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TRANSFORMATION TO LEAN PRODUCT DEVELOPMENT – APPROACHES AT TWO AUTOMOTIVE SUPPLIERS

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1. Introduction

The transformation to a lean product development system was studied at two automotive suppliers of different sizes producing different types of products. The study covers the process from the initial state via the transformation approach, the problems along the way, some early results of the transformation and a comparison between the two firms in this respect. Both strive to change their operations to add more value in their delivery to the OEM (Original Equipment Manufacturer). The results show that the transformations are experienced as positive in both firms. It is demonstrated that this success is due to some of the methods and principles included in the lean product development framework.
Many automotive industry suppliers use product development (PD) processes divided into phases and gates similar to the one of Cooper [Cooper 1994], see Figure 1. Even though the latter has been revised over the years to mitigate many of the initial drawbacks, it is still its first version that often prevails. The process consists of identifiable and discrete stages preceded by review points or "gates". Each gate is associated with fulfilment of certain conditions (the two firms in this study use the term "phase" similar to "stage", which will also be used in this paper).

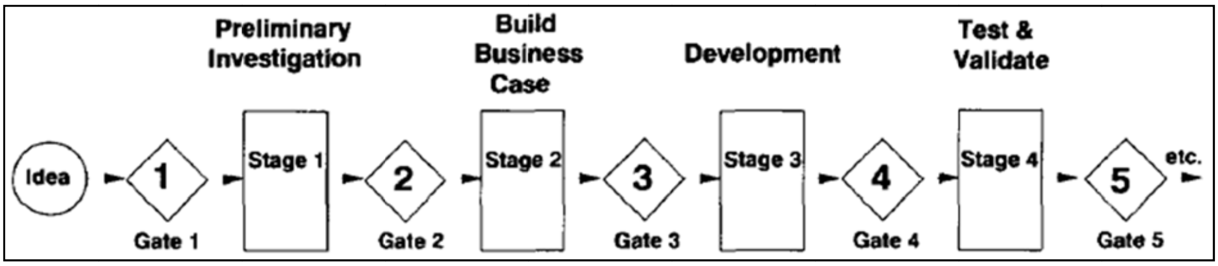

Figure 1. The Stage-Gate® process

Some drawbacks of, and problems associated with, the phase-gate process have in recent years become topics of discussion. Among those are wishful thinking in gate passing and focus on requirements associated with the gate rather than knowledge gaps that prevent fulfilment of the customer requirements. Another drawback is that the management tends to regard the gate documents as sufficient evidence that the project is running well instead of digging deeper into what is really going on and assuring that the knowledge gaps are closed. Furthermore, testing of few design solutions late in the product development process instead of many early is also a process drawback. The phase-gate time plan imposes an end date on the project team, which may have to pass gates without fulfilling the requirements of them just to comply with the plan. This is a devious behaviour in which time keeping takes priority over needed knowledge in the PD process. When solving problems

under pressure it is hard to set aside time to document gained knowledge. This task was not prioritized at the studied firms, and sufficient tools and routines for it were missing. A project experience documentation tool is available in the Product Lifecycle Management (PLM) system at one of the firms but the system is not used to the extent that was originally intended.
One approach to mitigate the negative effects of the phase-gate process and to possibly shorten development time is to use the Kennedy model [Kennedy 2008], which is employed by one of the firms in the study.

1.1 Unique opportunity to do research

Both firms in this study face similar problems during product development. They have independently of each other simultaneously decided to make the transformation from a traditional phase-gate process to an LPD based one with a clear focus on knowledge build-up. The possibility to study these transformation processes in parallel at close range contributes to the uniqueness of this study (see Table 1 and Table 2).

2. Research questions

In this context we find it relevant to pose the following questions:

- How can LPD be introduced at tier 1 suppliers in the automotive industry?
- What are the experiences when introducing LPD at an automotive supplier designing and manufacturing components?

