in Stockholm, is soon to be in ramp-up stage. An important aspect to take into account is that Bombardier Transportation is project-based, meaning that engineers works with products a limited time before work is changed into a new project.

1.2.2 Research question

This case study the internal processes and the management of improvements from external production to product engineers at the Physical Integration department at Bombardier. The goal of the study is to answer the following research questions:

1. Which processes should be used when communicating improvements between production and engineering?
2. How can lesson learned and knowledge be captured and shared to the next project?

1.2.3 Aim

The aim is to analyze the internal communication from when the engineers in Västerås ramp-down the design phase and send the technical documentation to the point where production of the product is ended.

The information of importance is improvements and lessons learned, discovered during production ramp-up and manufacturing at the site in Hennigsdorf, Germany. The thesis work includes identification and development of processes for how engineers in Västerås receive feedback on the design to be able to do it right the first time. To achieve processes with continuous improvements, the aim is that the whole department takes part of the feedback in a structured way to become a learning organization.

The study needs to include empirical investigations with a theoretical foundation, aiming to deepen the understanding of the organization.

1.2.4 Delimitations

Thesis work includes 30 university credits during 20 weeks of research in the spring of 2015. Focus will be on proposing improvements to the processes involving Physical Integration.
1.3 Company background

Bombardier is the largest manufacturer of planes and trains, with transportation solutions as business jets, commercial aircrafts and high-speed trains. The global and aerospace headquarter is located in Montreal, Canada and transportation headquarter is located in Berlin, Germany. Bombardier has a worldwide workforce of 76 400 people and business areas are split in Aerospace and Transportation, Figure 2.

![Company business areas](image)

**Figure 2. Company business areas**

By the end of 2013 revenues and workforces was divided as seen in Figure 3. The biggest markets counted in revenue are Europe followed by North America, (BT standard presentation, 2013).

![Breakdown by revenues and workforce](image)

**Figure 3. Breakdown by revenues and workforce (BT standard presentation, 2013)**

1.3.1 Bombardier Transportation

Bombardier Transportation (BT) is counted as the global leader in rail industry. They offer a portfolio consisting of rail solutions with trains, sub-systems, maintenance services, system integration and signaling. BT has production and engineering at 63 sites and 18 service centers in 26 different countries with the headquarters in Berlin, Germany and has an installed base of vehicles that exceeds 100 000 rail cars and locomotives. The biggest market is in Europe were 67% of the revenue and workforce is placed, Figure 4, (Bombardier global website, 2015).
In Sweden Bombardier is a complete supplier of rail solutions with delivery of vehicles, drive and control systems to signaling and complete maintenance. Well known products have project names as high-speed train X2, the REGINA-train and BOMBARDIER CONDESSA for Öresund fixed link. More recent projects include the development project Gröna tåget that is important for future high-speed projects. Bombardier Transportations seven business areas is shown in Figure 5, (Bombardier Sweden website 2015).

1.3.2 Bombardier Västerås

Site Västerås is included in the Rolling Stock Central & Eastern Europe (CEE), in close cooperating in the business unit Single Decks and with sites in Görlitz and Hennigsdorf, Germany. They develop vehicles in the business unit for the Scandinavian and Swedish market. CEE Västerås have approximately 250 employees and are responsible for sales in Scandinavia, project management, design responsibilities, product introduction and integrated logistics.
support, quality insurance and bids for the local market as well as bid support to other sites, (Bombardier Västerås business description, 2015).

1.3.4 Bombardier Hennigsdorf

Bombardier Berlin is the headquarter site of the region Central/ Eastern Europe & CIS (CEE). Bombardier Hennigsdorf is the largest site for manufacturing and where Bombardier Sweden manufactures most of their products. The product portfolio for Bombardier Hennigsdorf includes metros, regional trains, intercity trains and high-speed trains. It has a ground area on about 650 000 square meters and employs approx. 2800 persons. The site contributes with engineering, product development, research & development and procurement for projects that are not on site. Engineering on the site consists of more than 1100 employees and works with development and verification of complete vehicles or systems for European and Asian sites. Competencies consist of vehicle concepts, vehicle engineering and specialist engineering. Testing consists of type- and homologation tests. Test tracks with different lengths enables tests executed on running trains.

Production competencies at the site include manufacturing of car bodies where their core competency rests in aluminum, pre-assembly and final assembly. Production has their final assembly including both electrical and mechanical assembly for all types of car bodies and vehicles in three assembly halls. Assembly is made on stands and in line production. This is where BT Sweden produces their trains, Figure 6, (BT Standard presentation Hennigsdorf, 2015).

Figure 6. Final assembly facilities in Hennigsdorf

1.3.5 Bombardier Västerås – Propulsions & Controls

Propulsion & Controls (PPC) develops and delivers propulsion systems with high reliability and low losses. The drive system includes propulsion converters (traction and auxiliary converters), drives (motors and gears) and train control & management systems (TCMS). The Customers are train integrators that designs and assembles chassis, traction and rear suspension to finished trains. Trains are in most cases sold to governments in Western Europe or China that have government railway companies. Of all sales, about 70% is internally to own builds and 30% to external train integrators, (Bombardier Västerås business description, 2015).
Research will be executed as a case study based on theoretical and empirical analysis. The methodology will guide the data collection in a structured way that will make sure that triangulation with the theory is possible. The approach to research is started with a comparison between qualitative and quantitative research in order to introduce the reader to the subject of case studies. A framework is presented with the needed methods for collection of empirical data in interviews, observation and through documentation.

2.1 Introduction

In this case study, practical examples from a global development and manufacturing company as well as theoretical work is evaluated. The goal is to apply the findings into the daily practical work at BT. The knowledge building is based on interaction between literature theory and real life experiences. Differences are expected since they differ in the way that theory is extracted from continuous observations and forms a general knowledge. Empiricism is a reflection of the reality and is based on individual observations as experiments or interviews, (Eriksson & Wiedersheim-Paul, 2011). The study will be based on empiricism with support of theory; a research method will be presented in the following parts of the chapter.

2.2 Qualitative and Quantitative Research

When choosing research methodology there is a need to understand the goals and preferences of possible approaches. A quantitative approach often consists of analyzing existing statistical data or data collected from large groups. The research question is often stated as a hypothesis. Data can be gathered in a short period of time and can through analyzing get a hands-on answer to the hypothesis. A qualitative approach collects data from a variety of sources and looks at the problem as a participant observer. The observer reflects on the process and analyzes information as it emerges. Data collection often consists of interviews, observations or combinations of procedures and continues until adequate information appears. Outcome is presented as an explanation of the problem describing key aspects, (Hancock & Algozzine, 2011). The research methods described by Hancock & Algozzine (2011) can be confirmed by a table overviewing differences between quantitative and qualitative data, Table 1, (Eriksson & Wiedersheim-Paul, 2011).
<table>
<thead>
<tr>
<th>Orientation</th>
<th>Data</th>
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*Table 1 - Differences between Quantitative and Qualitative data (Eriksson & Wiedersheim-Paul, 2011)*

_Hancock & Algozzine (2011)_ describes case studies as another qualitative research but also puts it to comparison with quantitative and qualitative studies as a general research tradition. Briefly described, a researcher identifies research questions and defines what is known, based on multiple sources of information. This is followed by a research process to analyze the case. Information is collected until the case can be defined and the key aspects are reported.

### 2.3 Case Study Research

The methods and theories of case studies are according to the book by Hancock & Algozzine (2011). They define case study research as “an empirical investigation of a present-day phenomenon that is conducted within its natural context with multiple sources of evidence”. The case study is a research strategy which focuses on understanding the dynamics present within single settings. It combines different data collection methods and it may contain evidence that are qualitative, quantitative or both, (Eisenhardt, K.M., 1989). More substantially, a case study can be introduced in a numbered list of characteristics:

1. Focuses on an individual representation of a group or an organization but mainly a phenomenon.
2. The phenomena being researched is studied in its natural context limited by space and time.
3. It’s grounded in deep and varied sources of information. Such as employees quotes, interviews and observations.

Additionally, case studies researchers often try to identify themes or categories of behavior and events rather than proving relationships or test hypotheses. When collecting data from multiple sources the researcher usually needs to spend more time in the environment in question. Hancock & Algozzine (2011) proposes a sequence of procedures they recommend in a case study:

1. Setting the Stage
2. Determining What We Know
3. Selecting a Design
4. Getting Information from Interviews
5. Getting Information from Observation
6. Getting Information from Documents
7. Summarizing and Interpreting Information
8. Reporting Findings
The design of the case study can be either holistic or embedded with a study of single-cases or multiple cases. A holistic design includes a single-unit analysis and an embedded design studies multiple units of analysis, Figure 7.

![Figure 7. Basic types of designs for case studies, (Yin 2003)](image)

2.4 Data collection methods

Collection of data for the case study will include interviews, observations and use of documentation. The following part describes the theory of data collection with the different methods.

2.4.1 Interviews

Interviews can be described by Yin (2003) as follows; “Appear to be guided conversations rather than structured queries”, but that can be followed more or less. There are different types of interviews: open-ended nature, focused interview and survey type.

