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RE-CONCEPTUALISING VALUE IN THE ENGINEERING DESIGN PROCESS: THE VALUE CYCLE MAP

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ABSTRACT

Introducing a "Cheaper, Faster, Better" product in today's highly competitive market is a challenging target. Therefore, for organizations to improve their performance in this area, they need to adopt methods such as process modelling, risk mitigation and lean principles. Recently, several industries and researchers focused efforts on transferring the value orientation concept to other phases of the Product Life Cycle (PLC) such as Product Development (PD), after its evident success in manufacturing.

In PD, value maximization, which is the main objective of lean theory, has been of particular interest as an improvement concept that can enhance process flow logistics and support decision-making. This paper presents an ongoing study of the current understanding of value thinking in PD (VPD) with a focus on value dimensions and implementation benefits. The purpose of this study is to consider the current state of knowledge regarding value thinking in PD, and to propose a definition of value and a framework for analyzing value delivery. The framework—named the Value Cycle Map (VCM)—intends to facilitate understanding of value and its delivery mechanism in the context of the PLC. We suggest the VCM could be used as a foundation for future research in value modelling and measurement in PD.

Keywords: value; Product Development (PD) process; Lean; process modelling; Product Life Cycle (PLC); process improvement

1 INTRODUCTION

In response to market opportunities and challenges, firms have been exploiting different management and technology strategies to support and maintain their processes' performance. Although these tools have contributed to system improvement, the complex nature of Product Development (PD) can limit the advantages gained. Therefore, research continuously attempts to develop new tools that can meet the needs of organizations. The interest in applying a value-oriented approach in PD has grown since the concept was transferred from the manufacturing environment in the 1990's. Effective generation of Value in Product Development (VPD) process generally refers to the capacity to generate knowledge/information that satisfies requirements. VPD has become important due to the empirical evidence of value orientation's success on the operational level (e.g. [1] and [2]), because value thinking holds promise as a method for low-cost improvement, and because of the readily-transferable common language between PD and manufacturing processes [3]. However, despite the value approach's advantages, the degree to which value orientation can be implemented and the extent of its effectiveness has not been fully shaped in PD. Several reasons for this have been suggested, such as a "shallow understanding of lean and/or lack of system view" [4], the difference between the nature of processes in manufacturing and product development (e.g. [5]), and a lack of "performance measurement culture" [6]. Hence, we aim to develop a framework that clarifies the structure and delivery mechanism of value while considering the dynamic and complex context of the PD process. We use the terms "value concept", and "value thinking" to refer to the practice of considering the desired attributes as defined by internal and external customers of each process. The term "value" refers to the attributes of interest in a product or a process. Furthermore, the term "value approach" is used to refer to the modelling and measurement techniques developed based on "value thinking". Finally, "value dimension" is used to refer to value structures, which we view as perspective, entity, and attribute as explained in forthcoming sections.

This paper reviews and discusses the current understanding of value thinking application in product development. The literature is analyzed and compared using a classification scheme based on the value dimension(s) adopted and the benefit expected from applying a value approach. The paper concludes by introducing a framework that intends to facilitate the understanding of value creation in the context of the PLC with a focus on PD, and which we suggest could be used as the basis for developing a value modelling and measurement approach in future research. The paper is organized as follows. Section 2 provides background, motivation, and objectives of the subsequent discussion. In section 3, the current knowledge of value thinking is analyzed by comparing different value approaches. The purposes we consider are support of process flow logistics and support of decision-making through modelling or measuring value. Section 4 presents the development of a value conceptual framework in four main steps: value definition, value delivery, value delivery in PD, and the value cycle in PLC. Section 5 discusses the scope and applicability of the presented framework. Finally, main conclusions are presented in section 6.

2 BACKGROUND, MOTIVATION, AND OBJECTIVES

Value thinking, as part of lean theory, aims to continuously improve the organization performance. Womack and Jones [2] formulated five principles to achieve lean thinking by focusing on generating value and eliminating waste. The first principle is specifying value. Value is defined based on the needs of the internal customer, which is the next activity in the process, and the external customer, which refers to the end user of the product. The second principle is identifying the value stream. This step includes mapping all the activities and processes from raw material to the finished product. Afterwards, in the third principle, flow is achieved through the continuous forward-streaming of value-added activities. In the fourth principle, the customer pulls value. This means that an upstream activity starts only when a downstream activity initiates it. Finally, the perfection principle requires a company to continuously improve the system. Based on empirical evidence in VPD (e.g. [7]), value thinking has proved its usefulness because of the common standard language established, the ability to visualize the current state of a process with respect to the desired future state, and the focus on activities that satisfy customer requirements. Nevertheless, there are several gaps that challenge VPD such as the need for a system view, a measurement culture [6], and strong leadership and disciplined execution [8]. Moreover, lack of understanding of value thinking and lean theory can lead to severe problems when companies focus on cutting waste, such as excessive time and cost, at the expense of product quality [8].