3. Related theories and theoretical framework

The pioneering scientific paper describing LPD is the one of Ward et al. [Ward et al. 1995], and the concept was further described by Morgan and Liker [Morgan and Liker 2006], and Ward [Ward 2009]. These writings are based on observations made by North American researchers at Toyota Motor Corporation in Japan. Ward et al. describe the set-based concurrent engineering approach in which multiple solutions are explored to find the best design solution. Ward also describes how design decisions are made as late as possible in order not to unnecessarily constrain the possibilities in the product realization process, which Liker and Morgan describe as a socio technical system. In [Ward 2009] the Knowledge Value Stream (KVS) and the Product Value Stream (PVS) are described as two essential components of the Toyota product development system.
The KVS is an organization's gradual build-up of knowledge about its products, associated technology, customer needs and production technology etc. that is needed to realize the product. This knowledge is precious and therefore needs to be preserved and further developed for future needs. The PVS is the realization process of the actual product. An interpretation of these two streams is shown in Figure 3. Ward also describes the Structured Problem Solving (SPS) loop of Toyota [Ward 2009], which he calls LAMDA and which is described below, see Figure 2.
Kennedys PD model [Kennedy 2008] is based on observations made by Ward [Ward 1995] combined with experience from traditional phase-gate processes. A double arrow is used to differentiate between the KVS and the PVS. The model incorporates methods for knowledge consolidation and build-up, short design and test cycles, and risk elimination by set-based design, see Figure 3 and Figure 6.

3.1 A3 reports

A3 reports (A3s) have received their name from the standard size (A3) of the paper they are printed on. This format was chosen since it is, or used to be, the largest paper that would fit into a fax machine. A3s have evolved into a concept in itself which also incorporates problem solving by SPS loops, communication and coaching - both vertically and horizontally in the organization [Sobek 2008]. A3s can be used to document problem solving, proposals, status reports and many other kinds of information that can benefit from a compact format. When used for problem solving, one way of structuring the A3 for SPS is to align its sections with the phases of the PDCA loop or the LAMDA loop. The outcome of a problem solving loop is knowledge about the problem and its solution. This can easily be communicated both horizontally and vertically in an organisation by means of A3s. Their compact format helps make them essential building blocks in the continuous improvement and learning process of a firm. They are therefore often posted on the walls of design offices to contribute to the visualisation of the design work and thereby enhance learning and information transfer.

3.2 Problem solving loops

The two common problem solving loops in LPD are LAMDA and PDCA, see Figure 2.

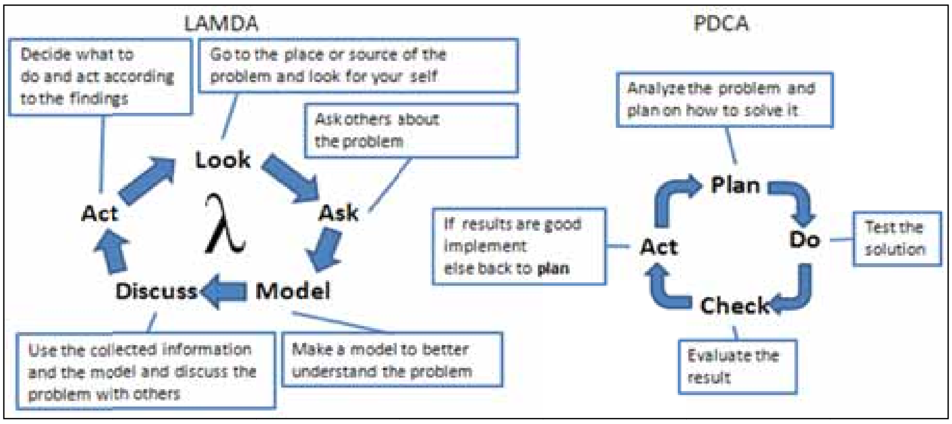

Figure 2. The LAMDA loop [Ward 2007] and the PDCA loop [Sobek 2008]