Hancock and Alguzzine (2011) on the other hand say that “interviews can be structured, semi-structured or unstructured”. The researchers focus on semi-structured interviews and say that they are “particularly well suited for case study research”. The structured questions and the flexibility the answers give, enables follow-up questions designed to dig deep into issues. The interviewee is invited to express themselves freely and the interviewer receives material to analyze qualitative. The authors also propose several guidelines to follow when conducting interviews, which is summarized below:

1. Identify participants who can provide key insights
2. Develop an interview protocol with baseline questions
3. Consider setting for interview
4. Set up an way to record the interview data
5. Inform the interviewee about how the material is going to be used

Hancock and Alguzzine (2011) are describing the interview types Yin (2003) mentioned as Interview Instrumentation, the different types are described below:

**Interview as informal conversation**

Questions are asked ongoing during a conversation and may lead to deep understanding. Hard to compare and analyze as questions will differ between interviewee.
Interview as guided conversation

Interviewer defines sequence and controls the conversation with questions. Relaxed conversations that can be controlled but important topics may be missed and answers can differ if they are put in a different way depending on participant.

Interview as open-ended responses

Interview protocol decides wording and sequence, answers are open-ended. Builds a foundation of information possible to analyze but may restrict the interviewee with a standardize wording.

Interview as fixed responses

Fixed options to answer fixed questions, easy to analyze but makes the interview impersonal and richness limited.

When a type is decided upon, the list presented earlier can be used to prepare for the interview. Hancock and Alguzine (2011) also present a list of steps that can be used when developing the interview protocol:

1. List the research questions that your study will explore
2. Break research questions into researchable sub questions
3. Develop possible interview topics or items for each sub question
4. Cross-reference interview topics or items with each research question to ensure that nothing is overlooked
5. Develop interview structure and protocol for interviews
6. Identify minimum information to be gathered from each respondent
7. Confirm appropriateness and adequate of protocol and conduct interview

The interview protocol guides the interview and the answers can be written down or electronically recorded for later documentation.

2.4.2 Documents

Eriksson, L.T., & Wiedersheim-Paul, F. (2011) describes two different classifications of data, primary data and secondary data. Were primary data is collected by the researcher and secondary data is existing. As described by Yin (2003), documents should be used primary to confirm and augment evidence from other sources. Strengths in documentation as evidence is described as stable information, unobtrusive, exact and have a broad coverage. Weaknesses consist of hard to access and one-sided selectivity. Documentation includes five types:

- Letters and communication
- Agendas, announcements and meeting reports
- Administrative documents as; proposals, progress reports and internal records
- Formal studies
- Newspapers or other media

Documentation can provide the research with useful information from multiple data sources. When combined with data from interviews and observations, summary and interpretation is of importance in order to address the research questions, (Alguznine and Hancock 2011).

2.4.3 Observations

Voss et al (2002) describes the use of triangulation in case research, where the use of different methods to study a phenomenon helps to add reliability. Methods that are commonly used are interviews, questionnaires, direct observations and analysis of documents.

Yin (2003) describes two different approaches for observation, direct- and participant-observations. Direct observations can be made by making a field visit to a site related to the subject of research or by receiving observed information. Activities involve observations of meetings, sidewalk activities or factory work. Protocols are usually filled in during observations.
to log experiences, using a formal or casual layout. Direct observations are described as time effective but might result in a non-realistic view. Participant-Observations are modes of observation were the participant take part in activities at the site and participate in events being studied. In cases this method is a way of getting an accurate portrayal of the phenomena in question.

### 2.7 Summary of methodology

Research will be collected in a qualitative methodology with an aim to understand the meaning of processes and tools. Interviews and observations are the main source of information. The case study will include multiple sources in an embedded approach on a single case.

**Interviews**

Interviews will be held semi-structured with open-ended responses in order to build on knowledge from earlier interviews and get the most out of the interviewees with a chance for follow-up questions.

**Documents**

The situation is well suited for collection of secondary data, in a running project and with no running production for data collection.

**Observations**

Direct observations will be used at the study visits in order to gather information in a short amount of time.

The methodology in Figure 8 will be based on research questions with theoretical and practical studies that will be analyzed with triangulation in a summarizing analysis.

![Figure 8. Case study design](image-url)
Theoretical studies will be based on subjects related to the aim of the thesis and will be compared with the practical studies in the analysis.

3.1 Continuous improvements

Continuous improvements are by Bhuiyan & Baghel (2005), defined as a culture of sustained improvement targeting the elimination of waste in all systems and processes of an organization. While others relates the subject toward other topics and says that continuous improvements is “a companywide process of focused and continuous incremental innovation” or “an offshoot of existing quality initiatives like total quality management or a new approach to achieve creativity”. Becket et al (2000) says that organizations should maintain closed-loop control processes to allow process outputs to modify inputs, continuously improving the production process. Becker’s reasoning is similar to Liker (2009) that is saying that processes needs to be standardized to be able to make continuous improvements. Overall, literature shows that there is no theoretical basis for continuous improvements; it’s rather used as a general term that can be found in different methods as Lean manufacturing, Six Sigma, Balanced scorecard and total quality management (Bhuiyan & Baghel 2005).

3.1.1 Lean

Continuous improvements are known as a part of the Toyota Production System (TPS) that is the frame for Lean Production. Lean is a production method that has the aim be resource-economic and time-efficient. The goal is to produce only what the customer wants when needed, using as little resources as possible. Waste (anything which doesn’t add value to the product or service) that do not add to value is eliminated. The expected quality is delivered at the right time to satisfy the customer need, (NE.se). Lean production is not confined to the activities that take place in the manufacturing function of a company, rather it relates to activities ranging from product development, procurement and manufacturing over to distribution, (Karlsson & Åhlström 1996).

3.1.2 Toyota Production System

In the book The Toyota Way by Liker (2009) he explains how Toyota works by the principles of lean and how the right combination of the philosophy, processes, personnel and problem solving tools can create a Lean and learning organization. There are four parts of the 14 principles that builds the foundation for the technique and the tools for TPS. They can be summarized as follows:
• Part I: Long-Term Philosophy
  o Principle 1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals

• Part II: The right process will produce the right result
  o **Principle 2.** Create continuous process flow to bring problems to the surface
  o Principle 3. Use “pull” systems to avoid overproduction
  o Principle 4. Level out the workload
  o **Principle 5.** Build a culture of stopping to fix problems, to get quality right the first time
  o Principle 6. Standardized tasks and processes are the foundation for continuous improvement and employee empowerment
  o Principle 7. Use visual controls so no problems are hidden
  o Principle 8. Use only reliable, thoroughly tested technology that serves your people and processes

• Part III: Add value to the organization by developing its people and partners.
  o Principle 9. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others
  o Principle 10. Develop exceptional people and teams who follow your company’s philosophy
  o **Principle 11.** Respect your extended network of partners and suppliers by challenging them and helping them improve

• Part IV: Continuously solving root problems to drive organizational learning.
  o **Principle 12.** Go and see for yourself to thoroughly understand the situation
  o Principle 13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly
  o **Principle 14.** Become a learning organization through relentless reflection and continuous improvement

The TPS house in Figure 9 illustrates that TPS is based on a structure where the people is the central part, the foundation based on standardized and stable processes, the pillars JIT and Jidoka lifts problems to the surface and the roof sets goals in quality, cost and time, but most important the center for the structure, a continuous improvement.

![Figure 9. TPS house (Liker & Morgan 2006)](image-url)
**Kaizen - Continuous improvements in Toyota Production System**

Part II principle 5 and 6 can be explained as follows; the people are driving the lean process and rigorous standardization is people who work hard as a team to achieve common objectives. The personnel do the work with high levels of skill and discipline and reflect on the process and work to improve it. This activity happens on a continuing basis. It is getting closer to true continuous improvement. (Liker and Morgan 2006) While principle 5 stops the process which leads to improvements, principle 6 adds operations to standardize and improve in that way. Part IV includes the primary of continuous improvements, principle 14. It contains the process for eliminating waste with help of continuous improvements (kaizen). A common tool for finding waste is the “5 why – method” and is the method used when performing continuous improvements. Kaizen is the Japanese word for “change for better” and is defined as a process that minimizes waste through value-adding improvements. The kaizen process teaches personnel to work effective in small groups to solve problems, document and improve processes, collect and analyze data and perform self-control. This process moves a big part of the decisions to worker level and can be decided throughout team decisions. (Liker 2009) A kaizen-workshop is a way to implement changes in a short period of time, it has three phases; prepare, workshop and conclude. Following is the way of doing a kaizen-workshop according to *The Toyota Way* (Liker 2009).

