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RELATING VALUE METHODS TO WASTE TYPES IN LEAN PRODUCT DEVELOPMENT

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1. Introduction

The Product Development Process (PDP) has a significant role in determining the success of a product, as it defines its features, cost, and delivery time. Since the main output of a PDP is the ‘design recipe’, improvement methods need to focus on information processing, quality, and delivery. Various tools have emerged in response to this need, such as risk mitigation and communication approach. Other tools are still being developed and improved to address the issues surrounding dynamic and uncertain creation and processing of information.
Lean product development (LPD) is a promising tool to improve the PDP, focusing on enhancing value and eliminating waste. Value in PD can be defined as ‘a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer’ [Womack 1996]. Lean provides a wide range of tools that aim to increase the value such as standardisation of processes, effective communication, flow concept, and set-based engineering (e.g. [McManus 2005]. Lean thinking also identifies types of waste that need to be eliminated. According to McManus, these are: over-production, over-processing, waiting, transportation, unnecessary movement, defective product, and inventory [McManus 2005].
Although there is increasing interest in LPD reflected by an increasing number of publications, LPD has not yet achieved the desired success [Siyam 2011]. This paper proposes that LPD can be more effectively used in the PDP when it focuses on information value and waste, and addresses issues such as the dynamic and complex environment of the PDP. The paper illustrates the current lean value methods used and proposed to enhance value, types of information waste addressed, and the dependency between them based on a literature review. The paper concludes by introducing a guideline that can be used to understand the relationship between value and waste of information, and their impact on attributes such as time and cost.

2. Background, motivation and methodology

Engineering design can be regarded as an information creation and transformation process that aims to deliver a ‘recipe’ that satisfies the customer requirements [Browning 2000]. Designers integrate their experience, knowledge and creativeness in developing information that ultimately specifies the product features. At each phase of the design process, there is a different extent of information, which is being transformed from one state to another as a result of decision-making [Hick 2002]. Since information has direct effect on products, through the design of its components and functions, understanding information in terms of its structure, transformation, format, processing requirements and knowledge needed can be a critical factor for the success of PD. However, gaining this understanding is difficult due to the dynamic and complex network of dependent requirements, design teams, and processes.

In an effort to improve the PDP by focusing on information, we propose that LPD can yield better results if increased focus is placed on understanding value and waste of information as part of lean thinking. Research in LPD developed various approaches to enhance process aspects such as flow by applying lean value methods like just in time (JIT) and the concept of small batch size. Moreover, waste types in PD have been explored, such as defective information and rework. However, there is inconsistency and lack of linkage between value methods, waste types, and parameters, which limits the assessment of information towards improving its processing, content, and delivery. Therefore, the motivation of this study is the need for a better integration of information analysis in LPD, and the need for a tool to link and understand the causes and effects of value and waste of information in PD.

The main questions addressed here are: (1) Which lean value methods can be used to support generating valuable information in LPD? (2) What are the waste types common in information? and (3) What are the causes and effects of value methods and waste types? To address these questions, we use content analysis of literature on LPD, with a focus on value and waste. The publications were scanned for definitions, types, methods, causes, impact and parameters.

Throughout this paper, the term ‘lean thinking’ is used to refer to lean approach including philosophy and guidelines aiming to maximise value and minimise waste. The best practices and desired attributes developed in lean thinking are described as ‘value methods’ or ‘lean value methods’. The term ‘waste’ is used to refer to any unnecessary elements or activities in the process or product. Finally, ‘value’ refers to attributes and behaviour of interest in a product of processes.

3. Overview of value and waste of information

The value and waste of information can be analysed by considering three main dimensions of the PDP. The first dimension is *transformation*, which is the process of transforming information from one state to another by applying knowledge and consuming resources. The second dimension is *deliverable*, which is the nature of information or data which include characteristics such as context, accuracy, and relevance [Zhao 2008]. The third dimension is *transmission*, which is the delivery process of output from one activity, person, or phase to the other, and includes flow of data, transportation and storage tools. Figure 1 shows an example of car radiator design activity showing value methods and waste types related to information in each dimension. For example, at the transformation level, standard techniques can enhance the value of information by ensuring the capture of knowledge and providing a formal format for documentation. Waste here includes over-processing of information. In information transmission from one activity to the other, waiting for information is considered to be waste that could be reduced. We suggest that by understanding types of waste, and available value methods at each level, PDP can be improved. Therefore, value and waste will be further explored in the following sub-sections.