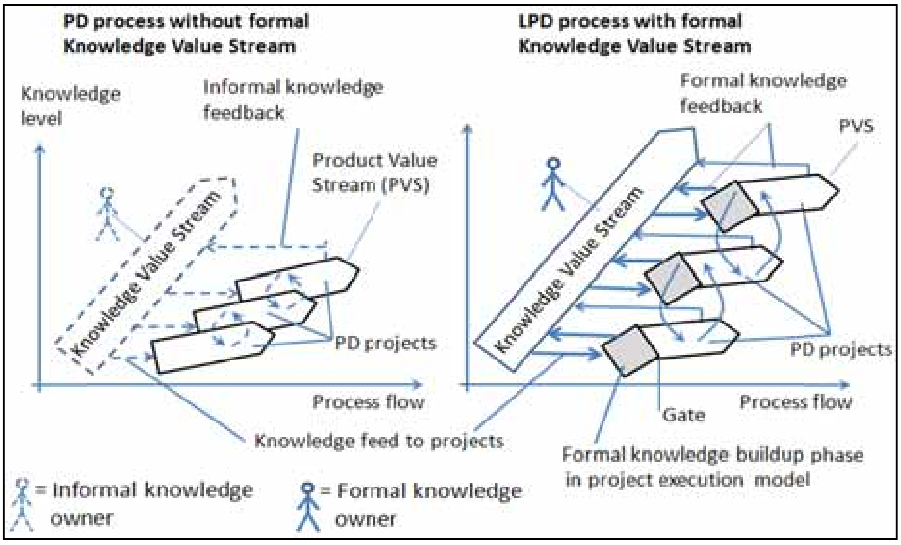

Figure 3. The model to the left shows the state before the LPD introduction, with the Knowledge Value Stream (KVS) as an informal process. Knowledge from one project is not systematically transferred to future projects. In the model to the right the KVS has been formalized. The projects now have initial (grey) phases to close possible knowledge gaps and there exists an organized way to transfer knowledge from previous projects to new projects. This makes it possible to launch projects at a higher knowledge level compared to in the previous PD process

The two loops are variants on the same theme, but the older PDCA focuses more on testing and evaluation while LAMDA is better suited for observations and collaboration. The important thing is to use a Structured Problem Solving process at all, and one which is geared towards the objectives in every situation and emphasizes documentation of the route as well as the results. If the problem solver receives coaching, the coach can recognize where in the loop he/she is and thereby better understand the situation and provide more qualified help. Documentation on A3s supports interaction since all information can be easily shared. An application of the PDCA loop in one of the firms is found on the fifth board used for Visual Planning as described below, see Figure 4.

4. Methodology

The research is an exploratory two case study at Autotube AB (Autotube) in Varberg, Sweden and Kongsberg Automotive AB (Kongsberg) in Mullsjö, Sweden, with internal and external development projects as embedded units of analysis [Yin 2009]. The analysis is based on a descriptive framework strategy combined with a rival framework. Evidence was collected through observations in meetings and workshops, questionnaires answered in workshops, records in computer systems, documents and interviews. Different methods were used depending on evidence type, given possibilities and the need for information. There were also elements of action research since members of the research team have conducted coaching, training and served as advisors to both firms as part of the study. The results have been analysed in discussions in the research team, by comparisons with theoretical frameworks and rival frameworks, by comparing the state before and after the transformations to LPD and by comparing the two cases. The research team had a reference group with members from the studied firms and representatives of two OEMs and another supplier, all from the automotive industry, associated with it. The reference group advised on the investigations and helped verify the validity of the results.

In order to take advantage of this research opportunity we had to adapt our methods to the circumstances of the individual firms. This led to the application of a common research design at the top level with the following local adaptations:

Autotube: On request from the firm, the research team launched a customized coaching and education programme which started with a self assessment in the form of a questionnaire processed and answered in a workshop. The programme continued with a series of workshops in which members of the research team participated. The assessment pointed out areas of improvements, see 6.1. Prior to the coaching programme the firm was monitored by members of the research team through their participating in a development project where the production system (of which PD is one part) was improved by implementing lean production. In total 15 people from design, production, purchase, marketing and management participated in these studies.

Kongsberg: The initial phases of four product development projects were followed. The projects, which used the firm’s new LPD process, were carried out in two different divisions. Information was collected through interviews, participation in meetings and visits to Obeya rooms and test facilities. In total 18 people from functions such as design, software, electronics, management, production, quality, test, production and project management participated in this study. Earlier the previous PD model had been examined by doing process mapping, participating in meetings of best practice groups, conducting semi structured interviews, studying best practice experience records, process descriptions and other relevant documents, conducting a workshop based questionnaire for self assessment and by assisting during internal training courses. In total 210 people were involved during this study.