![Phase 1: Preparation](image)

**Phase 1: Preparation**
- Decide on range
- Set goals
- Make preliminary map of present situation
- Collect relevant data
- Put the preliminary map on the wall of the project room

![Phase 2: Kaizen-workshop](image)

**Phase 2: Kaizen-workshop**
- Briefing about assignment and theory.
  - Who is the customer?
  - Analyze present situation.
  - Create future vision.
  - Implement.
  - Evaluation: Measure work

![Phase 3: Conclusion and follow up](image)

**Phase 3: Conclusion and follow up**
- Follow-ups with PDCA once a week
  - Overlooking status on further questions
  - Overlooking process values to ensure improvements
  - Discussing further improvements
  - Continuous improvements

**Figure 10. Kaizen workshop (Liker 2009)**

According to Figure 10 there are three phases related to the workshop. In the first phase it is important to set up a frame, plan and collect relevant data for a better flow at the workshop. The actual workshop starts with a briefing and education in basic Lean-concepts if needed. The process is analyzed with focus on value adding and non-value adding activities, to improve the process is methods as 5 why and other creative processes used. When solutions is developed a plan for implementation is made and initiated during the workshop. Changes is made, visual inspections executed and measurements about the result of the workshop is performed and improvements continue constantly, (Liker 2009).
3.1.3 Bombardier Operation System

Bombardier Transportation works according to the Bombardier Operation System (BOS) that originally is based on the frameworks for Lean production. Following can only be overlooked at the internal Bombardier site (2015). BOS consists of 5 principles

<table>
<thead>
<tr>
<th>Principle 1: Built-in Quality</th>
<th>Principle 3: People Involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I do not make, accept or ship a defect!” A mind-set used to achieve a high quality in each process and be sure that defects are not passed on to the next process.</td>
<td>“I know how to contribute to world class products!” At Bombardier the most valuable resource are the employees and they are supported to be motivated and empowered to excel.</td>
</tr>
</tbody>
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<tr>
<th>Principle 2: Short Lead Time</th>
<th>Principle 4: Standardization</th>
</tr>
</thead>
<tbody>
<tr>
<td>“I get the right part, in the right place, at the right time!” A goal to make sure those parts, modules and products is finished at the right time to reduce the time from order to a finished product.</td>
<td>“The dynamic foundation for high quality and productivity” Work should be performed according to core standards, principles, methods and processes to be able to improve</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principle 5: Continuous Improvements</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>“I perform better every day” Never be satisfied with the current state, identify root causes of problems and work to eliminate waste. Bombardier fosters a will to change in a structured and systematic way and become a learning organization.</td>
<td></td>
</tr>
</tbody>
</table>
Each of the principles consists of a number of elements; in the case of Principle 5: Continuous Improvements (CI) there are 6 elements that are explained below:

**Table 3. Elements of Continuous Improvements**

<table>
<thead>
<tr>
<th>CI 1: Business Improvement Planning</th>
<th>CI 4: Product Design Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>A process that enables the organization to set targets and integrate plans to be able to make concrete improvement plans through the whole organization</td>
<td>Processes and methods that can ensure manufacturing, assembly, installation, testing, and maintenance and operation requirements are addressed during product design and realization phases. Improvements are needed to propose innovative solutions that improve the product, reduce the cost and excite the customer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CI 2: Problem Solving &amp; Escalation</th>
<th>CI 5: Operations Process Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structured methods used to identify, analyze and eliminate variances between current situations and standards. The purpose is to identify the root cause and implement countermeasures</td>
<td>Continuous improvements of equipment and facilities that utilizes the best practices of lean manufacturing and enables use of BOS principles and elimination of waste</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CI 3: Continuous Improvements System</th>
<th>CI 6: Total Productive Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A system that supports an improvement culture among the employees where they identifies and eliminates waste. The goal is to reduce costs, improve throughput, reliability, quality, safety, ownership and accountability, and develop multi-functional employees</td>
<td>Activities to maximize productivity throughout proactive involvement of shop-floor personnel and sharing of standardize maintenance responsibilities. The process is used to reduce cost, improve throughput, reliability, quality, safety, ownership and accountability, and develop multi-functional employees</td>
</tr>
</tbody>
</table>

### 3.2 Cross-project learning

**Learning organizations & Knowledge management**

There is a big need to learn from one project to the next one in project-based organizations. But there are issues within those kinds of projects because of the complexity of capturing what is called “lessons learned” or “best practice”. There are two basic concepts for how organizations learn from projects.

Organizational learning is stated as what the employee learns by the company and also the other way, how learning is transferred in the company. This is also stated by Liker that “the highest level of The Toyota Way is the learning organization”, they says that you need the right combination of philosophy, processes, personnel and problem solving to become a learning organization as Toyota (Liker 2009). There can be issues with organizational learning that emerge from the research of Bapuji and Crossan say that the most important issues to consider is culture and organizational structure, (Williams 2008). Organizational learning can occur if two criteria is satisfied, “individuals, either appointed by management or anointed by followers, take their learning back to the system” and “the system has structures, processes and a culture in place to embed and support organizational learning”. There are found that capture of knowledge relies heavily on social networks and how the individual and system can collaborate. An important conclusion made by the author is that lessons learned can not only be made from failed or successful projects, she says that companies need to “focus equal
emphasis on learning from successful projects as those that appear to have failed or run off-course”, (Julian 2008).

During early research, knowledge management is described “to capture, codify, use and exploit the knowledge and experience of employees by developing better tools and methods and by developing a willingness and ability to use those methods”. This can be compared with the definition of learning organizations “to harness the learning capability of the firm and individuals within it through people development, empowerment, leadership and cultural change”. Four types of KM processes can be described and used at different times to transfer knowledge; socialization, articulation, combination and internalization. (Williams 2008) Some other models of knowledge management presented by Newell et al (2009) is the cognitive (knowledge as possession) or community (knowledge as situated in practice) model. Those models developed an understanding of how cross-project knowledge was used and how it is easier to connect people then people to documents. The research also revealed that when databases are used, knowledge of processes is more useful since it have more relevance across different projects. Process knowledge focused on how things were done, while product knowledge focused on what have been done.

Managing of lessons learned

Product development research differentiates knowledge as explicit or tacit, explicit knowledge is knowledge that can be readily identified, explained, documented, captured and shared. Explicit knowledge is synonymous with information which makes it possible to save in databases. Tacit knowledge, also referred as know-how, is harder to articulate, hard to record, are based on experience and closely connected to the way we carry out tasks and solve problems. Tacit knowledge is preferable transferred as shared experienced. Sharing is preferable done by practice, reflection or social interaction. A study from five German companies reveals that written reports fails to transmit key learnings from new product development teams. The researchers articulate that project-to-project learning ideally includes a steady flow of knowledge from project to project. Main focus is on post-project reviews (PPRs) at the end of projects to capture knowledge, generate documentation and gathering of the teams shared experience. Each PPR leads to more knowledge that can be shared at future kick-off meetings. Managers need to focus on stimulating individual learning and find ways to generate and transfer tacit knowledge. They also need to combine lessons learned sessions with activities as mentoring and knowledge brokering, (Goffin et al 2010). Figure 11 describes a scenario where post-project reviews create lessons learned documents for explicit knowledge and a knowledge broker collects tacit knowledge. Information from post project-reviews can in this way work as input at kick-off meetings before new projects are started.
3.3 Problem solving methods

Three different methodologies have been selected for comparison, PDCA (Joyce 1995), DMAIC (Sokovic et al 2010) and 8D used by Bombardier.

3.3.1 PDCA

PDCA is a problem solving format that is used to support Kaizen in TPS. It can be defined as a standardization of the improvement process with a framework for using different quality tools, (Berger 1997). The methodology was developed by Shewhart, further developed by Deming and analyzed by Joyce (1995). The four step for the framework in Figure 12:

<table>
<thead>
<tr>
<th>Act</th>
<th>Correct actions if the objectives are not met, standardization of successful solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>Establishing the facts, collecting data, analyze data, identify root causes and create solution.</td>
</tr>
<tr>
<td>Check</td>
<td>Collect data, analyze and evaluate solution</td>
</tr>
<tr>
<td>Do</td>
<td>Implement the solution</td>
</tr>
</tbody>
</table>

The methodology is iterative and should be done several times in order to improve, (Joyce 1995).
3.3.2 DMAIC

DMAIC (Define, Measure, Analyze, Improve and Control) is a methodology in Six Sigma that focuses on facts and provides a rigorous framework of result-oriented project management. The method can only be used if data can be expressed and defined, otherwise you cannot measure it, (Sokovic et al 2010). The DMAIC cycle is described in Figure 13 and the phases can simplified be described as follows:

- **Define**
  Identify, prioritize and select a suitable project.

- **Measure**
  Measure the key process characteristics, scope of the parameters and their performances.

- **Analyze**
  Identify causes and obstacles

- **Improve**
  Change process and optimize

- **Control**
  Sustain the gain through close-out report and update of best practice
3.3.8D

8D (8 disciplines) is a team oriented way of problem solving that PPC Västerås have used for significant problems. The strategy was developed by Ford Motor Company and is common used in product and process improvements to identify, correct and eliminate problems to focus on facts instead of opinion. The eight disciplines are described in Error! Reference source not found. Figures 14-15.

Figure 13. The method and phases has to be completed with tools selected according to need and demand, (Sokovic et al 2010).

3.3.3 8D

Figure 14. 8 disciplines methodology (Internal presentation)
Establish a mixed team of people with experience and authority.

Describe the problem clearly, specific and quantify. Clarify what, when, where and how much. Consider checklists and describe the problem without solution or cause. Focus should be put on initial and target situation. Use helpful tools as SIPOC or flow charts.

Implement a temporary solution until the rest of the analysis is made.

Investigation and root cause analysis is used to verify the actual cause of the problem. Use of statistical tools is suggested in order to get a deeper understanding. Tools are for example brainstorming, fishbone diagram or a tree diagram.

Verify the corrective action in order to eliminate the root cause of the problem. Test to make sure no side effects appears and result in new problems. Tools as brainstorming, histogram or priority matrix can be used.

