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Measuring Value in Product Development

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Executive Summary

"What is value in product development?" is the key question of this paper. The answer is critical to the creation of *lean* in product development. By knowing how much value is added by product development (PD) activities, decisions can be more rationally made about how to allocate resources, such as time and money.

In order to apply the principles of *Lean Thinking* and remove waste from the product development system, *value* must be precisely defined. Unfortunately, value is a complex entity that is composed of many dimensions and has thus far eluded definition on a local level. For this reason, research has been initiated on "Measuring Value in Product Development." This paper serves as an introduction to this research. It presents the current understanding of value in PD, the critical questions involved, and a specific research design to guide the development of a methodology for measuring value.

Work in PD value currently focuses on either high-level perspectives on value, or detailed looks at the attributes that value might have locally in the PD process. Models that attempt to capture value in PD are reviewed. These methods, however, do not capture the depth necessary to allow for application. A methodology is needed to evaluate activities on a local level to determine the amount of value they add and their sensitivity with respect to performance, cost, time, and risk.

Two conceptual tools are proposed. The first is a conceptual framework for value creation in PD, referred to here as the *Value Creation Model.* The second tool is the *Value-Activity Map*, which shows the relationships between specific activities and value attributes. These maps will allow a better understanding of the development of value in PD, will facilitate comparison of value development between separate projects, and will provide the information necessary to adapt process analysis tools (such as DSM) to consider value.

The key questions that this research entails are:

- What are the primary attributes of lifecycle value within PD?
- How can one model the creation of value in a specific PD process?
- Can a useful methodology be developed to quantify value in PD processes?
- What are the tools necessary for application?
- What PD metrics will be integrated with the necessary tools?

The research milestones are:

- Collection of value attributes and activities (September, 200)
- Development of methodology of value-activity association (October, 2000)
- Testing and refinement of the methodology (January, 2001)
- Tool Development (March, 2001)
- Present findings at July INCOSE conference (April, 2001)
- Deliver thesis that captures a formalized methodology for defining value in PD (including LEM data sheets) (June, 2001)

The research design aims for the development of two primary deliverables: a methodology to guide the incorporation of value, and a product development tool that will allow direct application.

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1.0 Introduction

In 1996, Womack and Jones wrote *Lean Thinking*, which has become the primary guide for the transition to lean within the aerospace industry. They suggest five principles for achieving a lean state. The first of these principles is to *precisely specify value*, which they define as:

> *A capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer. (Womack and Jones, 1996)*

This definition, however, does not provide the needed specificity for the product development (PD) process, so application of this definition of value to PD processes is rarely helpful. In practice, lean assessments of product development tend to fall back on an *a priori* characterization of which activities add value. Although simple applications of lean principles can often root out the obvious wastes found in most PD processes, optimization of the processes cannot be achieved without a firmer definition of value.

The research project, "Measuring Value in Product Development," has been initiated to:

- Define value attributes and metrics for several PD processes
- Develop a methodology to capture value creation in PD
- Create tools to allow application for process improvement

The objective of this paper is to lay the foundation for the above research activities. The first two sections, *Current Knowledge* and *Methods and Tools*, review the current state of the art. They are supported by two appendices at the end of the document. The next section, *A Conceptual Framework for Value Creation in PD*, proposes two conceptual tools, a *Value Creation Model*, and a *Value-Activity Map*, which shows the relationships between specific activities and value attributes. Subsequently, the section entitled *Key Problems and Questions* attempts to establish the obstacles that are currently being faced, and what questions need to be answered in order to continue. The paper ends with the *Research Design*, in which a research approach is proposed for addressing the unanswered questions and developing a methodology to characterize value within PD.

2.0 Current Knowledge

The current knowledge of value in the product development process is reviewed in the three subsections below. These include an overview of the PD process, the inefficiency and waste that can be found in current PD processes, and the current understanding of value within PD processes.

2.1 Product Development Process Understanding

In *Product Design and Development*, Ulrich and Eppinger separate the product development process into five stages that describe PD from the initial idea to production. (Ulrich and

Eppinger, 1995) These stages consist of:

- Concept Development
- System-Level Design
- Detail Design
- Testing and Refinement
- Production Ramp-Up.