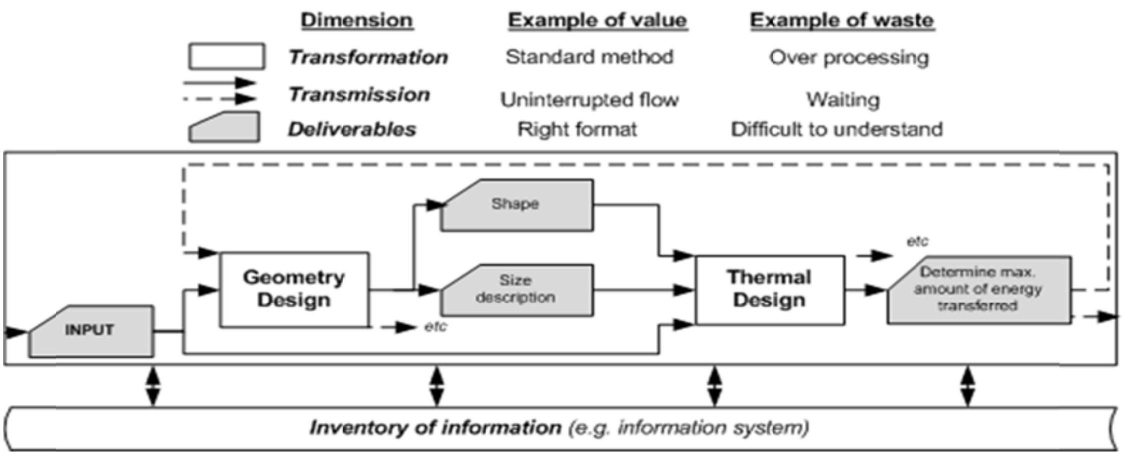


Figure 1. Example of value and waste in transformation, transmitting, and deliverable

3.1 Value of information in lean product development

The PDP has a critical impact on the definition of value as it defines customer requirements through the design. Produced information is valuable if it reduces the risk that the product will not satisfy the customers' requirements [Browning 2000]. Since there are multiple customers in the PDP such as the end user, design team, and organisation, determining whether information is valuable depends on the recipient's definition of value. To give some examples, a design team may consider information 'valuable' if it is relevant, usable, and in a specific format. For the end user, the functional specifications might have value if the product meets or exceeds their expectations. For the manufacturing department, information can be valuable if the design specification took appropriate account of manufacturing issues. Finally, shareholders could consider design information to be valuable if it defines physical features that result in sufficient revenues.