Based on the discussed value-lean advantages and limitations, value thinking implementation has expanded significantly in many fields such as healthcare, software, product design, and business management. However, within these fields, as well as in manufacturing, the focus, measurement, and understanding of value thinking vary and shift with time. In the PD context, the interest in applying value approaches has emerged recently, with several authors looking into the feasibility and benefits of value-based application outside the manufacturing field. This interest grew due to the need for a new improvement approach to enhance firms' competitiveness through their PD processes, as well as the distinct achievement that value approach has achieved in improving production processes (e.g. [2], [4], and [8]). Moreover, in PD, early implementations of value-based approaches, such as value stream analysis and modelling methods, have been reported to aid in reducing waste time by 50-90% [3]. This motivated many firms to adopt these tools. However, despite the success of 'value' in manufacturing and the promised advantages in PD, the degree to which the value method can be implemented in PD and the extent of its effectiveness in this context has not been fully shaped.

This paper attempts to address this gap by presenting a review of state-of-the-art in current understanding of value thinking and application in engineering processes. A conceptual framework is then presented to enhance value thinking application in PD. The main questions considered are: 1) what is value thinking? and 2) how are value attributes delivered?

3 CURRENT UNDERSTANDING: VALUE IN PD

Understanding value is the first step in Lean thinking as proposed by Womack and Jones. Value concept in the production context is defined as "a specific product that meets customer needs at a specific price at a specific time" [2]. However, in PD, value thinking is often associated with the capacity to generate knowledge/information through managing activities to produce a "recipe" that satisfies requirements. To develop a value approach that improves engineering process, it is essential to understand value thinking in the context of the dynamic and complex design environment. Therefore, several studies were conducted by researchers and industries to understand and to investigate value approaches in improving PD process.

In this section, the shift in understanding of value thinking within the engineering design literature is discussed, along with a description of value methods, their limitations and advantages. The literature is presented through comparing methodologies based on 1) value dimension explored and 2) value approach implementation purpose (i.e., the intended benefit). Finally, a summary of the main conclusions is presented.

3.1 Value Dimension

Value is a multi-dimensional concept that can be analyzed, modelled, and measured through various approaches. These approaches depend on the value dimension considered. Chase proposed that value dimensions include: perspective, entity, and attribute. Similarly, we analyze VPD based on value dimension as summarized in Figure 1. The figure shows the current understanding and language used to discuss value in product development processes, highlighting that value is a complex concept with multiple levels. At the first level, value perspectives, which identify to whom value is delivered, such as customer (end user), organization, and stakeholder (e.g. employees and shareholders), are addressed. For example, Browning et al. studied value with respect to customer [11], while Carlucci et al. [9] and Beauregard et al. [12] addressed value with respect to organization. Value perspectives are the system drivers, as they define the process performance objectives. These perspectives are critical since they determine the ultimate success of the product in the market. Moreover, the definition of "value" can differ from one perspective to the other causing priority and tradeoff challenges. For instance, with respect to customer value, product performance may be the primary objective; however, for some organizations minimizing the operation lead-time is valuable and may be of a higher priority. Therefore, identifying those perspectives with their objectives can be critical to the success of the product. At the next level, value is discussed in term of which entity, such as activity, information and resources, generates value. The entities role is to produce value for the system drivers (perspectives). For instance, Carlucci et al. studied how knowledge assets can create value when linked to the organization performance objectives [9]. Beauregard et al. studied how the coordination between resources and activities can create value to the organization [12]. On the other hand, Browning et al. looked at the activities and their dependencies and how generating information can reduce risk and create value to customer [11]. At the last level, Slack proposed attributes for value. These main attributes of value include: quality, time, cost and risk. These attributes are suggested as the performance measures that determine value level in product development process [5]. From literature, lead-time and risk were the two most used attributes to measure value in PD processes. For example, in the case study conducted by Carlucci et al. [9], the performance improvement obtained was a function of time reduction. In general, value attributes are referred to as cost, schedule, and performance [4], or just performance [9].

