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LEAN PRODUCT DEVELOPMENT IN PRACTICE: INSIGHTS FROM 4 COMPANIES

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ABSTRACT
This paper aims to elucidate practitioners' understanding and implementation of Lean in Product Development (LPD). We report on a workshop held in the UK during 2012. Managers and engineers from four organizations discussed their understanding of LPD and their ideas and practice regarding management and assessment of value and waste. The study resulted in a set of insights into current practice and lean thinking from the industry perspective. Building on this, the paper introduces a balanced value and waste model that can be used by practitioners as a checklist to identify issues that need to be considered when applying LPD.
The main results indicate that organizations tend to focus on waste elimination rather than value enhancement in LPD. Moreover, the lean metrics that were discussed by the workshop participants do not link the strategic level with the operational one, and poorly reflect the value and waste generated in the process. Future directions for research are explored, and include the importance of a balanced approach considering both value and waste when applying LPD, and the need to link lean metrics with value and waste levels.

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1 INTRODUCTION

Lean in Product Development (LPD) has been developed and deployed in an effort to enhance company operations (Browning, 2003). Companies are increasingly exploring the application of lean in design after its successful implementation at the operational level. LPD includes approaches and techniques to maximize value and minimize waste. This is achieved by organizing design tasks into an uninterrupted flow that is executed at a steady state pace without rework, backflow, or inventory (Oppenheim, 2004). However, the techniques of applying lean techniques to PD are not well established, and many practitioners are "learning by doing" to see what works and what not (McManus, 2005). Moreover, the definitions of value and waste in the context of design are difficult to articulate. Research on value tends to focus on exploring practices applied to enhance value, while research on waste focuses on the types and causes of waste.

Due to the need to understand and address the challenges faced in applying LPD, further investigation of LPD in industry is necessary. This study builds on the work of Siyam et al (2012) that considers the relationship between value and waste in LPD. The present paper summarises insights from one workshop attended by 4 organizations with practical experience of LPD. The workshop explored the attendees' understanding and practice regarding management and assessment of value and waste in LPD.

2 METHODOLOGY

2.1 Data collection: lean industrial workshop

The data presented here were collected during a one-day workshop from four main sources: 1) analysis of 4 presentations, 2) a discussion panel of 7 participants from 4 non-competing companies in different industries and 5 PD researchers and 3) physical notes, e.g. post-it notes that were filled out during issue mapping sessions in the workshop. The participants who attended the workshop are from medium and large organizations with complex products and have relatively good experience in implementing LPD. The discussion aimed to capture formal procedures, challenges, and insight into practical implementations of lean. The organisations that participated are summarized in Table 1 based on their key products.

Table 1. Organisations participating in the workshop

Delegates No.	Key product	Delegates No.	Key product
1	Telecommunication	**1**	Optics and electronics
2	Jet engine	**3**	Design and manufacturer of aircraft

Before the workshop, the participants were asked to reflect on state-of-the-art of lean in their organization, and prepare a 15-minute presentation summarizing their thoughts. These presentations provided an overview about conditions motivating adoption of lean, and examples of lean projects in their organization. The diversity of organization types within this study is not intended to allow for a comparison, but for exploring the range of LPD applications in different sectors.

A discussion followed the presentation session, and was organized into three main parts:

Part 1 ***Understanding: what is the current understanding of value and waste in LPD***? Participants were asked to use post-it-notes to map their understanding of how people, product, and process add value and introduce waste to stakeholders in the Product Development Process (PDP).

In outlining this task, the following definitions were given: 'people' are resources who are involved in the PDP, and include designers, manufacturers, and management. 'Process' comprises all the tasks and their sequence that deliver a product from concept to start of production. Finally, 'product' refers to the final physical product or the 'design recipe' created from the design process such as design documents containing specifications.

Part 2 ***Management: how can value be maximized and waste eliminated in LPD?*** Participants were asked to identify the most important practices used to maximize value and reduce waste as part of LPD in their organizations. Advantages and disadvantages of practices were discussed.