Table 1. Value methods and impact in PD

Dimension	Category	How is value enhanced?			How can value be assessed?		
		Cause			Effect		
		Value Methods	Description	Reference (E.g.)	Impact (E.g.)	Parameter (E.g.)	Reference (E.g.)
Transformation	Production Method	Standardization	Formalization: milestones of tasks sequence, document, etc	E.g. [McManus05] [Hoppman09] [Zhao08] [Chase00] [Browning00]	Variability, efficiency, errors, Knowledge capture and management	% Variability % Errors	E.g. [Browning00]
		Integration of supplier and customer	Key suppliers and customers are integrated early into the product development activities		Allow more efficient methods of manufacturing, reliability, lower cost	Manufacturing cost	
					Customer satisfaction, economical return	% Sales Economic profit	
		Set based engineering	Development of alternatives then converging them into a solution		Accuracy of decisions	Process lead time	
		Test then design	Reliable information		Time, iteration	Risk reduction	
		Simultaneous engineering (overlapping)	Cross-functional teams and meetings		Reduction in lead time	Lead time	
	Planning/ managing	Management of resources	Allocation of KA based on experience, and performance objectives		Reduce time, conformity to requirement, capture knowledge	Lead time, quality	
Deliverable	Performance	*Conformity*	Conform to technical performance	E.g. [McManus05] [Hoppman09] [Zhao08] [Chase00]	Reduce risk	TPM	E.g. [McManus05] [Chase00] [Browning00]
	Content	*Content Characteristics*	Context, accessibility, usability, and accuracy		Reduce risk, time, and cost	Risk, time, and cost	
		Integration of LC	Consideration of DFX, life cycle cost		LC performance	Lead time, cost, quality	
	Format	*Right format*	Well defined requirements by activities (format needed)		Reduce time and cost	Time	
		Flexibility	Adaptability for future change in a product design		Time, cost, customer satisfaction	Lead time, sales	
Transmission	Stream	Pull	JIT (use of partial information)	E.g. [McManus05] [Hoppman09] [Zhao08]	Reduce time and cost	Lead time	E.g. [McManus05] [Hoppman09] [Zhao08]
		Flow	Constrain WIP: Small batches		Inventory level	Inventory level/queue size	
			Takt time		Inventory, pace, discipline	% Job done	
	Transmission Method	*Reliability*	Right information, at right time, to the right person		Reduce LT, and increase accuracy	Lead time	
		Communication	Cross functional teams		Transparency and accuracy of process	% Error	
			Centralized, transparent communication system/tools				

Unlike with waste, lean thinking does not specify value types, but focuses on developing lean value methods that aim to improve value. The focus lies more on improving the PDP, and less on enhancing information 'value' with respect to the multiple stakeholders. In this section we present value methods and concepts developed to support producing information with high value and sort them into the three main dimensions discussed earlier. Table 1 summarises examples of these value methods, their impact, and suggested parameters for measure and control.

For example, on the transformation dimension, Chase proposes that as information flows and matures throughout the process, the tasks performed add value to the information by transforming it from an initial state of raw data to the desired state as defined by the next stakeholder used (e.g. designer, engineering, etc) [Chase 2000]. Within this dimension, the value methods proposed increase the effectiveness of activities from the point of view of their capacity for producing information. For instance, standardisation can support producing valuable information, because using standard documentation and processes can increase the probability of creating complete and accurate information in the correct format. The success of standardisation can be measured by parameters such as percentage of error reduction.

3.2 Waste of information in LPD

Womack defines waste as "any human activity which absorbs resources but creates no value" [Womack 1996]. In PD, because the value stream is represented by the flow of information produced within the product development process (PDP) [Graebsch 2007], it is crucial to regard waste in PD in terms of information. Waste of information is therefore considered as any information created, transformed and/or transferred without adding any value regarding the fulfilment of customer requirements. Several authors have studied the different types of waste in LPD [McManus 2005], [Oehmen 2010]. While the scope of waste types is similar in each case, not all authors consider the waste of information explicitly and the numbers and definitions of the waste types differ slightly. For example, [Haque 2004] define over-production as the creation of unnecessary detail, while [Oehmen 2010] associate the latter with the waste type over-processing.

The different understandings of waste types were collected through literature review, and found to be largely covered by Graebsch et al. Here, the definitions were analysed regarding causes of waste and how they impact the information flow in the PDP, i.e. what kind of waste can be observed in the process. Tables 2 and 3 show the waste causes and impacts for each of the three domains of: transformation of information, the product or deliverable, and the delivery of information. Some examples of parameters to understand the impact of waste are also listed in the tables, e.g. the time spent on non-value-adding work.