5. Results

The transformation processes of the two firms have some key components. Table 1 describes them as well as their roles in the processes. Some of the areas of improvement are described below and in Table 2. Although the firms mention perceived deficiencies in their respective operations, it should be emphasized that both are commercially successful and that their strive for perfection in PD is at a comparably high level.

5.1 Autotube

Autotube has approximately 300 employees and designs, produces and delivers to a few OEMs and tier 1 suppliers. Most products, which are not classified as complex, are tubing for gas and liquid in vehicles. The self assessment mentioned earlier suggested a number of areas of possible improvement:

1. Planning of PD projects.
2. Follow up on customer contacts.
3. Structured Problem Solving (SPS) in general.
4. Knowledge consolidation and dissemination in the organization.
5. Visualization to create transparency in PD projects.

6. Communication in PD projects inside the firm and with partners.

5.2 Kongsberg

Kongsberg has approximately 10 000 employees all over the world and designs, produces and delivers subsystems to many of the major automotive OEMs and tier 1 suppliers. Examples of products are components of interior systems, drive lines and chassis as well as wire components. With the exception of the wire components the products are of a complex nature. Areas of improvement found are:

1. Documentation of knowledge gained in development projects.
2. Focus on knowledge build-up in the phases between gates.
3. Closing of knowledge gaps when passing gates.
4. Communication in PD projects inside the firm and with partners.
5. Earlier testing in PD projects.

5.3 Visual Planning

The purpose of Visual Planning (VP) in the PD process is to create transparency (increase communication), to balance work load and to create a work flow in a project. Project members and possibly also others shall be able to get an instant view of the status of a project. This approach has been successful at both firms, although their respective arrangements and layout of the planning boards have differed. Both firms have their boards located in dedicated spaces where people involved in PD projects have recurrent meetings. All current PD projects are monitored regarding time, resources, objectives and problems, typically in weekly meetings. Both firms also have dedicated spaces for VP of individual projects. At Kongsberg the project managers have experimented with different layouts of these boards. One very interesting approach at the project level is the one shown in Figure 4. This board displays the project group's daily work and is divided into five main sections: Inbox, prioritized work tasks, work in progress, outbox and performance indicators. Work tasks from the overall planning of the project are first placed in the inbox and then allocated to team members in short, daily meetings. Each engineer works on two tasks in parallel and employs the PDCA loop. A task in process is placed in the "work in progress" section. When it is completed it is placed in the outbox and a new task is selected from among those with top priority. The performance indicators section has graphs showing the progress of the work displayed on the board, which makes it easy to monitor. The board seems to generate a sustainable cadence in the project work which does not overload individuals.

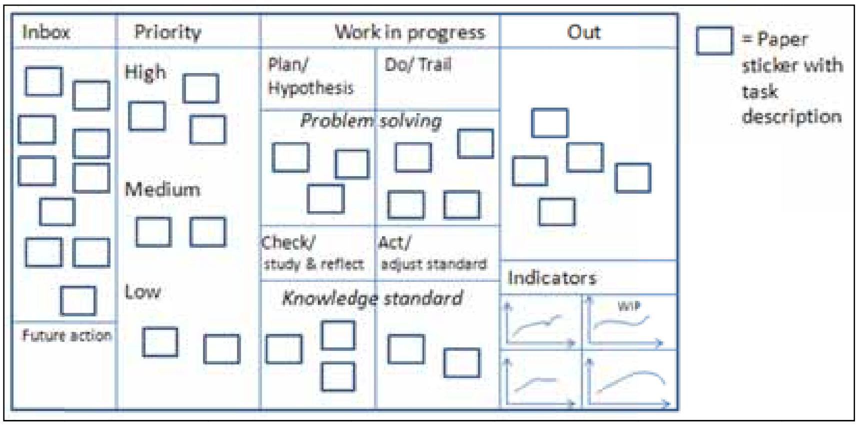

Figure 4. The principal layout of the planning board of the daily work in one PD project at Kongsberg

An interesting approach at Autotube is to use a lightweight foldable planning board, see Figure 5, which was designed and built during this study and is like a mobile Obeya room [Horikiri 2008]. Most of the firm's PD project managers use this type of board to communicate information about their projects whenever needed.