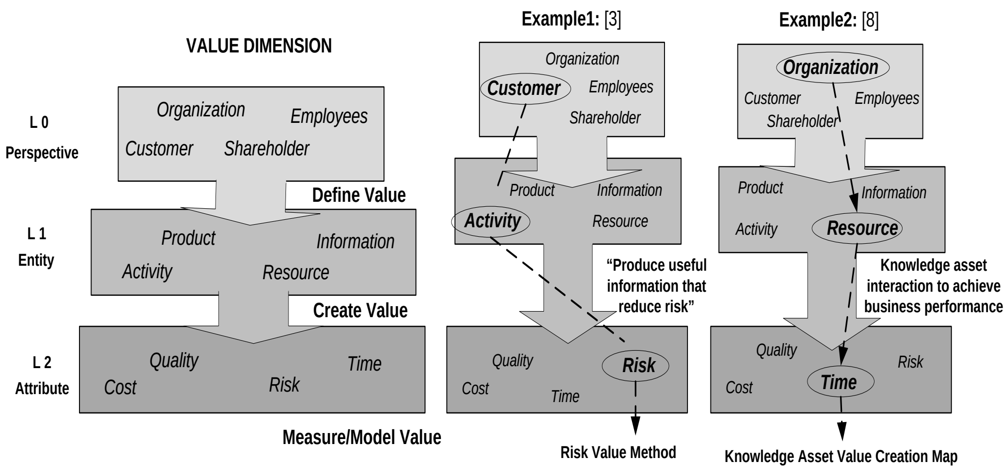

Figure 1. Value Dimension in PD

3.2 Value Purpose

In this classification, literature is compared in terms of each value approach's application purpose. Two main purposes are evident in the reviewed literature: improve process flow logistics, and provide decision making support. Ultimately, all value-based research aims to improve the system performance.

3.2.1 Process Flow Logistics: Load Leveling

Various studies have been conducted to explore value thinking's applicability to facilitate logistics improvement in PD. Logistics in engineering processes can be defined as "ensuring that right positioning of engineering resources is appropriate to support the flow of intellectual work in process" [12]. In general, authors in this category develop visual frameworks to help improve performance through value analysis. They have integrated traditional lean methods, such as Value Stream Mapping (VSM), into these frameworks. VSM is a technique that uses standard terminology and symbols in mapping a real complex system to a simple 2-D format for the purpose of analyzing and improving it [3] (Figure 2).

One process flow logistics model is that presented by Beauregard et al. [12]. At the enterprise level, Beauregard et al. explored lean application in product development through integrating lean manufacturing theories, product planning and other tools to achieve a better coordination of jobs, resources, and requirements in complex design processes. The methodology is implemented through five main steps: 1. Determine demand, 2. Construct the value stream of the bottleneck using a current and future state VSM, 3. Plan and schedule jobs at the bottleneck operation, 4. Co-ordinate job release with the bottleneck, and 5. Measure performance at the bottleneck while seeking continuous improvement as needed. Beauregard et al. focuses on the time aspects of value, where bottlenecks are thoroughly analyzed to match critical resources and activities (Figure 2). To measure the benefit of lean implementation, Beauregard et al. propose a financial model. Their "Lean business model" captures engineering system status and presents an abstract view of progress achieved through measuring lean savings [12]. The main benefits of this lean engineering logistics model are to enable adequate planning, better execution, and reduction in levels of risk. The main assumption to build this model is being able to adequate forecast system capacity.

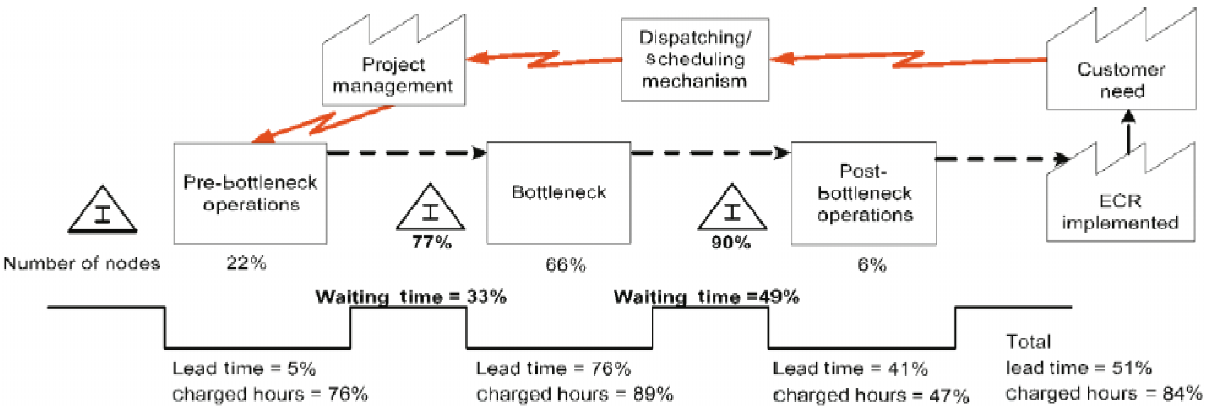

Figure 2. Value Stream Map (Beauregard et al., 2008)

In another study, Oppenheim develops an improvement methodology, named Lean Product Development Flow (LPDF), as a contribution to the emerging field of lean system engineering [8] (Figure 3). This method is based on the five lean principles [2]. LPDF schematically illustrates the flow using Value Stream Mapping where major project deliverables are identified over a weekly Takt time (equal and short time periods governing the regular 'drumbeat' of information transfer between tasks in the process). This method requires a detailed process plan and good leadership and management. Application of LPDF can be best applied to smaller design programs, with existing knowledge/data base, low risk of uncertainty, and mature technology program. The main aim of the LPDF method is to shorten PD schedules and reduce costs while maintaining value levels.