Table 2. Causes and impacts of waste in PD – Part 1

Dim.	Category	What is waste?		How can waste be assessed?		
		Cause		Effect		
		Description of waste causes	E. g. Ref.	Impact (waste type)	E. g. Ref.	Parameter (e. g. ref. [Kato 2005], [McManus 2005])
Transformation	Methods Management	Unclear or shifting targets	[Oehmen 2010] [Kato 2005]	Rework and correcting information	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	● Frequency of occurence ● time spent on non value adding work ● % ressources used ● Number of affected tasks ● Number of iterations ● Length of iteration (number of tasks) ● Duration of iteration
		Partial information	[Oehmen 2010]			
		Lack of time	[Oehmen 2010]			
		Unreliable process in communication with external stakeholders	[Oehmen 2010]			
		Lack of standards for data conversion	[Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	Over-processing	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	● Number of unnecessary actions ● Frequency of reformatting ● Existence of standards for documentation / delivery of informaion ● Time spent (e.g. reformatting)
		Overengineering (generating too much detail)	[Kato 2005] [McManus 2005] [Oehmen 2010]			
		Using defective information	[Haque 2004] [McManus 2005] [Oehmen 2010]			
		Reinvention, lack of stadards for re-use of information	[Haque 2004] [Kato 2005] [Oehmen 2010]			
		Unnecessary information (dublicate work)	[Haque 2004] [Kato 2005] [Oehmen 2010]	Over-production	[Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	● Frequency of occurence ● Time spent on non value adding work
		Unnecessary deliverables	[Oehmen 2010]			
		Delivering info out of sync / uncontroled processes	[Haque 2004] [McManus 2005] [Oehmen 2010]			
	Resources	Defective deliverables (information, products)	[Oehmen 2010]	Generating defective information	[Graebsch 2007] [Oehmen 2010]	● Frequency of occurence ● Time spent on rework caused by errors ● Number of affected tasks ● Number of iterations
		Obsolete deliverables	[Oehmen 2010]			
		Defective information attributes, poor verification	[Graebsch 2007] [Oehmen 2010]			
	Management	Unclear responsibilities	[Graebsch 2007]	Unclear responsibility, objectives, priorities	[Graebsch 2007] [Haque 2004]	● Frequency of occurence
		Unclear goals and objectives	[Graebsch 2007] [Haque 2004]			
		Unclear Rules	[Graebsch 2007]			
		Lack of standardization of processes	[Haque 2004]	Poor synchronization	[Graebsch 2007] [Haque 2004]	● Inventory part count: number of jobs in queue ● Delay time: average time a single job waits in queue ● Delay time statistics: mean and deviation, or distribution of wait times
		Poor synchronization in terms of content	[Graebsch 2007]			
		Poor synchronization in terms of time	[Graebsch 2007]			
		Non-conformance	[Haque 2004]			
		People	[Graebsch 2007]	Lack of resources	[Graebsch 2007]	● Amount of overtime hours ● Waiting time due to outdated IT-Systems
		Time	[Graebsch 2007]			
		IT	[Graebsch 2007]			
		Lack of system discipline	[Graebsch 2007]	Lack of Dicipline	[Graebsch 2007]	● Number of not executed or bypassed process steps ● Deviation of schedule
		Insufficient readiness to cooperate	[Graebsch 2007]			
		Poor schedule discipline	[Graebsch 2007]			