Figure 5. A foldable Visual Planning board used as a mobile Obeya room by Autotube

5.4 Structured Problem Solving (SPS)

Autotube: To improve the problem solving and documentation the LAMDA loop was introduced. In two cases the extra work imposed by this novelty overloaded participators. In two other cases the results were positive resulting in improved production equipment (design of production equipment is often part of the PD project) and improved internal routines. In one case the root cause of the problem was identified through this process, which shifted focus from what was previously – and unfortunately also erroneously – regarded as the problem and thereby avoided unnecessary work.

Kongsberg: The firm has an internal training course on how to use the LAMDA loop to solve problems and to close knowledge gaps in the product development process. LAMDA - and PDCA - are both used to varying degrees in different parts of the organization and the processes are documented on A3s (although that specific format is not compulsory) and should, according to the routines, also be recorded in the PLM system. It has taken some time for the engineers to fully adopt these routines though, and parts of the organization have still not done so. There is a great difference in SPS acceptance between departments run by the lean enthusiast, see Table 1, and other departments.

5.5 Knowledge consolidation and learning

Autotube: A3s were used to document gained knowledge and to make it available to others. The technique was found suitable to be used in conjunction with LAMDA and three problems were successfully solved with it. In one case the problem was too complex for LAMDA to offer any obvious way to simplify it. There is a clear pull in the organization for more knowledge build-up and this is judged to be an essential factor to increase value in the firm's delivery to the customers.

Kongsberg: The role of Knowledge Owner (KO) was introduced in order to establish a framework to formalize the knowledge value stream. The KO shall collect knowledge from the product development projects and document it as A3s to support designers in future projects. KOs are appointed to cover the full range of products but there is some uncertainty about how to define the function. The following variants have been suggested:

- The KO can belong to the line organization and manage a functional team of typically five to ten people.
- The KO can be an entirely new role belonging to neither the line organization nor the project organization.
- The field of KO expertise can be a certain product function or a more general one like plastics or structural mechanics.

It was found that the choice between these was not obvious. The KO will have a mandate to act on his/her own issues connected to his/her field of expertise in all of these variants.

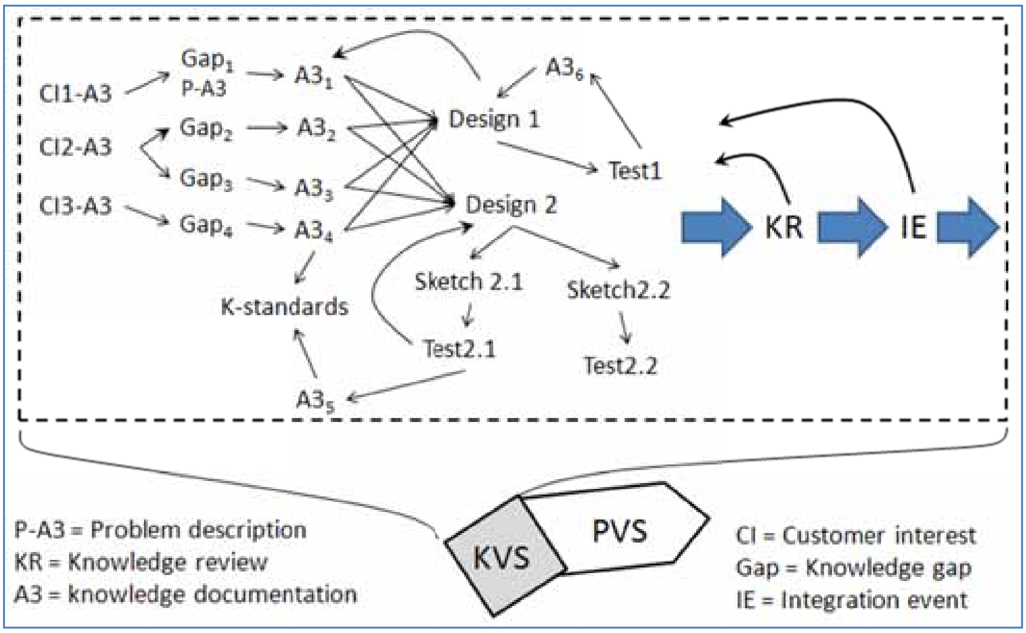

Figure 6. The main constituents of the knowledge build-up phase (part of the KVS). CIs and knowledge gaps needed to be closed in order to fulfil the CIs are documented on A3s. One way to close knowledge gaps is extensive short test and design loops of simple prototypes. Consensus on gained knowledge is established through knowledge review meetings. In IE meetings knowledge and functionality of the products is verified