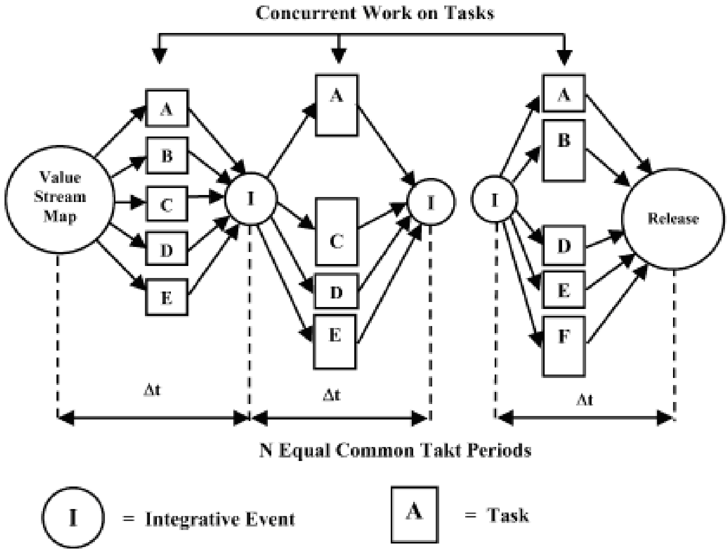

Figure 3. Schematics of Lean Product Development Flow (LPDF) (Oppenheim, 2004)

3.2.2 Decision Making Support

Literature suggests that value thinking can be used to support decision-making in process development through a) determining system performance level (Value measurement) and/or b) visualizing value flow (Value Mapping).

- **Value Measurement:** The research in this category aims to develop financial models or mathematical equations to measure the process performance level, i.e. uses value as an indication-of-progress measure to support decision-making. An example of a measurement-oriented value study is that conducted by Browning [4]. The study suggests that customer value is a function of product and process attributes; therefore, Browning suggested that customer value is created based on the process structure as well as deliverables. The model measured VPD through determining the ratio of benefit to cost for a given process architecture, through the value trajectory model (Figure 4). He proposes that understanding customer value based on benefit and cost margins can facilitate decision-making at the activity level to deliver sufficient benefit for the product's success in the competitive market [4]. In another study, Browning et al. proposes the risk value method that supports PD project planning and control [11]. The method integrates the technical performance measure (TPM) tracking charts and risk waterfall charts to evaluate the status of the design process, hence adding value in PD. Browning et al. argues that value added in PD is a function of risk reduction through creating useful information that improves the confidence in the TPMs (i.e., in the design recipe). The main limitations of this method are that measures can be "gamed" and information can be subjective [11].

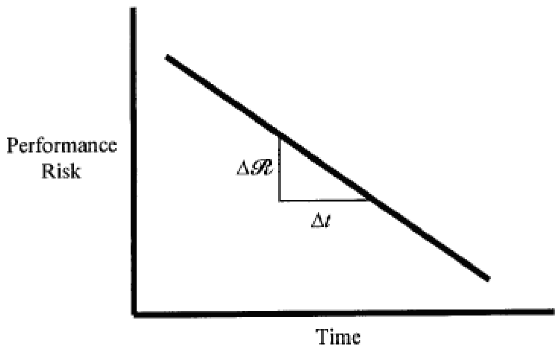

Figure 4.Change in Performance Risk over Time (Browning el al, 2000)

- **Value Mapping**: This category includes research that maps value flow in the process for the purpose of supporting decision-making. For example, Carlucci et al. propose a visual framework to understand value creation at the organizational level [9]. They suggest that value is derived from linking organization knowledge assets with specific performance objectives. They developed a visualizing representation, the Knowledge Asset Value Creation Map, which can help map and evaluate these connections. This tool is intended to support managers in taking decisions to allocating the appropriate knowledge assets according to priority rating with respect to their corresponding performance objectives. The first step in constructing the KAVCM is defining the specific organization objectives then translating them into measurable performance objectives. Secondly, the knowledge assets, based on their priority ratings, are associated with the identified performance objectives. KAVCM combines the Analytic Hierarchy Process (AHP) with a matrix of indirect dependency. Analytic Hierarchy Process is used to weigh the importance of knowledge assets, while the matrix is used to identify the dependency between the company's knowledge assets and the targeted performance objectives. This approach was supported by results from an empirical study in a large furniture manufacturer. In the presented case study, the application of KAVCM was reported to reduce product design activity time by 30% and reduce the time to carry out the sofa prototype wooden structure by 20%. The main limitation of this model is the high level of abstraction that limits the usefulness for process improvement. Moreover, the task of describing the relationship between knowledge assets and performance objectives challenging and subjective, therefore, the applicability of the approach as well as the extent of its benefit is uncertain.