Table 3. Causes and impacts of waste in PD – Part 2

Dim.	Category	What is waste? Cause: Description of waste causes	What is waste? Cause: E. g. Ref.	How can waste be assessed? Effect: Impact (waste type)	How can waste be assessed? Effect: E. g. Ref.	How can waste be assessed? Effect: Parameter (e. g. ref. [Kato 2005], [McManus 2005])
Deliverable	Performance	Defective strategic outputs (understanding of customers, make or buy decisions), defective information or activities (defective product), poor design for X, requirements management, planning or supplier identification, inadequate design tools, use of immature technology	[Haque 2004]	Defective information	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005]	• Frequency of occurence • Tasks affected by it • Number of caused iterations • Length of caused iterations • Duration of caused iterations
	Content	Unrefined information, lack of reviews, tests, verifications; lack of interpretation	[Graebsch 2007] [McManus 2005]	Poor Accuracy	[Graebsch 2007]	• very / sufficient / not at all
		Errors	[McManus 2005]			
		Unnecessary detail	[Graebsch 2007]			
		Low amount of information		Incompleteness	[Graebsch 2007]	• very / sufficient / not at all
		Information not meeting receivers need	[Graebsch 2007]	Poor Relevance	[Graebsch 2007]	• very / sufficient / not at all
		Subjective view instead of actual data	[Graebsch 2007]	Poor Objectivity	[Graebsch 2007]	• very / sufficient / not at all
	Format	Too much information	[Graebsch 2007] [McManus 2005]	Inappropriate Amount of information	[Graebsch 2007]	• too much / appropriate / too low
		Illegible text, interpretability, context unclear to receiver	[Graebsch 2007] [McManus 2005]	Difficulty of understanding	[Graebsch 2007]	• high / sufficient / low
		Inappropriate format	[Graebsch 2007]	Poor Conciseness	[Graebsch 2007]	• high / sufficient / low
Transmission	Transfer Flow	Scheduled waiting for information	[Kato 2005] [Oehmen 2010]	Waiting for information	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	• Time spent on waiting • Frequency of occurence • Inventory part count: number of jobs in queue • Delay time: average time a single job waits in queue • Delay time statistics: mean and deviation, or distribution of wait times
		Unscheduled waiting for information	[Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]			
		Information hunting	[Graebsch 2007] [Kato 2005] [McManus 2005]			
		Excessive approvals	[Graebsch 2007] [Kato 2005] [McManus 2005]			
		Information waiting for people	[McManus 2005]			
		Information provided to too many people	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	Over-dissemination of information	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	• Frequency of occurence • Number of affected tasks • Number of iterations • Duration of iteration • Length of iteration (number of tasks)
		Repeated sending of same information	[Graebsch 2007]			
		Excesive data traffic				
		Frequent interruptions	[Oehmen 2010]	Inventory - inappropriate storage of information	[Graebsch 2007] [Kato 2005] [McManus 2005] [Oehmen 2010]	• % time spent to retrieve information • Inventory part count: number of jobs in queue • Delay time: average time a single job waits in queue • Delay time statistics: mean and deviation, or distribution of wait times
		Large batch size	[Oehmen 2010]			
		Process design and variability	[Oehmen 2010]			
		High capacity utilisation	[Oehmen 2010]			
		Product feature inventory	[Oehmen 2010]			
		Capabilities inventory	[Oehmen 2010]			
		Obsolete information	[McManus 2005]			
		Lack of control	[McManus 2005]			
		Complicated retrieval / lack of direct access	[Graebsch 2007] [McManus 2005]			
	Transfer Method	Outdated information system	[Oehmen 2010]	Insufficient information system	[Oehmen 2010]	
		Change of ownership, structural barriers	[Kato 2005] [Oehmen 2010]	Ineffective communication	[Graebsch 2007] [Haque 2004] [Kato 2005] [McManus 2005] [Oehmen 2010]	• Time spent on non value adding work due to hand-off • Time spent on e-mails • Time spent on meetings • Time spent on movement
		Knowledge barriers	[Oehmen 2010]			
		Process barriers due to interruptions	[Oehmen 2010]			
		Spatial barriers: unnecessary movement of people or information	[Graebsch 2007] [Kato 2005] [McManus 2005] [Oehmen 2010]			