Implement a permanent solution and monitor to make sure it works. If not, go back a few steps and find a better solution.

Prevent recurrence of the problem by documenting and updating everything related to the process.

Ensure lessons learned with a review of the process with the team. Celebrate the success.

3.3.4 Comparison of methodologies

The main difference between the methodologies is that DMAIC and 8D are step by step problem solving methods while PDCA have several steps included in the first planning phase and the third do-phase. 8D is different because of the implementation of a temporary fix. The different methodologies can be seen in Figure 16.
The data collection will be performed according to chosen case methodology with gathering of empirical data as interviews, observations and documents. The chapter includes parts for how the data collection will be executed and a presentation of raw data. Raw data is presented department wise with documentation as secondary data and interviews & observations as more practical.

4.1 Execution

The execution will shortly introduce how the theory of methods is connected to the areas of interest in the organization and how the data collection will be executed.

4.1.1 Interviews

Interviews will be performed on a number of departments, Figure 17, all of them connected to the C30 project, that are involved when it comes to handling of problems and improvements. The interviews will be performed with a semi-structured approach and open-ended responses to get qualitative raw-data for future analysis.

![Interviewed departments](image)

Figure 17. Interviewed departments

Project management is leading the C30 project and co-operates with a number of departments. The product engineers works at Physical Integration and produces the technical documentation for production. That’s where methods are the link between Physical Integration and production; they produce the manufacturing strategy that includes production site layout, instructions and tooling. Production then realizes the vehicles with documentation from product engineers and instructions from methods. Product Introduction manages the commissioning and introduction of the vehicle to the customer and is responsible during the product lifetime. The questionnaires can be overlooked in Appendix 1 Interview protocols.

4.1.2 Documents

Documents will be reviewed in order to get an understanding of all processes in the C30 project and the processes for the work done in related departments. It’s of big importance to have a wide understanding of the processes to be able to do interviews and observations. Research will be divided in documents from the project and an overview of documents used in different stages in the product development and departments, Figure 18.
A standard MainLine and Metro Division (MLM) project document is reviewed with the related reference documents, MLM is a name previously used for Rolling Stock Central & Eastern Europe (CEE). The main document is the handbook that describes a structured overview of the management principles, processes and practices that is needed for project execution. Related to the handbook a number of System Manufacture Bombardier (SMB) documents are connected. In each project an Engineering Management Plan is developed to be applicable to the engineering function within the projects. SMB documents used by the engineering function are connected as reference documents to the Engineering Management Plan.

4.1.3 Observations

During the phase of data collection, direct observations with a casual protocol will be performed, Figure 19. Observations are made to get a deeper understanding of how the department in Västerås is working and how that can be connected to the production site in Henningsdorf. At the production site, it is of great importance to get a view of how problems are discovered and handled during different phases. Because of the distance between engineering in Västerås and production in Henningsdorf, observations at PPC in Västerås will get a different view of the geographical challenge’s, mainly because the engineers and production are located at the same site at PPC.
4.2 Raw data

Collected empirical data will be presented under projects, sites and departments. Documents will share the theoretical view of how processes are followed while interviews & observations will present a more accurate view of the execution. Focus will continuously be set at how improvements and problems are handled.

4.2.1 C30 project

Documents:

Bombardier Sweden was in 2013 awarded a contract for 96 metro vehicles and an option for 80 more from AB Storstockholms Lokaltrafik (SL). Bombardier is responsible for the design, manufacturing and to put the metros in commission. The project is called C30 and is a co-operation between five Bombardier sites worldwide. Bombardier Transportation in Västerås is leading the project and is also responsible for the engineering and quality. The scope of the project is to develop and deliver vehicles, central IT systems, documentation, training, spare parts, special tools and technical support. The project is a multi-site project with different responsibilities for each of the sites, Table 5.

Table 5. Project responsibilities (Orange book C30, 2015)

<table>
<thead>
<tr>
<th>Bombardier site</th>
<th>Site objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Office Västerås</td>
<td>• Centre for SL – contacts and renditions</td>
</tr>
<tr>
<td></td>
<td>• Place for majority of project management group</td>
</tr>
<tr>
<td></td>
<td>• Engineering</td>
</tr>
<tr>
<td></td>
<td>• Quality</td>
</tr>
<tr>
<td>Plant Västerås</td>
<td>• Project management of construction work, drive system</td>
</tr>
<tr>
<td></td>
<td>• TCMS (control and steering systems for rail vehicles), Design center</td>
</tr>
<tr>
<td></td>
<td>• Design and production of Drive Systems</td>
</tr>
<tr>
<td>Plant Hennigsdorf</td>
<td>• Hub for vehicle mounting</td>
</tr>
<tr>
<td></td>
<td>• Reception of all subsystems and components for Assembly</td>
</tr>
<tr>
<td></td>
<td>• Final Assembly of complete wagon and complete vehicles</td>
</tr>
<tr>
<td></td>
<td>• Static testing of vehicles, systems and components</td>
</tr>
<tr>
<td></td>
<td>• Dynamic test of the complete vehicle</td>
</tr>
<tr>
<td>Plant in Siegen and Derby</td>
<td>• Design and production of bogies</td>
</tr>
<tr>
<td>BST plant Qingdao</td>
<td>• Detailed design and production adaption of cart-cage construction and production of body shells</td>
</tr>
<tr>
<td></td>
<td>• Painting of body shells</td>
</tr>
<tr>
<td></td>
<td>• Mounting of floor, insulation and windows</td>
</tr>
</tbody>
</table>

The Bombardier Transport Integrated Processes (BTIP) is a standardized Bombardier Transportation process that covers the product development and project related processes, Figure 20.
Product development can be visualized with the Rolling Stock Value Chain (RSVC), an architecture describing gates from Bids to project closure, Figure 21. The RSVC architecture is describing how Bombardier works as a matrix organization with processes for project execution and gate reviews horizontally and the cooperation between departments vertically. Key phases for how the functions Design Engineering (Physical Integration) and Methods are integrated in the value chain:

- GR-1-1 Product Management, Bid & Launch
- GR1-5 Design, Industrialization and Sub-Assembly Production
- GR5-GR9 Start of Production & Ramp Up
- GR9 – GR End Series Production & Field Support

Projects is executed with a matrix organization where product engineers for an example, are responsible towards more than one manager, at Bombardier Transportation the engineers are responsible towards a department manager but also towards a manager in the core team for the project, an example can be seen in Figure 21.

The value chain is made of:
1. Gate Reviews descriptions (GR1-GRent)
2. Timeframe: When (synchronized with Gate Reviews)
3. Roles and responsibilities: Who (functions)
4. Processes: end-to-end connected activities
5. Product structure (Vehicle – System / Function – Equipment)
6. Deliverables: What and when needs to be delivered
7. Key Events driving the project (Key meetings, Milestones: Homologation...)
8. Common Critical paths
9. SMB Documents: which document and the time when it needs to be delivered
10. SMB Documents list
Figure 21. Rolling stock value chain architecture (Manage Execution of MLM Projects, 2012)
SMB documents

System Manufacture Bombardier (SMB) is a set of planning, scheduling and input documents that supports the product development. It is structured by project management with a top-level plan and further developed with function owned schedules. SMB documents are aligned with the Value Chain landscape and Gate Review process to connect different functions.

Interviews & observations:

<table>
<thead>
<tr>
<th>Interviewee role:</th>
<th>Purpose of interview:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process specialist</td>
<td>• Get an overview of Project Management</td>
</tr>
<tr>
<td></td>
<td>• Understand Project Managements view of Continuous Improvements &amp; Lessons Learned at Physical Integration and Production Site</td>
</tr>
<tr>
<td>Line manager</td>
<td></td>
</tr>
</tbody>
</table>

Staffing

In projects and departments, staffing is dependent on how many bids are won. A result is that it is hard to keep permanent staffing and in that way keep experienced personnel. Interviewees describes the staffing need for an department in terms of a pyramid where there are responsible engineers in the project, engineers who can execute assignments and engineers who only is qualified to perform tasks, Figure 22.

The pyramid describes a department that is in need of engineers in all of the layers, Physical Integration have only a few engineers with top –level experience. In order to fill the top spots with experienced engineers, Physical Integration need to keep engineers employed between projects. In Physical Integration the leading engineers should be the Design Area Coordinator and Integrator that are project responsible that delivers assignments and tasks. That are fulfilled for the moment, but a difference could be more permanent staffing that have a chance to reach the assignment step with more experience.

Connection between production and Physical Integration

To get a connection between production and Physical Integration, interviewees propose visits where engineers can get an understanding of the production and with a bigger insight understand problems. In this way a feedback loop is created from production to Physical Integration. Other suggestions include a reintroduction of an old employment, industrialization engineer. If Methods can’t fill their role as a connector and communicate input and feedback from production, a solution could be a coordinator with insight in both Physical Integration and the production.
4.2.2 Project management

Documents:
The responsibilities for Project Management include the following areas:
- Manage the decision-making process in terms of cost, quality, timeliness and product performance.
- Coordinate project related activities externally and internally
- Prepare initial Project Schedule and participate in Bid activities
- External and internal Project Leadership
- Communicate information to stakeholders
- Handling of Project risks and opportunities
- Coordinate and manage Project core processes
- Ensure deliverables for the customer
- Manage interfaces between sites, divisions and functions

(Manage Execution of MLM Projects, 2012)

Figure 23 describes the organization of the project management.