Furthermore, based on the study of other process improvement tools used in PD, McManus et al. conduct a study that explores Value Stream Analysis and mapping (VSA/M) application in VPD [3]. The author uses VSA to examine business processes using lean principles to support managers understanding of current state. Afterwards, VSM uses the results of VSA to simplify the complex system to a 2-D format. Afterwards, the current state can be examined through constructing first a high level, then a detailed mapping. Next, the desired future state can be reached through implementing improvement techniques with a focus on the identified gaps. To implement this value improvement method, McManus et al. propose developing an appropriate lean context. Based on an aerospace case study, the authors found that the application of value stream mapping tools in a lean context does correlate to process enhancement.

3.3 Summary

VPD literature includes studies that address value thinking or/and introduced a new value approach. This literature was further narrowed to analyse research which is supported by empirical evidence and which addresses the value dimensions discussed earlier. Based on the analysis, we propose VPD literature can be divided into approaches to enhance value thinking understanding or/and approaches developed to improve the VPD process. The models and measurement frameworks reviewed claim general benefits, including support for better planning and execution, reducing risk, schedule time, and cost, and determining the progress status of the system processes. Despite the apparent advantages of VPD, several limitations were also found. For example, the methods presented each address one dimension of value in the expense of the others. This limitation seems to contradict the major advantage of value as a multidimensional measure, and thus could limit the extent of value methods' benefits. Moreover, there is a lack of linkage between value understanding and value delivery approaches as well as value modelling and measurement tools. In addition, literature recognizes the difference between manufacturing and PD process; however, the methodologies presented do not explicitly address these differences. Finally, some assumptions, such as those in planning and forecasting requirements, may be a major limitation of the frameworks' applicability due to the unique and complex nature of PD.

4 THE VALUE CYCLE MAP

As a contribution to the understanding of value in product development, the *Value Cycle Map* (VCM) is proposed in this paper. The VCM is a high level framework of value structure in the product life cycle with a focus on design activities. The main aim is to facilitate future research in value modelling and measurement, as a strategic planning approach to improve performance. Therefore, two questions are addressed: what is value? And how is value delivered? The framework aims to integrates the current understanding of VPD, and Design Activity Management model [13]. Other concepts, like consumer response to product, were also considered to understand value delivery mechanism. We start with proposing a working definition for value. Afterwards, value delivery mechanism is discussed in the design activity context, illustrated using the Design Activity Management model. Finally, the value cycle is integrated into a model of the product life cycle through a simple input-process-output diagram. The value cycle map presented in this paper is the result of an initial study as part of a 4 year PhD research and is based on descriptive study of VPD.

4.1 Step 1: Value Definition

Maximizing value is a critical objective for product success in market. However, in order to deliver value, designers and management need to define what is valuable to the different system perspectives. Therefore, value initially can be considered to comprise, and not be limited to, four main types:

- **Product Value -**a desired capability/benefit that meets the quality, cost, and time requirements set by customers or end users.
- **Process Value -**ability to conduct effective and efficient processes that translate design requirements into useful information and physical components within budget and time constraints.
- **Learning Value -**"a company's ability to innovate, improve, and learn" [14]. This is tied to Organization Value.
- **Financial Value -**profit generated from delivering product.

Based on these presented types of value, and for the purpose of this study, we developed a working definition that integrates perspectives, attributes, and entities as presented in literature: "Value is a desired capability delivered through a product that meets the quality, cost, and time requirements set by customers or end users (*Product Value),* developed by performing effective and efficient processes that produce desired output within budget and time constraints (*Process Value*), in an organization that builds a common culture of respect, motivation, and self actualization for its employees (*Learning and Financial Value*)."

4.2 Step 2: Value Delivery Mechanism

To understand value creation and delivery, we propose that value can be viewed as a cycle based on consumer response to the product design [15] and basic model of communication (adopted from [16]). The product is the channel that connects the consumer with the designers [15], therefore, the organizations need to understand and support both ends of the channel (customers and designers) through executing and managing effective processes. One way to understand value delivery is looking at it as a cycle (Figure 5). The Value Cycle view is compromised of three main elements: source, transmitter, and value receiver. These elements correspond to the value dimension proposed in the literature review. The value source is the entity that produces value, such as design activities and knowledge assets. The transmitter represents the channel through which value is delivered. The value transmitter denotes product features and process attributes. Finally, the value receiver is the destination to which value is delivered and corresponds to value perspectives. Based on feedback from the value receiver, such as new user needs, and technology updates, changes are introduced to trigger a new cycle or support decision-making within the system.