4. Value and waste dependencies and guidelines

4.1 Domain Mapping Matrix (DMM)

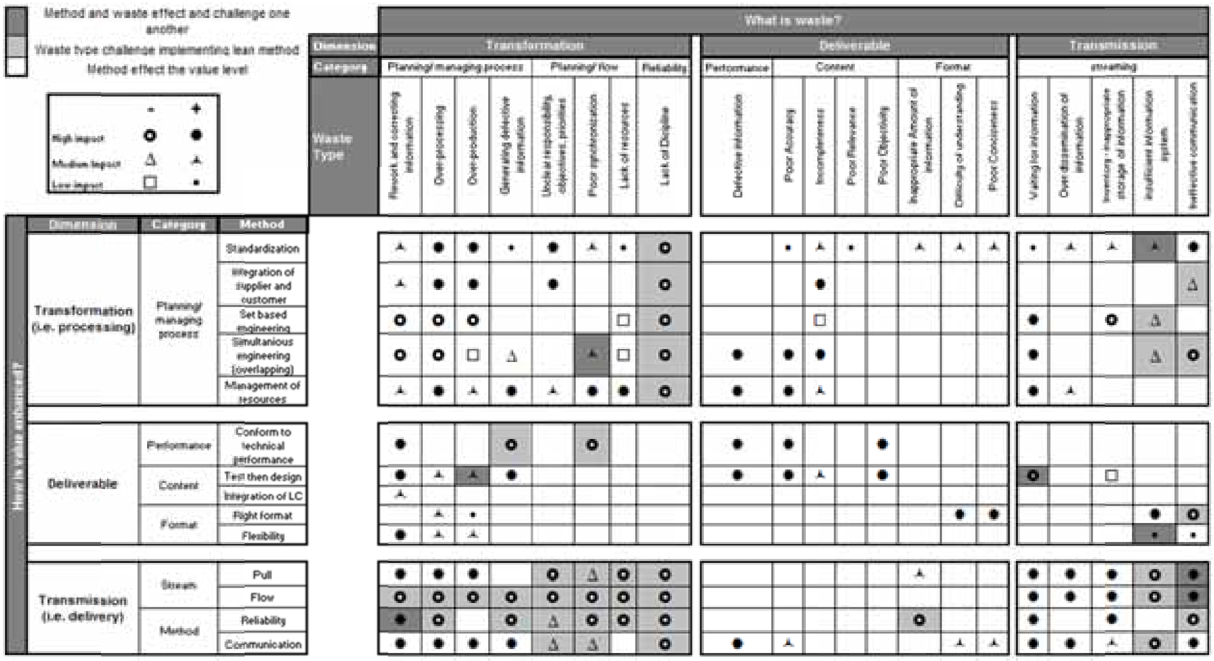
Methods in LPD literature aim to maximise value and reduce waste. However, the relationship between value methods and improvements achieved is not clear. Thus, we analysed the relationship between value methods and waste types using a Domain Mapping Matrix (DMM) in order to understand how value methods can impact waste reduction (see Table 4). In this DMM, we identified three directions for dependency; the effect of a value method on eliminating a waste type (row to column), the effect of a waste type limiting the application of a value method (column to row) and an effect in both directions. We also defined three levels of impact; high, medium, and low, with either a negative or a positive effect.

4.2 Analysis and discussion

The analysis of the DMM yields several insights that can be used for future development:

- **Criticality of waste –** Comparing the relative frequency of waste tackled by value methods can indicate the types of waste perceived to be most critical by method developers. Table 4 shows that the greatest number of value methods aim to tackle critical waste such as waiting of information, followed by those tackling rework, defective information and over processing.
- These critical wastes and some mechanisms to mitigate them have been discussed in literature. For example, Graebsch et al proposes that waiting of information can be tackled when information transfer is planned, and better schedule performance is promoted [Graebsch 2007].
- **Unbalanced focus of value methods –** Table 4 shows that value methods focus on eliminating and minimising waste in the transformation and transmission dimension of the process and less on the waste in the deliverable dimension. This lack of focus on enhancing the deliverable content and format could be considered as a limitation of current LPD.
- **Value method effectiveness –** When comparing the percentage of the high positive impact of value methods on waste types, we found that communication techniques, such as centralising discussion, can be used to tackle the majority of the waste types listed. Therefore, we suggest that further development of communication methods, such as communication methods that reduce searching for information, can yield satisfying results in eliminating PDP wastes such as over-dissemination and over-processing of information. Other value methods that have high impact on waste reduction and can be considered for further development include management of resources, standardisation, and pull of information.
- **Challenging the applicability of value methods –** We compared the feasibility of applying value methods by comparing the number of waste types counteracting each method's application. For example, rework and correction of information is a frequently occurring event in the PDP that makes achieving a 'steady pace' and 'uninterrupted flow' difficult.
- We found that according to this criterion, flow-based methods, including approaches such as establishment of takt time and steady pace of progress, are the hardest to implement due to opposing wastes such as rework, lack of resources, and over-production.
- **Applicability of set-based engineering (SBE) approach –** LPD literature suggests that set-based engineering is one of the promising directions in PD. However, based on table 4, the comparison of the effect of SBE on waste elimination shows that this method mainly aims to increase the success of the design by focusing on quality by generating an open design space, and pays little attention to waste introduced as a result.