![Organizational chart image](image)

Figure 23. Organization map for project management, (Orange book C30, 2015)
Interviews & observations:

<table>
<thead>
<tr>
<th>Interviewee role:</th>
<th>Purpose of interview:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Planner</td>
<td>• Get an overview of Project Management</td>
</tr>
<tr>
<td>Planning &amp; Project Control</td>
<td>• Understand Project Managements view of Continuous Improvements &amp; Lessons Learned at Physical Integration and Production Site</td>
</tr>
</tbody>
</table>

Continuous Improvements & Lessons Learned

Project Management is continuously doing Lessons Learned sessions at each gate review that is saved with each project's documentation database. Because of Bombardiers matrix organization set-up, the interviewees express that there is no gain for projects to learn or help other projects. The department has to pick up the lessons learned and integrate those in their processes. Departments remain while projects start and end, as a result Physical Integration needs to learn their own lessons learned in their processes and personnel that implements improvements. Project Management's view is that lead engineers should be the function that collects improvements and lessons learned to build a knowledge base with accurate information. The next step is that department process owners include handling of lessons learned in the process to get use of the collected knowledge. If this can be accomplished, with a loop of lessons learned that is collected and implemented in new projects, it is the essence of a matrix organization.

Examples from other companies include a system where collected lessons learned had to be handled and fulfilled before the point could be deleted, follow-ups by a board of directors made it carry through. Another suggestion was to motivate the assembly personnel to analyze problems in production in a more structured way so that it could lead to solving the problem at root cause.

Production

Related to the production, interviewees identify the production of the first metros as the phase where most problems will be detected. The main focus should be to find and handle those problems, as early in production as possible. It's also important to collect changes and understand the problems so that Bombardier can learn from the changes made. Information valuable for Physical Integration is collected in change requests and protocols during workstation reviews.

4.2.3 Engineering - Physical Integration

Documents:

Engineering

Engineering consists of a number of departments that has the purpose to:

- Design and manage technical development and system integration
- Manage technical requirements, including delivery of technical documentation
- Achieve the required homologation for operational service
- Take part in Project Management and Project Core Team related activities
- Deliver project commitment according to Quality, Time and within Budget

(Manage Execution of MLM Projects, 2012)

Product development is described in Figure 21 and can be used to get a good overview of the processes. Further description of the engineering department and Change Management can be shown in Appendix 2. Due to the scope of the thesis, further explanation will focus on engineering department Physical Integration.
Physical Integration

Physical Integration is developing the design for electronics, exterior, interior and cab. A mock-up in real size is built in correlation with the development. The deliverables for procurement, suppliers, operations and end-users consists of quality-assured technical documentation. Documentation is mainly part-lists, 3D models, detail drawings and assembly drawings. Each product area in the department has a Line Manager that has department responsibilities and the Design Area Coordinator (DAC) is project responsible for the product area, Figure 24.

Figure 24. Organization schedule, Physical Integration (Internal document)
Internally, Physical Integration has the responsibility to coordinate interfaces towards Methods and Production related to final assembly. Whereas Methods and Production needs to ensure applicable processes, procedures and tools for efficient project execution. The areas of focus are in the phases of Gate Review 4 and 5 (GR 4 & GR 5) that includes Industrialization and 1st Unit Production Readiness. Physical Integration is responsible for the industrialization that is made in GR 4.

The purpose of Industrialization is to adapt and further industrialize the product to customer needs and available manufacturing and assembly capabilities. The process task is to produce all product documentation to build, assemble, test, introduce and later to maintain and operate the product. The phase is ended with a handover to production in cooperation with methods. A main contribution to the industrialization is workstation reviews that are being held between product engineers, integrators and methods. The goal is to confirm with methods that the design and timeline is accurate so that methods gets inputs for assembly and can produce assembly instructions, (internal document).

Organizational Interfaces

Engineering ↔ Methods:
- Engineering delivers designed products so that Methods can industrialize for manufacturability.
- Meetings are set up to secure delivery dates of part lists and drawings.
- Methods are checking on DfM during design reviews.
- Provides technical requirements for manufacturing and logistics.
- Release of Manufacturing Bill Of Material (MBOM) based on Engineering Bill Of Material (EBOM)
  (Manage Execution of MLM Projects, 2012)

Engineering ↔ Production Control:
- Engineering communicates status of train after completion of type test, including defects and damages.
  (Manage Execution of MLM Projects, 2012)
Interviews & observations:

<table>
<thead>
<tr>
<th>Interviewee role</th>
<th>Purpose of interview:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line manager</td>
<td>• Get a view of how Physical Integration works with continuous improvements and lessons learned.</td>
</tr>
<tr>
<td>Line manager</td>
<td></td>
</tr>
<tr>
<td>Design Area Coordinator</td>
<td>• Identify inputs to product development, existing and desired.</td>
</tr>
<tr>
<td>Product engineer</td>
<td></td>
</tr>
<tr>
<td>Product engineer</td>
<td></td>
</tr>
</tbody>
</table>

Staffing at Physical Integration

The needed staffing during product development vary a lot, in the C30 project with peaks at 60 persons that drops to as low as 10 persons. In April 2015, the end of the C30 project permanent staffing ads up to 31 employees. The pattern depends on how contracts are won and brought in to product development. Figure 25 describes staffing for Physical Integration in the C30 project, blue is permanent staffing and Bombardier hired consultants, red is consultants from staffing company Cyient that are onsite and green is Cyient consultants offsite.

An overview of the staffing for the department shows a clear view of how dependent Physical Integration is for new projects. Figure 26 shows the demand of engineers during the coming years where the pink, baby blue and yellow parts is possible projects that are incoming.
Interviews have described the staffing situation as an issue that makes the continuous improvements process hard and that knowledge is lost when consultants come and go. Using consultants is a good way of handling peaks in the workload but they do not feel the same ownership of products and they are not as keen to finish the work as the permanent staffing. The positive parts with permanent staffing are that they take responsibility and can use knowledge in future projects. In consideration to that the department usually takes use of earlier experience of in a product area where someone has worked before.
Continuous Improvements

During interviews with staff from Physical Integration it stands clear that they are not working with continuous improvements in a standardized way. Mainly, they improve the design based on own experience from earlier projects, not based on feedback or documentation. Improvements may be done on reference projects that are documented as 3-D models or drawings in Catia. On the department, there is no meetings dedicated for problem solving, those are handled between the Design Area Coordinator (DAC) and the product engineers. Experience is according to interviewees obtained when designing a product and thereafter is involved in problem solving in production. Engineers are in some cases involved in production support where they can gain much experience from problems occurring during the first build. Engineers are in place at the suppliers for First Article Inspections (FAI) and in the final assembly for First System Installation Inspection (FSII) if there is a complex product. According to interviewees this gains good experience, but the information is personal and possible improvements can only be applied if working in the same product area in the next project. To work with improvements, product engineers ask for dedicated time in the development process where they can collect and handle improvements.

Lessons learned

Because of the matrix organization where projects are started and ended, the department’s remains to future projects, it’s the departments that need lessons learned related to their tasks in the projects. From the interviews it stands clear that lessons learned is something that is made only on the engineers own initiative. An example is a one-pager that is filled with recommendations for the future. In C30 a big difference is that Methods have been active early on in the project to work as a way of lessons learned function with experience from earlier production problems. Product engineers want to have documentation of design solutions that is collected. A suggestion from interviewees is a database that is divided in projects, zones of the train and products. Also an interactive way of using and adding information is requested. Other suggestions involve more personal interactions with a more senior engineer that have big experience. But to come up with a value adding meeting it’s important to have a set design and requirements, with other words a set framework.

Existing input

The input from Production to Physical Integration is very limited and its primary problems that are transmitted. But to improve, the product engineers and managers also want suggestions to improve a solution or further explanation. Design input can be collected from project documentation, Catia models from reference projects, supplier experience and concept information from Vehicle Design. It stands clear that interviewees with more experience have a better understanding of how to gather data. The current input from production consists of:

- Methods feedback from earlier German projects with a focus on problems
- Experience from visits or production support

The feedback from German projects can be followed up and in cooperation with German parts of Physical Integration checked to control how well earlier solutions worked. But it is up to the product engineer in question to collect input from earlier engineers in the product area and lead engineers.
Desired input

Product Engineers want better input in the startup phase of projects. They express the importance of knowing how previous designs worked in the production phase and what changes that was made. To fulfill this, the following suggestions were made:

- Visits in production to see and understand problem
- Problems, suggestions for solutions or improvements needs to be documented in a useful way
- Database with product specific data
- Project documentation structure with reference projects, integrated with Catia viewer
- Work with experienced peers to discuss possible solutions
- Workshops with production problem solving personnel

An example from PPC is where product engineers had one-on-one meetings with senior and experienced engineers that could come with useful inputs on product design. During the project, product engineers have been able to communicate with an experienced lead engineer for interior that been able to come up with feedback on solutions. The lead engineer has the aim to collect and distribute interior solutions between sites. But due to placement on a different site and a changing industrial design, it has been hard to use the experience of the lead engineer.