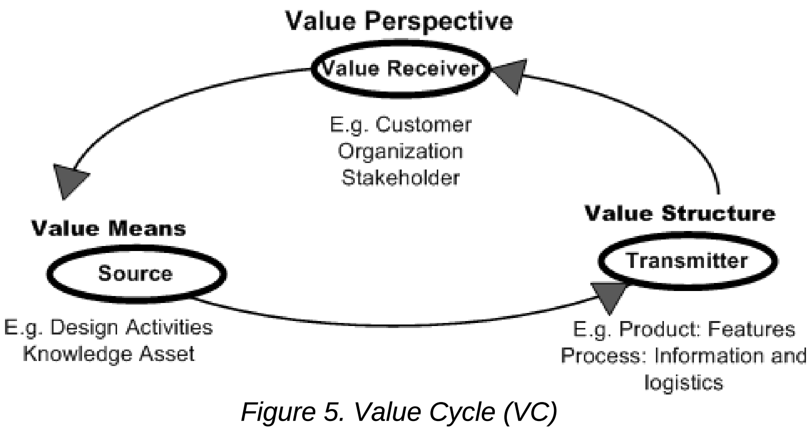

Figure 5. Value Cycle (VC)

In the next step of building the value cycle map, we look at a detailed level of analysis through studying activities in the PD process. The analysis is based on the Design Activity Management

(DAM) model [13]. The aim is to develop a more detailed analysis of the value cycle in PD as a foundation for future development of value-based study on design activities.

4.3 Step 3: Value in Product Development – Deployment of the Design Activity Management model

Value attributes are generated during product development, but can be measured only with high uncertainty or in later phases of the PLC. In general, value in PD can be determined based on an evaluation of activities' performance through the quality of information generated. As a base, we use O'Donnell and Duffy's Design Activity Management (DAM) model [13] to understand design activities' performance. O'Donnell and Duffy distinguish between a design activity and a design management activity to measure and manage performance (Figure 7). Design activities are problem solving activities which include decision gates after their analysis, synthesis, and evaluation cycles. The results are accepted or rejected in this basic design cycle. On the other hand, design management activities aim to manage and evaluate attributes of the design process, such as time (Figure 6).

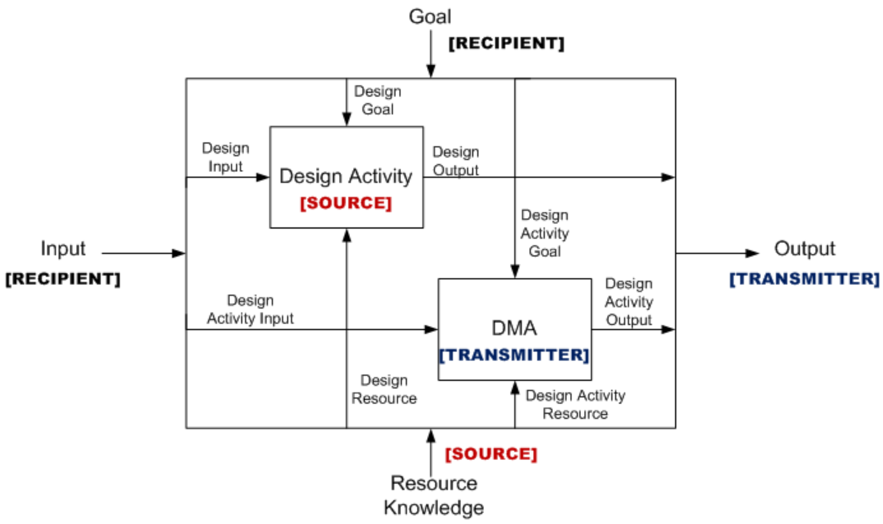

*Figure 6. Design Activity Management Model (*O'Donnell et al., 2005*) vs. Value Cycle*

When integrating the design activity management model with the value cycle, the three elements of the VC can be analyzed. The source of value can be seen as the interaction between 'Resource Knowledge' and 'Design Activity'. The transmitter can be viewed as the 'Design Management Activity', which measures internally the value, as well as the process 'Output' which transmit value externally. The recipient can be mapped to the 'Input' and 'Goal', as they define value and set performance targets by which the system operates. Similarly to the 'customer' in Manufacturing, the value in PD has two customers/receivers: the first is the next phase or activity in the process, and the second is the ultimate user of the product. Since the output of design activity that is received by the next phase of the PLC is a "recipe", this "recipe" is the internal transmitter of value. Therefore, understanding these interactions and controlling them can facilitate value maximization at the process level.

In the final step, we look at value in the PLC. This higher abstraction level is essential to illustrate value as a network of elements that potentially connect performance measures and system objectives within life cycle phases. Furthermore, this will also allow a high-level analysis of the factors and system attributes contributing to value creation in PLC.

4.4 Step 4: Value in the Product Life-Cycle: The Input-Process-Output Diagram

It is insufficient to focus on value in a single phase of the product life cycle because of the complex network of interconnected elements and factors that create and deliver value. Therefore, we integrate steps 1-3 in a high level analysis of the PLC. To facilitate the understanding of value in the PLC, we start with a simple input-process-output model as a representation of the PLC (Figure 7). The product life cycle starts when triggered by new requirements, such as market competition or customer needs. The process is composed of activities that can be focused on one or more type such as: design, production, or management. For simplicity, three main phases are considered: product development, manufacturing and release and disposal. Finally, the output is a product or service provided based on demand, requirements, and organization capacity. Both product and process attributes exhibit value and waste.