Table 4. Value methods vs. waste types



- **Discipline as an enabling waste –** Lack of discipline has the highest negative relationship among waste types that limit the application of a value method. Therefore, enhancing discipline can have a considerable effect to facilitate and enable a successful implementation of LPD such as standardisation and flow.

The main limitation of this analysis is that it is based on general cases, such as techniques maturity, PD phase and industrial context, thus does not consider specific situations, attributes and factors that influence value and waste levels. Therefore, future work should further analyse the dependency between value methods and waste relative to specific circumstances.

4.3 Guidelines

Based on the value and waste description tables and comparison, guidelines were developed to match specific waste types with corresponding value methods, and parameters to monitor and measure waste of the system. Table 5 shows a sample of these wastes, value methods, and parameters. For example, if an organisation aims to reduce waiting time, methods such as simultaneous engineering can be used. Results can be monitored by measuring resource utilization and time wasted.

Table 5. Guidelines for waste elimination through value methods application

Dim	Waste types	Value Methods (e.g.)	Parameters (e.g.)
Transformation Improvement	Rework and correcting information	Test then design, pull, communication	Risk, time, # of errors, number / duration of iterations
	Over-processing	Standardization, integration of supplier and customer, management of resources, pull and communication	% of variability, manufacturing cost, # of sales, quality, time, # of errors, # of unnecessary actions
	Over-production	Standardization, integration of supplier and customer, pull and communication	% of variability, manufacturing cost, # of sales, # of errors, time
	(Generating) defective information	Management of resources, accurate content, and communication	Time, risk, cost, quality, # of errors, # of rework / iterations
	Unclear responsibilities, objectives,	Standardization	% of variability, # of errors

	priorities		
	Poor synchronization	Management of resources	Time, quality, % of inventory
	Lack of resources	Management of resources	Time, quality
	Lack of discipline	Standardization, Management of Resources, Communication	% of variability, time, quality, # of errors, # of tasks accomplished
Deliverable Improvement	Incompleteness	Integration of supplier and customer, and simultaneous engineering	Time, # of error, % of rework, # of sales, manufacturing cost
	Poor Relevance	Standardization	Time, % of variability, # of errors
	Poor Objectivity	Test then design	Risk, # of rework, # of sales
	Inappropriate Amount of information	Standardization	Time, # of rework, # of errors, % of variability
	Difficult to understand	Format	Time
	Poor Conciseness	Format	Time
Transmission Improvement	Waiting for information	Simultaneous engineering, management of resources, pull, flow, communication	Time, quality, % of inventory, % of resource utility, waiting time, errors
	Over-dissemination of information	Pull, flow, communication	Time, quality, % of inventory, % of resource utility, waiting time, errors
	Inventory (inappropriate storage)	Pull and flow	% of inventory, time
	Insufficient information	Format	Time
	Ineffective communication	Pull, flow, communication	Time, # of errors, % of inventory

5. Conclusions

Enhancing value and eliminating waste of information in PD can provide a competitive edge for an organisation by introducing high-value products. Therefore, understanding and analysing value, waste and their relationship can be a first step towards LPD efforts in improving PD.

This paper has presented initial findings of a literature review of value methods, waste types and their relationship. The paper introduces a detailed analysis of value methods and waste types and metrics to monitor both. Afterwards, the relationship between value methods and waste types was explored. Finally, a guideline to eliminate waste when applying value methods is presented. The guideline includes metrics to measure the impact of value methods applied on the level of value and waste in the process. The guideline can be used to frame the discussion of how can value be enhanced and waste be eliminated in PDP. Future work may include a further investigation of the relationship, measurements and impact of value and waste in information based on specific phases in the PDP.

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