Part 3 ***Assessment: which metrics are used in LPD?*** In the last part, participants were asked to consider what general information is needed to assess lean performance, and also identif metrics used

in their organisation. information refers to information that prescribes or describes the system, while assessment metrics are measurements that describe the system and can be used to monitor it.

2.2 Data Analysis Method

A general inductive approach used to the qualitative data that was collected during the workshop. The general inductive approach provides simple and systematic procedures to qualitative data can produce reliable findings (Thomas, 2006). In the analysis of the workshop, the general inductive method was used to 1) summarize the raw textual data, 2) link research objectives with summary and findings, 3) produce reliable findings, and 4) develop a framework of the findings. The textual data include information presented in the PowerPoint presentation, transcripts of the taped talk, and post-it notes. The textual data was scanned for keywords including ‘’, ‘definition’, ‘method/approach’, and ‘metrics’. Afterwards, results were grouped into ‘understanding’, ‘management’, and ‘assessment’.
This analysis method it provides a simple and straightforward approach suitable for the of data collected in the workshop and the focused nature of the research questions. The procedure included four main steps to code the data:

1. Organizing the textual data: the data collected, including recordings, physical notes, drawings, and post-it notes were transferred into a common format a document with all the data.
2. Comprehensive reading: the text was carefully read to familiar with the content and themes.
3. Establishing categories: the text was sorted into the main themes conveyed by the text.
4. Establishing sub-categories: main points in each theme were identified and summarized.

Using this method, three categories of information discussed during the workshop were identified:

- Challenges motivating lean implementation,
- Lean thinking in product development and services,
- Future directions.

Each of these categories is discussed in detail in the following sections.

3 CHALLENGES MOTIVATING LEAN IMPLEMENTATION

All participants expressed a sense that their processes could be improved. For example, the participant from the Optics and Electronics organization highlighted some problems that could be an opportunity for improvement through lean methods, such as “over-running projects, long duration between project reviews, hidden waste, and long durations for engineering change”.
In general, participants faced three main drivers to implement lean in their organization: high complexity, market pressure, and perceived success of lean methods in other organisations and contexts outside PD. For each company, one of these drivers seemed to be dominant. The drivers were identified from the analysis of presentations conducted by the industries representatives.

3.1 High complexity

Workshop participants came from companies that produce complex products or deliver services. They all perceived complexity management as a major challenge driving the need to apply lean tools, while complexity was also seen as an obstacle to successful implementation of lean tools.
For example, the participant from the aerospace sector talking about engine design discussed complexity in terms of a massive number of iterative processes, long lead times, uncertainty in customer requirements, integrated teams, and complex matrix structure and physical location. This causes difficulties in identifying processes inefficiencies, understanding activity dependencies, identifying the impact of improvements on the process lead-time, controlling and measuring the performance and progress, and communicating problems.
Moreover, the aerospace company and optics and electronics company discussed using lean tools to facilitate daily meetings with employees to discuss rapid schedule changes, visualizing the deviation between planned and actual schedule, and finding the preferred schedule in light of the complex products.

3.2 Market pressures

Due to the need to improve as part of the global competitive market, organizations are in continuous aspiration to enhance their process. LPD was seen as one of the available approaches that can lead to improvements. For example, one of the reasons for the company in optics and electronics to adopt lean is the market pressure due to an increase of orders conditional to short lead time and the global pricing

pressures driving down selling process. This is a starting point for many organizations striving to maintain their position in the global market.
The aerospace industry described a pressure due to the relative performance in comparison to the market. Their application of lean was motivated by the fact that their products were expensive relative to their competitors.
Finally, the aerospace company indicated that lean is a prerequisite for new contracts, as suppliers / customers may require that their customers/providers are 'lean' in order to fulfil their supply chain requirements. Thus, the company uses LPD in order to meet these requirements.

3.3 Perceived success of 'Lean Thinking' in other contexts

Searching for an improvement tool, the aerospace company explored approaches such as lean, six sigma, theory of constraints, and check-plan-do. For some organizations Lean was chosen because of its proven success on the operational level.
In the optics and electronics company, radical changes were necessary in manufacturing, in order to satisfy customers. After seeing the benefits obtained, the organization started to apply lean thinking in the engineering processes. As a result, the organization achieved improvements that include reduction of the lead time from 15 days to 5 days, increase in the designers productivity, and visualizing waste. Afterwards, they explored expanding lean application to other phases.