5.6 Project model

As mentioned in Table 1, at Kongsberg a shift from a traditional phase-gate process to a more knowledge-based process was one of the components in the transformation to LPD. The new process is divided into two flows: The knowledge value stream (KVS) and the product value stream (PVS). In the KVS the knowledge gaps are closed and gained knowledge from existing projects are merged with existing knowledge from previous projects to update the knowledge standards for reuse in subsequent projects. In the PVS the detailed design work is carried out, production prepared and drawings released. The main difference from the previous PD process at the two firms is the formalization of the KVS and an initial phase prior to the PVS being part of the KVS (grey area in Figure 3 and Figure 6), where project specific knowledge gaps connected to customer interests (CI) are closed in short design and test loops. The gained knowledge, CI and knowledge gaps (Gap) are documented in knowledge briefs (KB) that are equal to A3s. In the KVS, gates and phases are replaced with knowledge reviews (KR) and integrating events (IE). In knowledge reviews, knowledge gaps are identified and tasks are defined in order to close the gaps. These tasks are then placed in the inbox of the VP board described in Figure 4. In integrating events the state of the entire product is considered. If multiple tracks are used to solve problems, less successful tracks are terminated. In the IE the assembly of the product is also studied regarding fulfilment of customer interests and requirements.

Kongsberg uses phases and gates in the PVS as imposed by the standards APQP and ISO/TS 16949, which are still largely governing the automotive industry.

5.7 Comparison of cases

Table 2 shows a comparison between the two firms in this study. The application areas in the first column correspond to the areas of improvements that they have identified.

Table 1. Studied components of the transformation processes at the two firms

Component	Role / Impact at Autotube	Role / Impact at Kongsberg
Lean enthusiast - has a strong belief in LPD. This person promotes LPD in the organization.	The lean enthusiast is the design manager, who promoted the idea of introducing LPD. He/she tried to create a pull for LPD in the organization.	The lean enthusiast kept the process alive prior to the strategic decision and promoted activities that informed Kongsberg about LPD. This person also supported the strategic decision of the management to transform to LPD. The lean enthusiast encouraged others to follow.
LPD networks - LPD interest groups.	The design manager participated in different LPD networks to evaluate and benchmark other companies. It was valuable to see the big picture and get inspiration.	Design managers of Kongsberg participated in the LPD interest group. The membership in the network provided Kongsberg with experience from others trying to adopt LPD.
Coaching programme in production.	The company participated in a national coaching programme to implement lean production. This created an appetite to also introduce LPD.	Lean production had been implemented prior to LPD. The latter was however not inspired by the former but rather by the lean enthusiast.
Early information - new findings in LPD. Books, seminars etc.	This information was important as the LPD way of working has in some way changed over time.	This information helped promoters of LPD and others in the firm to understand the advantages with LPD and convinced them to continue to promoting it within the organization.
Strategic decision. At one point the top management of the firm made a strategic decision to adopt LPD.	The strategic decision was taken mainly by the design manager and the technical manager. The top manager saw the first step of LPD and went along with the intention and formally approved it.	The strategic decision was taken by the top management of the firm. This created the necessary momentum in the organization and the promoters of LPD could formalize their ideas.
Education and training - the way individuals are educated in LPD.	Education and training was provided by the academic partners in this research project. Some training in the coaching programme for production could be used in PD.	Solid and reliable partners for education made the members of the organization believe in the new philosophy of product development.
Change of PD-project model, or not.	The project model was not changed but is only used as a guiding principle and is not an obstacle in the transformation to LPD.	The new project model based on LPD is a clear signal how managers and project leaders shall run PD projects.
Pilot test of LPD.	Pilot tests of SPS, A3s and Visual Planning were carried out.	The firm ran four test projects in which the new LPD process was used. This provided input to refine it.
Full introduction of LPD.	The firm is comparably small, so the introduction is fairly simple. The strategy is to create a pull in the organization for more lean methods.	After the test projects, the new LPD process will be implemented in one division. Further implementation will depend on the experiences from this.
Function for education and refinement of the LPD process.	Education and refinement of the LPD process is carried out in infrequent workshops, but also in shorter dedicated improvement sessions every second week led by the design manager.	This function very quickly accepted the idea of LPD which supported the promotion of it. This process is more of a push than a pull for new working methods.