Communication input and output

With a focus on Physical Integration, a flowchart for inputs and outputs has been put together from interviews, Figure 27. A more detailed picture of the communication can be overlooked in Appendix 2. The chart makes the communication visual and shows that Physical Integration only gets feedback from the production through methods and problems through change management and the tool FIX. Problems or changes communicated through FIX are handled by a product engineer at Physical Integration which leads to personal experience. But if consultants at Cyient are making a change, no feedback on the problem is reaching Physical Integration.

![Figure 27. Physical Integration communication](image)
4.2.4 Methods

**Documents:**
Methods is part of the department for Technical Services and are the function that develops the manufacturing strategy including methods needed, processes, tooling and physical implementation of the workstations at the plant. They also influence the engineers to design products into a manufacturable product according to contractual requirements. (Manage Execution of MLM Projects, 2012) In C30 they are active in a relatively early phase and participate in gate reviews and workstations meetings. Methods also plan, coordinate and validate assembly of the first units to enable series production. As described in documentation, Methods also support production to ensure that continuous improvements are realized to achieve an optimal production process.

In the C30 project, Methods are involved early on. They work together with engineering from GR 1 to GR 4 where they are the responsible function to realize the metro and in GR 6 hand-over to production control for series production.

**Organization Interfaces**
Methods ↔ Production Control:
- Methods provide Production Control with work instructions and detailed layout in order to plan the realization of the vehicle.
- Methods are handing over responsibility of product realization to Production and Production Control after 1st product realization and completed validation of the industrial process.
(Manage Execution of MLM Projects, 2012)

**Interviews & observations:**

<table>
<thead>
<tr>
<th>Interviewee role: Methods – Design for Manufacturing C30</th>
<th>Purpose of interview:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Get a view of how Methods is involved in different phases.</td>
</tr>
<tr>
<td></td>
<td>• How work is done during production support.</td>
</tr>
<tr>
<td></td>
<td>• Understand how problems in pre-series are handled.</td>
</tr>
</tbody>
</table>

**Steps in methods work**
In C30 Methods have been involved in the following steps:

- **Bid** – Methods made a preliminary calculation of expenses in production to include in budget for initial bid to customer
- **DfM** – Based on the concepts and models made by engineering, methods analyzed how suitable the design solutions were for the manufacturing process.
- **WP** – As a part of the industrialization, Methods performed a work preparation including instructions for assembly, tooling, jigs and safety precautions.
- **Validation** – Pre-series manufacturing results in a validation of products and assemblies.
- **Production control** – Transfer of validated product to production control.
DfM

The goal for DfM is to through standardization lower cost and time of production and at the same time increase quality. The standardization results in identification of faults and problems at an early stage. The giveaway is that it’s more expensive to eliminate faults detected in a later stage, Figure 28 shows an estimation in cost difference.

Other benefits of DfM standardization:

- Possibilities to in an easy way transfer design into standard-layouts at production sites
- Creation of general standards for suppliers.
- Development of pre-assembly units
- Pre-validation of assembly concepts
- Improved communication and teamwork

Continuous Improvements

During the work in production support, Methods will collect blocking points and improvements in a document, for both fast resolution and in the case of improvements for future projects. Methods will also during pre-series make a lessons learned document. According to the interviewee, no of this documents are actually used for future work. The lessons learned document is delivered to a lessons learned department, but has no knowledge of the outcome. In the C30 projects, Methods have started with very limited input. It’s a problem that there is no description in the workload that says that someone has to follow up on lessons learned or collecting input before project start. To handle this, the interviewee suggests a kickoff-meeting in the beginning of a project with a presentation of past problems. In that way, lessons learned can be fulfilled and checked during the project. This part is included in the workload, but as a “nice to have” that rarely is executed. To get a closer connection with production, the interviewee suggests that engineers needs to take part in the assembly and see problems occurring live, to get a better understanding and learn for the next project.

4.2.5 Production site – Hennigsdorf, Germany

Documents:

Production can be divided in two parts; Production Control and Production. Production Control is responsible for planning of sales and operation. But main focus is on production
planning and control, including production schedules, production flow and control of the progress. Other responsibilities include internal logistics, control of inventory and management of the material flow. Production on the other hand is the function that organizes and acts as supervision for the manpower. They are also responsible for plant and machining capacity and works for efficient performance management in order to increase productivity. Mainly they staff production with skilled and trained personnel.

The purpose of the phases:

**GR 6 - Start of Train-Level Validation & Qualification**
(1\textsuperscript{st} Train produced & ready for Type Testing)
- Confirm readiness for type test
- Confirm completeness of 1\textsuperscript{st} train
- Confirm production schedule of pre-series

**GR 7 – Readiness for Series Realization**
(2 weeks prior to start of series production)
- Confirm part availability and coverage
- Confirm ability/responsiveness of organization to close open points
- Confirm feasibility of production ramp-up

The production concept for C30 is to have the final assembly in a line with 7 workstations and a test station, each of the stations with a varying degree of pre-assembly. In total 96 metros will be produced, each consisting of four cars. Pre-series are were the first trains is assembled, a production support team is collecting and solving problems that occur and realizes the train for series production. Further description of the pre-series and series production can be overlooked in Appendix 3.

**Red MR**
The RED-MR process is a method to make changes in a fast way to avoid stops in production or pre-production. Usual application of the process is when parts has incorrect dimensions, incorrect number of parts in bill of material, incorrect drilling that can be reworked or reconnection of cables without the need for additional material. A flow chart over the process can be overlooked in Appendix 2.

**Interviews & observations:**

<table>
<thead>
<tr>
<th>Interviewee role:</th>
<th>Purpose of interview:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager Production Control</td>
<td>Get an overview of the production facilities and the production process.</td>
</tr>
<tr>
<td>Production Control</td>
<td>Understand the way production is handling problems.</td>
</tr>
<tr>
<td>Team Leader, Assembly</td>
<td>Discuss how a closer connection between engineering and production can be made.</td>
</tr>
</tbody>
</table>

**Pre-Series production - Production support**

Description of how occurring problems are handled during pre-series production:

Methods are the lead of assembly of the first metros in the pre-series; they are in charge of a group called the co-locating team, also called production support. Production support consists of member from Methods, Production Control, Production, Quality and Engineering. The process followed during production support can be seen in Figure 29.
During production support, Methods are documenting problems that need to be handled. Headings in the document are describing date, article and responsibilities, but most important a description of defects, comments on possible solution and progress.

Interviewees propose that engineers have to see problems live in production. Production support is a part-solution, but a limited number of engineers can be sent. Assembly personnel expresses that engineers don’t have the insight of limitations in production. During study visits and interviews, both engineering and production explained that problems are not analyzed in a standardized way. Their main argument is that there are so many problems that there is no time to think about any methodologies for problem solving. If engineering receives a problem they need to solve, it relies at big extend on experience from earlier problems.

Series production
When the metro has passed the pre-series production, series production is started. Another set-up for problem solving is used and can be seen in Figure 30.
they cannot be solved by assembly personnel straight away. Problems are followed up each day to check status. Interviewees confirm issues with documenting problems for future lessons learned and a shortage of a structured way to analyze problems and effects of solutions. The whole process is very dependent of the experience in the personnel.

4.2.6 Production site – PPC Västerås

Documents:
The scope for PPC in the C30 project is to develop and deliver propulsion, TCMS HW, Orbiflo (central IT systems), documentation, training, spare parts, special tools and technical support.

Interviews & observation:

<table>
<thead>
<tr>
<th>Interviewee role:</th>
<th>Purpose of interview:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teamleader, I-teams</td>
<td>• Get an overview of the production facilities and the production process.</td>
</tr>
<tr>
<td>Teamleader, Pre-series</td>
<td>• Understand the way production is handling problems.</td>
</tr>
<tr>
<td></td>
<td>• Discuss how a closer connection between engineering and production can be made.</td>
</tr>
</tbody>
</table>

Continuous improvements & Lessons learned

PPC in Västerås is performing continuous improvements during pre-series where they have a team that is working with new products continuously. In the pre-series, the improvement team is in close cooperation with engineers that also have their workplace on the production floor. Both engineers and pre-series team take part in daily meetings to solve problems that is occurring. Problems are listed at planning boards and responsibility is handed out for solving the problem.

Lessons learned are posted by all employees and workshops are held by the project management. Interviewees say that PPC are good at posting and collecting lessons learned, but that they rarely use them.

4.2.7 Product Introduction

Product Introduction is a department that is ensuring efficient management of experience feedback from previous projects by running a FRACAS process.

Interviews & observation:
Product Introduction works mainly with problems after the production and is therefore not included in this thesis.
The purpose of the part is to analyze the raw data and compare the findings with the theoretical framework with a mindset to answer to the research questions. The principles by Liker (2009) is considered a base for the analysis, primary the areas of creating a learning organization, continuous improvements and seeking the root-cause of problems. The first part connects how Physical Integration needs improvement suggestions and lessons learned from the production with support from methods. The subject of how engineers can be involved in the production articulates the need for involvement in order to gain experience that cannot be communicated or shared through documentation. The following parts are more solution oriented, first with a proposed way of handling problems in the production line in order to specify and document causes and for more complicated problems find the root-cause of the problem. The last part focuses on the importance of keeping permanent staffing at Physical Integration to keep the experience and foster engineers that can take responsibility for less experienced engineers and product areas.