4 LEAN THINKING IN PRODUCT DEVELOPMENT AND SERVICES

This section highlights the current understanding, management and assessment of value and waste in LPD revealed from analysis of the presentations and the workshop discussion.

4.1 Understanding value and waste in LPD

The representative from the design and manufacturer of aircraft defined value as 'what is contracted', 'measure of productivity' and 'doing the right thing'. However, 'the problem with value is that we (designers and managers in the aircraft industry) do not know what the customer wants especially'. In contrast, the representative defined waste as the opposite of value, which occurs if inquiries are necessary regarding the status of information and/or schedule.
The discussion revealed that people, product and process were believed to have specific characteristics or conduct actions that make them 'valuable' or 'wasteful'. For example, participants discussed that people add value by having the necessary knowledge and experience, producing innovative ideas, and generating information that meets requirements. On the other hand, people add waste when they over-process, lack required knowledge, and produce defective output. Table 2 is a summary of the workshop results on the current understanding of how value and waste are added by people, product, and process.

Table 2. Understanding of value and waste revealed through the workshop

Add value/ waste by	**How: Add value/valuable**	**How: Introduce waste/are wasteful**
	People add value or introduce waste if they…	
Characteristics *(Skills and experience)*	Apply knowledge and experience effectively.	Have inadequate knowledge. Do not communicate. Have a wrong perception of requirements, management authority, etc. Do not have the required skill set. Are over-skilled. Lack experience. Gain but do not reuse knowledge. Focus on past projects. Show no trust. Cause conflicts. Over–think matters. Lack understanding of the big picture.
Productivity *(tools used and work environment)*	Produce innovative ideas. Produce information that meets requirements.	Over-process results. Produce defective output. Do not share a common practice. Work in an inappropriate environment.

		Work in too many projects. Make mistakes.
Add value/ waste by	***Process adds value or introduces waste if it…***	
Characteristics	Is reusable. Is standardized. Is flexible. Is visible. Can capture knowledge. Is predictable. Mitigates risk. Can measure performance.	Has no metrics/control. Has excessive inventory. Produces designs that do not satisfy all regulations. Shared knowledge is lacking.
Productivity	Has input, output, tradeoffs and constraints that are defined and visible. Involves effective application of design tools.	Under/over processes. Processes defected input. Is inefficient Has excessive waiting time. Requires reformatting of data. Time wasted in satisfying regulations. Includes rework. Uses wrong inputs. Uses changing information. Uses conflicting / produces over-loading information.
Add value/ waste by	***(Information) product adds value or introduces waste if it…***	
Content	Can reduce risk. Can improve quality. Meet requirements. Is mature. Is in the right format. Is innovative. Is reliable. Is flexible.	Have a high complexity. Form defective information. Satisfy requirements partially. Bring no Return On Investment (ROI). Is absolute at launch. Form conflicting information. Scope creeps. Is difficult to manufacture. Information is too detailed for that stage. Preliminary information is wrong.

As can be seen from the table above, the attributes, which represent people, process, and product and which add value or introduce waste to stakeholders, are interdependent. For example, it was concluded from the high complexity of information that the design process is difficult to standardize and predict. During the workshop, participants expressed their difficulties in identifying elements that define value and waste. The representative from the aerospace industry expressed that focusing on waste is more desirable because 'knowing how waste looks like is easier than knowing how value looks like'.

4.2 Managing value and waste

Practices used as part of lean range from general management practices, such as leadership and training to specific procedures, e.g., modelling through Value Stream Mapping (VSM). In this section, examples of on-going lean projects in the participating companies are presented, followed by a list that summarizes current management approaches as applied in industry.