Table 2. Application areas of LPD. Appraisals (Ap) are given according to the following: BT = Being Tested, TP = Tests are Promising, Ac = Accepted as a new method, N = Nothing is done. CI = Correspondence to area of Improvement from Sections 6.1 and 6.2

	Autotube	CI	Ap	Kongsberg	CI	Ap
Knowledge Value Stream (KVS)	The aim to consolidate knowledge resulted in the testing of A3s and SPS.	4	TP	The KVS is part of the first phase of the LPD process and the intention is to close all knowledge gaps before a binding offer is sent to the customer.	7	Ac
Customer Interests (CI)/Voice of the Customer (VoC)	To get a better picture of customer interests all visits to customers are registered in a log together with observations made.	2, 6	BT	As part of the new LPD process, three to five main customer interests shall be defined for each project.	10	Ac
Structured Problem Solving (SPS) on A3	Training and coaching were carried out as part of the study and gave immediate positive results.	3, 4, 6	TP	The firm has an internal training course in SPS and robust learning. It took some time to change the minds of the engineers to document and share their deep knowledge.	7, 10	Ac
Visual Planning (VP)	VP is used for both customer projects and internal projects. Planning meetings are conducted every Monday morning. Afterwards a smaller VP meeting for the design department is held. Some project managers use foldable planning boards that serve as mobile Obeya rooms.	1, 5, 6	A	Each product development project that runs according to the new LPD process uses some kind of Obeya room where VP is used. The layouts of the boards differ. One successful layout is described in Figure 4. Visual Planning has not been successful in geographically distributed projects.	9, 10	Ac
Integrating Events (IE)	IE were used on a few occasions to try out this new concept. They were more efficient than the traditional design reviews: At the very first attempt product design deficiencies were found and corrected at an early stage.	6	BT	IE are becoming common practice in projects using the new LPD process. They are used to confirm design convergence and closure of knowledge gaps, and to evaluate and select between multiple solutions to a design problem.	9, 10	Ac
Knowledge Owner (KO)	KOs exist informally in the firm, i.e., no one has yet been formally appointed.	-	N	KOs have been appointed in the organization. There are however different alternatives for their areas of responsibility. See 6.5.	7, 9	BT
LPD model	The firm uses a self developed PD model which is now being combined with a KVS.	-	N	The new lean-inspired PD model is a clear signal from management how PD projects shall be run. See 6.6.	7, 8, 9, 10, 11	Ac

6. Discussion

This paper presents the initial phase of the introduction of LPD in two firms. The facts that the latter are of different sizes and that their products differ in complexity contribute to the generality of the results. The research team has since long relationships with both firms which counteract preconceived conclusions. The reference group has also found the results reliable. Since automotive industry firms often operate under the same quality assurance standard TS/ISO 16949 and the same business practice, we feel confident that our results are applicable also to other automotive suppliers.

7. Conclusions

The results and the discussion above lead us to the following conclusions:

- Good communication is a key success factor in PD projects in the automotive supply chain.
- Structured Problem Solving (SPS) is a powerful technique.
- Time must be allocated to adopting knowledge consolidation by means of A3s and SPS.
- SPS and Visual Planning (VP) are relatively easy to make feasible. This improves communication and makes work more efficient, thereby freeing time to adopting additional LPD methods such as knowledge consolidation and reuse of knowledge.
- LPD as presented in this paper supports knowledge build-up and reuse.
- The roles of the Knowledge Owners in the two firms were difficult to define with respect to organisational position and detailed responsibility.

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