5.1 Improvements & Lessons learned

Methods and Production Control are the responsible functions during pre-series production and series production. To get improvements and lessons learned from the production phases, engineering needs to be involved in problem solving to get experience from production. The production experience relevant for Physical Integration needs to be connected to responsible engineers that can distribute information in future projects. Williams (2008) describes two criteria’s for organizational learning where we can relate to the first criteria expressing that individuals have to take their learning back to the system, in this case Physical Integration. If individuals bring their learnings back from production, they can learn and use the knowledge in future projects. The second criteria are that the system needs structures, processes and a culture in place to support organizational learning. Whereas the engineers need documentation and processes to rely on, they need documentation from the responsible functions Methods and Production Support. In pre-series Methods collects and documents problems and lessons learned that would be valuable as input to future projects for engineering. Becket at. al (2000) says that organizations should maintain closed-loop control processes to allow process outputs to modify inputs, continuously improving the production process. In this way production output should also become a source of input to engineering phases.

Input as lessons learned and documented problems could become a source for responsible engineers that can build knowledge to a database for product related data. A database would be a suitable solution for storing solutions that is useful for all product engineers at Bombardier, but also a way of connecting engineers at different sites and projects as a network. As Newell et al (2009) describes models for the understanding of how cross-project knowledge is used and how it is easier to connect people then people to documents. A simplified overviewed cross-project process is illustrated in Figure 31. An important function is Methods that need to distribute their findings from pre-series, something that are not working for the moment. In the C30 projects, Methods have been involved at a very early stage and a natural way of delivering the documentation would be that they before each project have a workshop with findings from earlier projects. The findings can through documentation be included in a database for collection of more product specific findings.
In order to use the process, Methods has to summarize and deliver information at the kick-off meeting and together with engineers that have been involved in the production be the knowledge brokers.

5.2 Engineering involvement in production

In interviews, all functions mentioned that there is a need for engineers to visit the production. Mainly to get an understanding of problems that is revealed in the assembly of pre-series vehicles. Engineers at PPC in Västerås have the opportunity to be placed at the same site where they have their workplace on the production floor during pre-series and takes part in problem meetings continuously. An advantage for PPC is that they as a production site works according to the BOS principles for lean production. As described in the theory of BOS, principle 5. Continuous Improvements includes improvements on product design with support of processes and methods that can ensure manufacturing, assembly, installation, testing and maintenance. Engineers at PPC have close access to all the functions above which according to interviewees leads to a close follow-up on the designed products. In order for engineers at Physical Integration to get a closer connection to the production, they need to take part in problem solving in the production to gain feedback on designs and experience for future projects. Goffin at .al (2010) defines the experience knowledge as tacit knowledge that should be shared in order to capture experience and transferred to future projects. Physical Integration needs to have post-projects reviews in order to summarize the tacit knowledge as a step to have input for start-up meetings in new projects in the role as knowledge brokers.

In addition to engineering’s experience, Physical Integration needs lessons learned to build a base of knowledge around products related to the department. Product related information are defined as explicit knowledge by Goffin at .al (2010) and can be documented and captured as information, which makes it possible to save in a database.

5.3 Standardization of problem handling

In order to collect explicit knowledge about the production of products related to Physical Integration, problems during production needs to be handled in an accurate way. Interviews and observations lead to the understanding that problems are solved in an unstructured way. At the moment it’s up to the personnel at the production site how they solve problems and there is no process, methodology or checklist that needs to be followed. For example, if the cause of the problem is vague, this in worst case creates a new problem when a new solution is implemented. The unstructured handling of problems conflicts with the BOS principle 5 that states that continuous improvements means that you never should be satisfied with the current state, identify root causes of problems and work to eliminate waste. A divergence is the fact that the pre-series metros need to be built under time pressure and the production support team can’t waste time on analyzing every problem. A partial solution could include a classification of the problem with different approaches depending on the extent of the problem. But production and primary pre-assembly needs a process for substantial problems...
that defines the root cause of problems and assures documentation, in order to solve the right problem. Physical Integration would gain from an analysis of the root cause in two ways:

1. Physical Integration, that in some cases is making changes in drawings for production support, doesn’t need to execute several changes if the root cause is found and the accurate problem is solved.

2. Physical Integration is able to take part of an analysis of the problem that defines who is responsible for the problem that have occurred and will know what have been designed in an undesired way. Information that can be used as feedback and build knowledge in a possible database.

Possible methods for problem solving are PDCA, DMAIC or 8D, described in the theory study. 8D imply a thorough process but are described as a time consuming method that is used for problems with big impact. DMAIC can be excluded based on the fact that it is part of the framework of Six Sigma. The PDCA methodology is easily overlooked and connects to the lean mindset of the BOS principles. Connecting the need for a problem solving method, obtained problem solving theory and the existing production support process, a proposal for a new methodology has been developed. The goal have been to customize PDCA and 8D to propose a method that can be integrated in present processes and have a focus on finding the cause of problems and document the problem solving.

The developed process is described in Figure 32 and is customized with a fast track for problems with clear causes in order to speed up the handling. The detailed analysis is created to handle problems with unclear causes in order to find the root cause and avoid solutions that are made for the wrong cause and doesn’t solve the problem.
Figure 32. Proposed problem solving process
Observe
The problem is defined at the workstation in production where assembly personnel discovers the problem and calls upon responsible for production support. The problem is noted in report structure where methods collects problem during pre-series.

Cause checklist & classification
The second step is used to identify the cause of the problem, also this step is supposed to take place in the workstation with the responsible assembly personnel and the production support team. Use of a checklist is required in order take all possible causes in consideration. Points on the checklist have to be developed, but examples of points to consider are parts, material, assembly methods or chains of tolerances. A classification of the problem with knowledge about the cause can describe the need for further work.

If the problem has a clear cause there is a fast track with the regular PDCA method in place to develop a solution in a timesaving manner. The following explanation will describe the steps for a detailed analysis in order to solve problems with an unclear cause.

Temporary fix
A temporary fix is needed in order to avoid stops or shorten stops in production. The step relates to the Red-MR process that is in use and can be used as a way of doing temporary fixes if the criteria's for the process is fulfilled.

Plan
In order to solve the problem that have unclear causes, a root-cause analysis has to be performed, suiting tools are; brainstorming, fishbone diagram or tree diagram. The root-cause analysis aims at finding the underlying cause that creates the problem. Production support and assembly personnel participation creates different views on the problem which is preferable. With a defined cause, a solution can be developed and verified in the production.

Do
Implement the solution permanently.

Check
Analyze the solution and evaluate the outcome.

Act
Correct the solution if small changes ca be made in order to solve the problem. Document the outcome and deliver report to administrative function.

Documentation needs to be developed so that it can be made in a fast way, for the fast track only with a one-pager and for the detailed analysis with additional documentation. The documentation will work as support for sharing of tacit knowledge by the knowledge brokers in the post-project reviews and kick-off meetings. But the main purpose is to use it as information source in creation of a product based database.
5.4 Staffing at Physical Integration

An important part for creating a learning organization is to gain tacit knowledge through visits at the production site. When looking at the charts for staffing it becomes clear that there are a limited number of employees at Physical Integration that will work at the department during several projects. That makes it important to have the mindset described in Figure 22. Staffing pyramid, where there are a limited number of employees that need to have an understanding of the department process. Engineers that are positioned in the top of the pyramid have an important role when it comes to sharing of knowledge. This relates to the earlier part about involvement in production and how engineers gain from understanding the requirements of production. The subject is described in the theory of managing lessons learned; sharing is preferable done with social interaction. In this case in the interaction with less experienced engineers during product development. Interviewees identified that Physical Integration makes improvements mainly on experience. In order to foster the experience of engineers, they need to work in several projects and that can only be secured if they are hired as permanent staffing. Both interviews and observations have shown that consultants come and go; many only works in one project and can’t in that way use the acquired experience in future projects. Permanent staffing seems to take more responsibility for the products and will be able to build a base of knowledge on the department. The theory of lean in TPS, describes in chapter 3.1.2 Toyota Production System, the subject with several principles:

- Part I: Long-Term Philosophy
  - Principle 1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals

- Part III: Add value to the organization by developing its people and partners.
  - Principle 9. Grow leaders who thoroughly understand the work, live the philosophy and teach it to others
  - Principle 10. Develop exceptional people and teams who follow your company’s philosophy

Staffing at a department as Physical Integration should be based on a philosophy that answer to goals bigger then execution of specific projects and in that way thinking more long-term. In order to develop staffing they need to gain experience to understand the processes and be able to teach them to others. Engineers need to get experience as product engineers and through knowledge from several projects grow in to a role where they can fulfill tasks and lead teams.

An example can be made in the coming timeframe, according to Figure 33, there will be a gap with a low need of engineers. But the upcoming projects, X,Y and Z has a big workload in the future. Instead of letting engineers go, a lesson learned period of the C30 projects would fill the gap. Engineers can instead work with problems that occur in the production, on-site problem solving with a focus on root-cause analysis, which would make the engineers more experienced. With a bigger understanding of their previous solutions, the initial phases of the upcoming projects could be executed faster with higher quality.
Figure 33. Leveling of staffing at Physical Integration (internal document)
By applying the theoretical basis with observations and interviews, the following conclusions could be drawn. To make them even clearer, these also summarized in Figure 34.