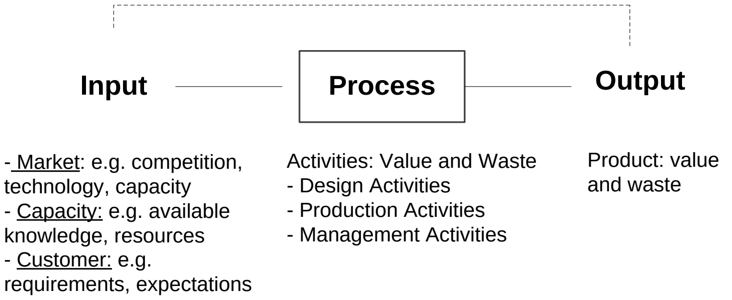

Figure 7. Input-Process-Output

The life cycle should be studied and understood in the process, organizational, and environment context (Figure 8) where value is an outcome of multiple layers of goals, people, and capacity. In each of these layers, there are direct and indirect factors that affect the value level. For example, on the organizational level, culture is an essential factor that affects teamwork. As a result, the value level is affected by the information sharing culture in the product development phase. In addition, the technology available in the environment context directly affects the quality, time, and cost of the processes, and can indirectly affect the hiring culture in the organization due to the automation shift.

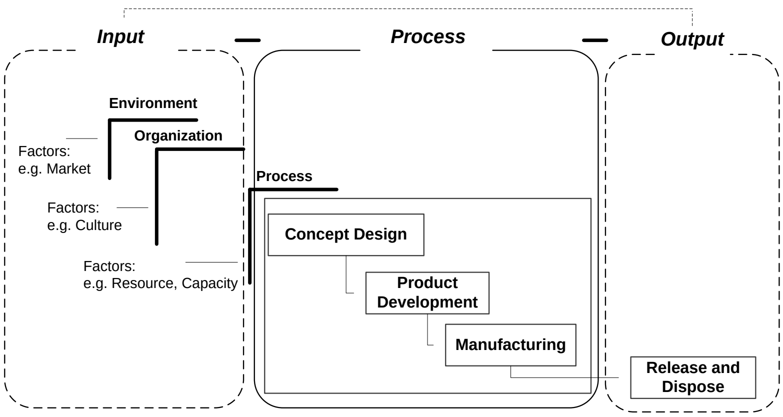

Figure 8. PLC in I-P-O

The proposed framework (Figure 9) integrates the previous discussion into the Value Cycle Map (VCM) which provides an overall framework for the definition and delivery of value. The map shows the source, transmitter, and receiver as part of several layers of the system. Because external and internal factors have an essential role in the value cycle, the VCM shows some external factors such as culture, technology, and resources' knowledge. The internal factors shown are attributes of the product and process, such as levels of complexity. In addition to these factors, on the organizational level the framework shows PD and manufacturing activities as the sources of value. The output of these processes is the value transmitter. Adopting Hales' model of the project set in context [17], the outputs of design activities are: specification, concept, layout, and drawings. Moreover, the outputs of manufacturing processes are production, components, and product. These outputs transmit value through measurable attributes, such as: performance, cost, schedule, and risk. Finally, customers, organization, and other stakeholders receive value. For instance, the organization receives value through meeting demand, learning and knowledge obtained, market share, and profit. The model facilitates understanding of how value definition and dimension evolve in each phase. For example, value in concept design can be a function of capturing the right requirements with their tradeoffs. However, value in PD is a function of information generated and the level of activity coordination. In manufacturing, value is a function of the activities that contribute to producing physical components of the product.