4.2.1 Examples of current lean projects

Examples of currently on-going projects in LPD were discussed during the workshop:

- Jet engine company: The main aim of applying lean in this organization was to identify the sources of waste and to design a robust design process using process simulation. This has been applied to the HP turbine disc as a case study, using a detailed map of 29 activities and their processing and value-added time. The organization attempted to understand process inefficiency, activity input, output, and constraints, as well as the impact of improvements on process lead time. Three main tools were used: Value Stream Mapping, Design Structure Matrix to manage iteration

and analyse front-load process, and simulation. The maps use colour-coding to show the efficiency of each activity. For example, green indicates high efficiency, which is considered to be the ratio of value-added time to total processing time. Yellow indicates that the activity efficiency is between 50% and 75%. Based on this understanding, opportunities for improvements were identified. Moreover, due to the high uncertainty leading to difficulty in estimating the duration of the processes, the company approximated the distribution of the worst, best, and most probable duration by asking designers questions. The input data for these models were captured in workshops with people from different functions involved in defining the process. Main benefits from this approach were thought to include the analysis of what-if case scenarios, scheduling, identifying improvements to be made, engaging people, and automating processes. One of the outputs of this project was a list of wastes that were most common.

- Optics and electronics company: Participants from this company described the shift to lean culture as starting from a 'chaos' state that requires 'control'. Afterwards, the processes need to be 'simplified' then 'automated'. Finally, lean culture needs to be 'sustained'. Their approach to lean includes the usage of visual management to run the business, conduct daily team meetings every morning, and focus on discovering problems when they are small. To achieve the desired outcomes, essential factors are needed such as timely decision-making, early identification of KPI variances, and minimizing meeting time/maximizing problem solving time. For example, stand-up meetings are attended by cross-functional team members who meet for 15 minutes around a white board using a pre-set agenda to discuss progress, made decisions, and solve problems. Moreover, in the visual management system, a project board has been introduced showing information such as overall project plan and short-term actions, and metrics for prototype parts. The main aim is to visualize the process and identify the hidden waste in the cycle. The implementation procedure starts by simplifying the process and displaying it on the white board. Afterwards, information such as engineering change, task responsibility, process time, and targets and actual progress are visualized and documented. Colour-coding is used to differentiate between projects which are on time, slightly behind, or a few days behind the schedule. Finally, workplace organization was another project during lean implementation. For this, the workplace was organized and then audited regularly in order to maintain a standard order of work.
- Aircraft design and manufacture company: This organization used several approaches to implement lean, starting from tool-focused to lean thinking as a working culture. The first step was training 'change agents' in the organization to implement lean. Afterwards, tools were applied such as 5S, 7W, data capture and mapping (e.g. person-mapping). Studying the environment, various improvements were identified. In the fourth step, a support system was deployed. Next, KPIs were established as a measurement system. KPIs that were used included delivery time, overhead cost, quality, and safety.

4.2.2 Approaches for maximizing value and minimizing waste

The participants were asked to describe the three most common approaches used in their companies to maximize value and minimize waste. The three approaches that emerged were: visual management, standardization, and Key Performance Indicators (KPIs). For each approach, benefits were discussed. For example, having KPIs was believed to facilitate process control, progress identification, and driving good behaviour. For each benefit, a number of practices were suggested as a mechanism to achieve the benefit. For example, 'engaging people' was one of the practices discussed to facilitate an open culture. Finally, corresponding challenges were presented. Table 3 summarizes the discussion results.

The success of LPD practices and the extent of the benefit obtained were thought to depend on a few factors. For example, workshop participants from the jet engine company emphasised the importance of having a powerful sponsor who enforces changes, having a dedicated improvement implementation team, and having a controlled process.

4.3 Assessing value and waste

In the third and final part of the workshop, the evaluation metrics used in LPD were explored. First, participants discussed general information, which describes the process and includes activity, resource, and design information. Second, metrics that are used in tracking process performance and thus enhancing the effectiveness of lean / value implementation were found to include elapsed time, queue

time, and deviation from schedule. Participants in the workshop expressed the difficulty of establishing a list of metrics that reflect their actual progress. For example, the design and manufacturer of the aircraft industry use balanced scorecards, which help them to identify if they are 'doing well.' However, at the end of one year, it was found that the organization did not perform as well as the scorecards system indicated. Establishing a reliable measurement system and suitable metrics seems to be a challenging task.