- Physical Integration needs engineers that are hired as permanent staffing in order to become a learning organization. The product engineers need to work in several projects to gain the required experience for a role with more responsibilities.

- A way of gaining experience is to have a closer connection to the production. Therefore, all engineers need to participate in problem solving during the pre-series in order to understand the production requirements, see design problems occur and develop solutions based on problem and cause analysis.

- Problem solving has to follow a standardized process, adapted for the scale of the problem, which forces involved staffing to analyze and document the steps. An example is presented in chapter 5.3 and focuses on an identification of causes that leads the participants to the needed process.

- The result of problem solving and engineers partaking benefits:
  1. Experience for future projects, also called tacit knowledge that need a knowledge broker to share the experience in future projects.
  2. Documentation of problems secure product specific data, earlier referred to as explicit data.

- The results consisting of improvements and lessons learned needs to be captured and shared to upcoming projects through post-project reviews and kick-off meetings with involved functions; Production, Methods and Engineering. The process for sharing tacit knowledge needs to be done by social interaction during reviews and meetings. Explicit knowledge in form of documentation should be delivered to Physical Integration from Methods because of their leading role in the production support.
6.1 Thesis remarks

Raw data
The first step before interviews and observations included a thorough reading of documents connected to the C30 project and processes in which the included departments are involved. The documents worked as a base of knowledge that during the interviews and observations could be verified and further developed. Interviews have mainly been performed at BT Västerås with proposed personnel. Due to project deadlines, several interviews were rescheduled and some cancelled. With methods only one interview could be performed due to their period wise presence in Västerås, which can lower the validity of information. Observations and interviews at BT Hennigsdorf was weakened by absence due to illness, but could be solved with additional visits at PPC production site in Västerås.

Analysis
The subject of improvements and lessons learned is in many cases an area of responsibility for managers. This in interviews often refers to processes that are written in principles or processes, but might not be followed. Another obstacle was that it late in the research came up information that there was a “continuous improvement department” and “lessons learned department”, the departments was not mentioned in the interviews could not be analyze. But an interested remark is the fact that there are departments that works with the subjects that are not used in the operative work.
Production of the C30 metro is starting up in the autumn of 2015, hence the analysis can only be made on earlier production setup and involvement of the engineers. The analysis of problem solving in production are in the same way only developed as a strategy with the answers from interviews about C30 production based on plans and experience.
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WEBPAGE


NE.se, Lean production: <http://www.ne.se.proxy.lib.ltu.se/uppslagsverk/encyklopedi/lång/lean-production>

# 1 Interview protocols

<table>
<thead>
<tr>
<th>Nr</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>How are you working with continuous improvements on daily basis?</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>How are your department having hand-overs of lessons learned between projects?</td>
<td></td>
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<tr>
<td>3</td>
<td>How would you like to receive improvements and lessons learned? In what form?</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Do you have suggestions on how we should communicate improvements from production to (Physical Integration), CEE engineering?</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Can you share an example from another department or companies were the communication between the production department and design department worked very well?</td>
<td></td>
</tr>
<tr>
<td>Nr</td>
<td>Question</td>
<td>Answer</td>
</tr>
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<td>----</td>
<td>--------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>6</td>
<td>In which project phases can changes be made?</td>
<td></td>
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<tr>
<td>7</td>
<td>Which tools will be used for communication in the C30 project, between Methods and Engineering?</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Will the problems and improvements that not ends up as a MR be documented?</td>
<td></td>
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<tr>
<td>9</td>
<td>Will engineers in Västerås be able to take part of productions idea management?</td>
<td></td>
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<tr>
<td>10</td>
<td>How will Product Introduction deliver feedback from the project?</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>What kind of lessons learned will be saved by project management?</td>
<td></td>
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<tr>
<td>12</td>
<td>How will lessons learned be distributed after the project?</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>How will lessons learned be used in future projects?</td>
<td></td>
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<tr>
<td>Nr</td>
<td>Question</td>
<td>Answer</td>
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<tr>
<td>----</td>
<td>--------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>6</td>
<td>What feedback do you get on the result of your previous products from previous projects?</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>At project start-up, which input data do you need on your product?</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Describe an event where you had to make production related changes of your product?</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>How are engineering involved in production support?</td>
<td></td>
</tr>
<tr>
<td>Nr</td>
<td>Question</td>
<td>Answer</td>
</tr>
<tr>
<td>----</td>
<td>--------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>6</td>
<td>Can you in short describe the different steps for methods work from project start until completion? For how long will methods be involved in the production during C30 project?</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>What is the goal for your work during the realization-phase?</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>What is methods role during production support?</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>How are engineers from Physical Integration involved in production support?</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Where is the changes made after the DDR-phase documented?</td>
<td>Is the documentation shared with engineering in any way?</td>
</tr>
<tr>
<td>Nr</td>
<td>Question</td>
<td>Answer</td>
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<tr>
<td>----</td>
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</tr>
<tr>
<td>6</td>
<td>Describe the work done during production of the first products in a metro series?</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Which documents are used during production of the first product?</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>How is production working with the production support?</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>How are improvements collected during the different phases of production?</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Are there any follow-ups on collected improvements?</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>And how are production co-operating with methods? (During different phases of assembly)</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>How is production cooperating with engineering? (During different phases of assembly)</td>
<td></td>
</tr>
</tbody>
</table>
2 Engineering raw data

For engineering the 5 main phases can be described accordingly:

- **Project Strategy & Initiation Phase**
  - Analyzing initial requirements and contribute to bid & sales process
  - Contribution of initial concepts, modeling and specifications. This is needed to ensure the technical possibilities to realize the as-bid vehicle, functions, systems and equipment.

- **Launch & Conceptual Design**
  - Preparation and planning of how Engineering contributes to the product with SMB documents.
  - Requirement management, identification and allocation
  - Allocate resources
  - Freeze concept design
  - Identification of design input requirements
  - Issue base of Technical Requirements at sufficient quality level

- **Preliminary Design Completion, Supplier Design Process**
  - Integration of supplier design input
  - Affirm freeze of major design interfaces
  - Release 100% of engineering content for Technical Requirement Documents
  - Completion of vehicle integration and characteristics prediction reports

- **Detailed Design Completion, Supply Chain & Industrialization Readiness**
  - 100% release of Engineering Bill Of Material (EBOM), part drawings and wiring design
  - Conformation of specialist engineering analysis.

- **Project Preparation and Realization**
  - Support of production process with resolution of problems (Non-conformity reports and Technical Open Issues) found during First Product Realization.
  - Complete verification and validation assessments.
  - Achievement of full homologation
  - Ensure proper project closure (lessons learnt).
How a standard Engineering Project organization at Bombardier Transportation is built up can be viewed.
Physical Integration detailed input & output

The Figure describes a more detailed view of input and output according to Physical Integration.

Change management

The function has the task to ensure correct vehicle configuration over the vehicle life time. For change management this includes close cooperation with the Project Change Board to ensure that modifications (MR) are coordinated and that changes do not interfere with vehicle functionalities, safety or homologation. They lead the Engineering change board, ensure and documents the vehicle configuration and distributes approved changes to engineering (ER). All changes are documented, reviewed and approved in the C30 FIX Lotus Notes Database. (Engineering mgt plan, 2013)The process for how Change Management is handling a change is described below.
Change management process
Red MR process
Activities and responsibilities when handling RED-MR changes

- Operations Site Hennigsdorf identifies a problem and informs the assembly support team (AST) → Quality, Methods / Engineering
- AST checks, if a document change is necessary
- If yes, AST ENG discusses potential solution with responsible ENG for the assembly group
- AST creates RED-MR in FIX incl. applicability, document numbers and future revision of affected documents
- CM creates collecting-MR for affected assembly group (if not yet existing)
- AST enters the RED-MR number in the collecting-MR
- AST creates red-marked-documents from the existing documents from the production line with use of the agreed Stamp
- For red-marked-documents modifying supplied parts, new documents need to be delivered to the production line by Shop Order Control
- AST enters the date, the RED-MR number, the Project and Train of the first implementation of the red-marked-documents
- AST signs the red-marked-documents (ENG, Q & MET)
- AST attaches digitalized red-marked-documentation into the MR and creates an ER for CM-OPS / no ER for ENG
- CM-OPS creates the effectively
- CIM after regular CM-Process
- Implementation feedback in production is collected in the RED-MR
- Revision in PDM of the affected documents is controlled with the collecting-MR
- Methods-Review checks if changes on the RED-MRs and collecting-MRs are the same
3 Production raw data

Pre-series
Pre-series is considered a start-up and learning period with extended production tact to 7 work days per car and a total of 6 metros. Methods are responsible for the assembly and validation of the pre-series. The setup consists of a static line production with the following goals:

- Validate design and interfaces
- Validate manufacturing and final assemblies
- Validate quality aspects and functional performances
- Type-testing and endurance testing

Series production
The series production will work in a two shift model with a tact time of 2.5 days per car. The production will now be set up in a flow line production and produce 90 metros. Responsibility for final assembly is transferred from methods to Production Control, (internal presentation).