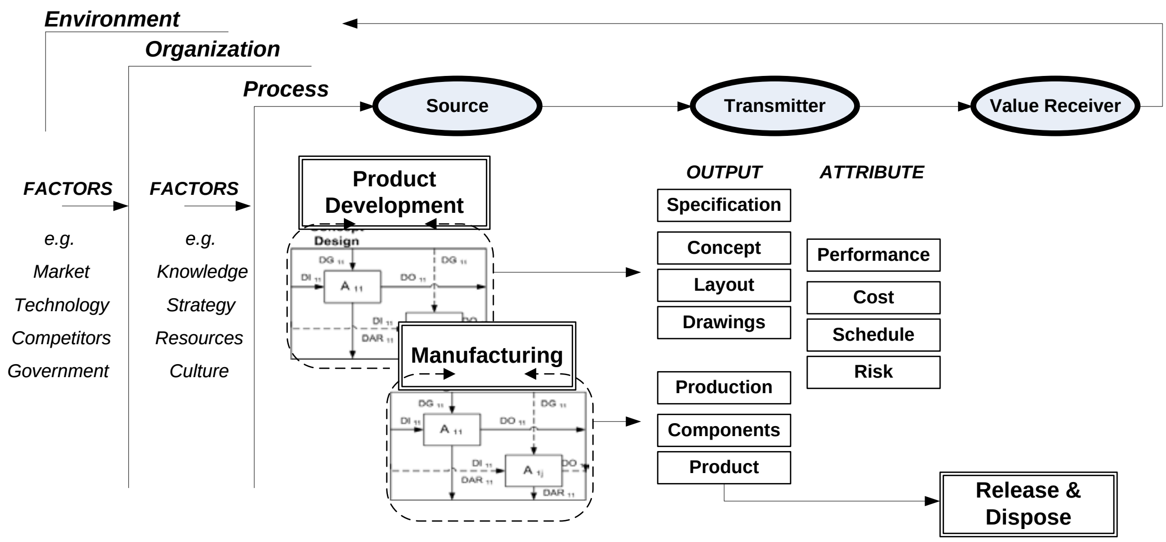

Figure 9. Value Cycle Map

4.5 Summary

Based on the current state of knowledge in the literature, we developed a framework for value definition and delivery in PD. In our framework, value is decomposed into four main types: product, process, learning, and financial value. Value is defined as desired capability delivered through product that meets the quality, cost, and time requirements set by customers or end users, developed by performing effective and efficient processes that produce desired output within budget and time constraints, in an organization working for continuous improvement. Furthermore, we introduced the VCM framework that addresses the second question of value delivery. We propose that value is delivered through a channel of source, transmitter, and receiver and is created as a function of factors, attributes, activities' execution, and management; these interact as part of the value creation and delivery system. The VCM framework is a visual representation of value creation and delivery mechanisms that is intended to support understanding system value on a high level of abstraction (considering the PLC) as well as on a detailed level (considering PD activities). Through understanding these sources, factors, and their dependencies, we propose that control and measurement techniques could be established to manage these critical aspects and improve the system performance.

Besides providing an organizing framework to help position future VPD research, we suggest the VCM could help industries adopting the five lean principles in PD, in particular by assisting them in defining value and taking the various perspectives into account.

5 DISCUSSION

This paper has focused on clarifying value thinking and approaches in product development process. A review of VPD literature yielded possible opportunities and gaps when transferring value concepts from the operational level to the engineering processes. For instance, value thinking could improve processes through improving process flow logistics and supporting decisions (e.g. [12], and [8]), and by linking organization phases through the standard language of value approach. However despite these advantages, several gaps could limit value thinking's applicability and benefits. These gaps include the subjectivity of measures used, the need for forecasting, and the lack of an integrative view of system attributes. Therefore, considering these limitations and opportunities, this paper has proposed a new definition for value concept and delivery. Narrowing the scope of this study to address these two questions (what is value and how is it delivered) on both detailed and abstract levels is necessary to develop more objective value measures that integrate factors of uncertainty, iteration, and uniqueness of design.

The paper can facilitate future work on value PD in several ways. First, decomposing value into product, process, learning, and financial can assist in gaining a holistic understanding of different types of value that range from management's strategic planning and economical profit to technical performance measure and risk reduction. Second, a model of value delivery is proposed based on a communication channel model comprising three main components, namely source, transmitter, and receiver of value. Each of these three components supports and corresponds to one of the value dimensions seen in the literature review. We propose that understanding and managing these components of the value cycle could support value control and optimization. For example, understanding sources of value on the process level, such as activity structure, could support decision making regarding which structure alternative might optimize the value created and therefore reduce cycle time. Third, the consideration of value delivery on the detailed level of design activities contributes to understanding how the activities goals, input, output, and resource would generate value and ultimately yield measurable attributes. Finally, including the more abstract level of value delivery in the PLC is important to understand external factors affecting value in the organization and environment context. Moreover, it will assist in linking the various phases of product life cycle with a standard language and goal. In summary, therefore, the main benefit of the proposed framework is to build a foundation for future work on value approach through enhancing the current value state of knowledge. Consequently, these measures of value can contribute to PD performance improvement through supporting decision-making and logistics.

6 CONCLUSIONS

Generating value can be used as a driving force for successful product development in highly competitive markets. Therefore, understanding what value is and how value is added, especially in dynamic engineering processes, can be critical to profitable projects. This paper has argued for the need to re-conceptualize the understanding and application of value in PD for the purpose of improving process performance. A conceptual framework of the value cycle in the activity and environment context was introduced, aiming to clarify value structure and delivery mechanisms through analysing the relationship of system elements on both detailed and abstract levels. The framework is based on the current understanding of value dimensions and purposes in PD as revealed in the literature, as well as customer response to the product. Future work may include investigating the applicability of this framework through a case study. In addition, we suggest the framework could be used to build methodologies for improving process performance through modelling and measuring value.

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