5 DESCRIPTIVE MODEL

The results of the workshop aim to provide examples from industry to assist organizations in developing: descriptions of value and waste; an understanding of appropriate lean tools to be used; and metrics that reflect their actual performance. Therefore, we developed a descriptive model that summarises the results of the workshop and may facilitate the application of these findings in practice. The model aligns examples from understanding, management, and assessment of value and waste against people, process, and (information) product (Table 4). For example, 'people', which includes designers and management, can add value by applying knowledge. The value level people produce can be improved by practices such as training and visual management (e.g. person-mapping). The value level generated by people can be assessed by measuring person-hours spent on a project and the processing time. The table provides the template that can be customized to a company's situation.

6 SUMMARY OF INSIGHTS AND FUTURE DIRECTIONS

To summarise, insights from this study included:

- ***Conditions motivating lean:*** workshop results show three main conditions that motivate implementing LPD. These are: the high complexity of PDP, market pressure, and perceived success of 'Lean Thinking' in other contexts. A comparison between lean and other improvement approaches to justify the decision for lean and the extent of lean suitability and benefit in a specific company is not yet explored.
- ***Tendency to focus on waste, not value:*** organizations tend to define and focus on what is waste and what its causes are to minimize it.
- ***Identifying stakeholder:*** one limitation of lean in PD is that it requires as a first step to define value with respect to stakeholders. However, this is difficult to achieve in design, due to the complex network of stakeholders with conflicting values. The representative from the design and manufacturer of aircraft said '*the problem with value is that we do not know what the customer wants especially when there are multiple customers who value things differently*'. The second challenge after capturing different conceptions of value is to proritize them. This is difficult as the prioritization is dynamic and depends on the progress of the design/phase. Moreover, identifying which values and wastes contribute to which stakeholder in the process is challenging.
- ***Linking value and waste with performance*****:** there are various metrics that are used in the context of LPD. However, these metrics are poorly linked to value and waste. In addition, LPD approaches are poorly defined in the context of organizations in terms of their impact on enhancing value and minimizing waste.
- ***Value Stream Mapping in PD:*** Although Value Stream Mapping is a popular tool in manufacturing, in LPD there is little emphasis on its usage due to the difficulty of developing VSM maps and identifying the value and waste line. It was argued by the workshop participants that the value and waste line is not practical because it is difficult to localize their measure reflecting the contribution of an entity/task to the overall process.
- ***Lean tools are not enough:*** For example, VSM is very useful to analyze activity efficiency, but in the PDP it is not enough as it is difficult to understand the dependencies between activities and their durations. Supporting tools are needed. DSM and simulation to support VSM are suggested.

Table 3: Current management approaches

Method	Benefits	Practices (procedure)	Challenges
Visual management	Facilitates understanding	− Simplify process and search of information. − Define activity, input, output, added value, process time, etc. − Collect data using tools such as DSM, A3, etc. − Share and update frequently in a public display: whole picture, metrics, progress of task, overall plan, short-term action, and processing and waiting times. − Understand process inefficiencies. − Make visible inefficiency of activities: use different colour codes to show the efficiency of the activities. − Document engineering changes. − Differentiate between good vs. bad iterations.	− Unclear who should use it and how − Problems associated with publicity of confidential information − Problem with losing history − Skill to present data work − Difficult to have a common language − Time-consuming for clear and concise information − May contain a lot of information − Can be complex – lack of skill in how to present data in a simple way − So many statistics that they may not be useful − Abstract information (people do not know how to use this information) − Different sets of visual management – cultural challenges (people think there is hidden information in the other set)
	Facilitates discussion, communication, decision, and improvements	− Display and analyse collected data for meeting discussions. − Hold workshop with the visual board with multifunctional teams. − Facilitate discussions/use of approximation. − Analyze what if case scenarios. − Identify improvements: schedule, manage iterations, automate, etc. − Identify responsibilities, targets, and actual.	
	Facilitates open culture	− Engage people. − Share project ‘whole picture’.	
Standardization	Facilitates Productivity: reduces variation, duplication, start uptime	− Have a daily 15-minute meeting with standard agenda. − Develop checklist of what needs to be done at each stage-gate. − Establish a problem solving techniques. − Develop workplace standards.	− Constrains design − Constrains flexibility − Standardised incorrect procedures − Stifles continuous improvement
Key Performance Indicators	Facilitates controlling process and identifying progress, and driving good ehavior	− Use reporting strategy, e.g. A3. − Clear idea of status and performance progress. − Link performance indicators to rewards. − Publish metrics.	− No one wants to be seen to be doing badly − May drive wrong behaviour − Difficult to define measures for PD − Uncertain if KPI reflects actual performance − Time-consuming − Tendency to measure what is easy, not what is useful − Does not necessarily measure value for the end-user

Table 4: Descriptive model

Entity	**Understand:** *How is value added?*		**Manage:** *How to improve?*	**Assess**
People	Characteristics	Apply knowledge and experience.	Training Visual management *(e.g. man mapping, collect, and share info., make inefficiencies visible, document, and engage people)* Standardisation *(e.g. have daily meeting, develop check list)* KPI *(Link to rewards)*	Person-hours spent on project Process time (charged hours)
	Productivity	Produce innovative ideas. Produce information that meets requirements.		
Process	Characteristics	E.g. Reusable, standardized, flexible, visible, predictable.	Visual management *(e.g. simplify process)* Standardisation *(e.g. develop work standard)* KPI *(e.g. select to have clear idea of status and performance progress)* Combine tools *(e.g. DSM, VSM, and simulation)*	Cost/schedule performance Elapsed time Value-added time *(Process Time)* Queue time Deviation in schedule
	Productivity	E.g. define input, output, tradeoffs and constraints, and apply effective tools.		
Product	Content	E.g. Reduces risk, improves quality, meets requirements.	Visual management *(e.g. Identify improvements)* Differentiate between good vs. bad iterations Standardisation *(e.g. Technique)*	Risk *(e.g. TPM, technical risk)*

Based on these findings, several research questions emerged:

- ***What is the current understanding, management, and assessment of value and waste?*** The establishment of a guideline for organizations to better understand, manage, and assess their value and waste could help achieve successful application of LPD.
- ***How to link value/waste with local and strategic metrics?*** Local metrics such as processing time, and strategic metrics such as project budget, need to be connected to the value and waste level of the process in order to assess the overall performance in LPD.
- ***How to make the value and waste levels visible, and how to use value and waste levels in decision-making?*** The assessment of value and waste needs to be visible for cross-functional teams to use it for decision-making. Moreover, their presentation should be such that informed and accurate decisions can be made.
- ***How to identify the impact of the improvement methods?*** Lean methods, their impact and limitations need to be explored. This is necessary in selecting the right type of approach based on required improvements and organization capacity.
- ***How to differentiate between 'good' and 'bad' iterations?*** The lean approach does not fully address the iteration characteristics of design. Establishing general guidelines to differentiate between good and bad iteration is essential and dependent on the organization requirements.
- ***How to establish an effective measurement system?*** This includes: How to select useful measures? How often to measure and how visible should the measures be? How to know if the designers are doing the right thing? And how to link effectiveness with ultimate financial benefit?

7 CONCLUSIONS

This paper aims to provide insight into current industry understanding, management, and assessment of value and waste in practice through analyzing results of a one-day workshop. The findings may provide pointers to other companies aiming to understand, manage, and assess value and waste in their LPD approach. The study also provides examples to support organizations in developing their own understanding and selecting appropriate tools and metrics to be used.

The findings suggest that, in companies doing or aiming towards LPD, waste is more commonly evaluated and tracked than value. Moreover, the LPD practices have benefits and limitations that still need to be explored. Finally, the metrics used are poorly-linked with stakeholders in an LPD context

and may not be sufficient for decision-making. Future directions for research include further examining the concept of value and waste, emphasising the importance of a balanced approach between value and waste during LPD implementation and their critical linking with metrics.

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