In 1999, the Lean Aerospace Initiative (LAI) PD team further refined this model (see Figure 1). The steps are modified to reflect aerospace practice. More importantly, the information flow is tracked, with each step using internal inputs (the outputs of previous steps) and external inputs (constraints, common practices and standards, etc.) to produce a set of information products passed to the next level. Risks are also considered at each step. Figure 1 shows the highest level of the LAI PD team model. Each of the steps, inputs, and outputs shown is expanded in some detail in the full model. (PD Team, 1998)

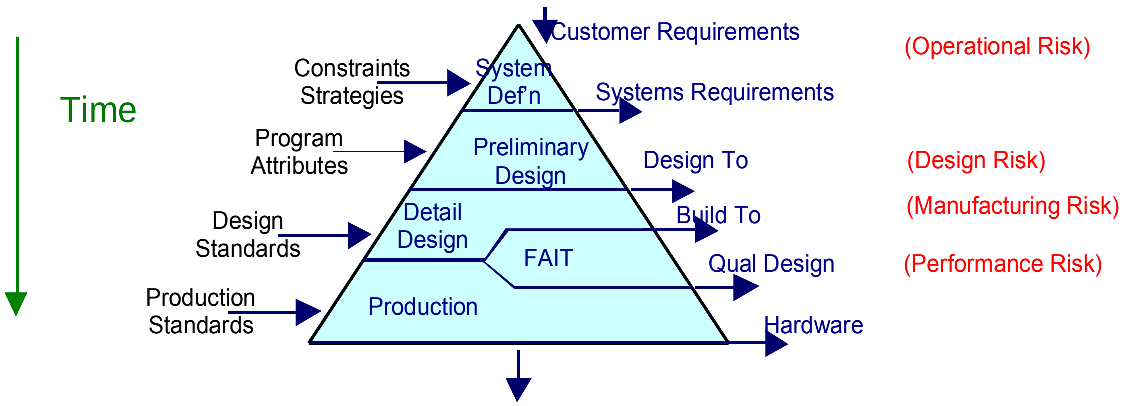

Figure 1: Product Life Cycle Process (PD Team, 1998)

2.2 Waste

According to Womack and Jones, activities can be generally divided into three categories.

- Activities that add value
- Activities that do not add value but are necessary (type 1 *muda*)
- Activities that do not add value and are unnecessary (type 2 *muda*)

In general, type 2 *muda* should be eliminated and activities that are rated type 1 *muda* should be made highly efficient. (Womack and Jones, 1996) These guidelines are used in current state of the art PD process improvements. PD processes are mapped, and activities are labeled as *value-added*, *necessary-waste*, and *waste*. However, these labels do not adequately gage the value of individual activities. The assessments are made *a priori* and thus do not sufficiently reflect the degree of value that is added. Instead, there should be a more intensive gage that measures the *precise value* of these activities. This gage is essential for refining the PD process.

2.3 Product Development Value

Here, past work is placed within a proposed framework for defining value within product development. At LAI, value at the highest level, often dubbed *total lifecycle value*, has been subject to intensive study within the past few years. To relate total lifecycle value to the product development process, one must dive through the different *perspectives* of value, the various *entities* that make up the PD process, the various *attributes* value can have locally within the PD process, and finally arrive at quantifiable local *metrics*.

It is difficult to quantify value, particularly within the context of product development, because there are many *perspectives* on value. These perspectives depict the complexity of value, which is seen differently by the business customer, end user, shareholder, employee, and environment. Each of these will typically have a different perspective on what is valuable. For example, Womack and Jones have based their definition on customer value, whereas Keen suggests that shareholder value is the driver of the modern age. Most recently, Donovan, Tully, and Wortman have proposed that management processes should be developed to ensure simultaneous optimization of investor, customer, and employee value. (Donovan et al, 1998) The multiple perspectives of value have been recently explored by the LAI executive roundtable. This meeting resulted in a white paper authored by Eric Rebentisch. (Rebentisch, 2000)

The question has also been addressed by Slack, who suggests that it is acceptable to work within a one-dimensional model focusing on customer value, as long as an analysis of the other value perspectives is carried out prior to implementation of any change. He further states that a straightforward approach to customer value modeling will facilitate the lean effort (Slack, 1999).

Once the customer value is given emphasis, one is still faced with a variety of *entities* that can contain value or waste. Slack decomposes customer value into some basic attributes such as cost, performance, and timeliness, but does not relate these attributes to the tasks or other entities within the product development process. PD value can reasonably be assessed in terms of the value of activities, the information they create, the product or product package they assemble, the smooth flow of the combined activities, or some combination of the values inherent in these entities.

At a deeper level, each of these entities might have several *attributes* that might be considered valuable. The notion of value attributes is also not well understood. A typical view, used by Browning for his enhanced DSM modeling, is that the *performance*, *risk, schedule*, and *cost* of the developing design characterize value. From a different viewpoint, McManus has stated that product development consists primarily of the flow of information, and chose *form*, *fit*, *function*, and *timeliness* as the most important attributes of this information. Similarly, Slack, Walton, and other researches have proposed over 25 similar attributes, listed in Appendix A.

A final level of value, critical to any attempt to improve or optimize value, is that of quantitative metrics. The attributes mentioned above need to be, for each specific case considered, expressed in terms of a measurable and available piece of quantitative information.

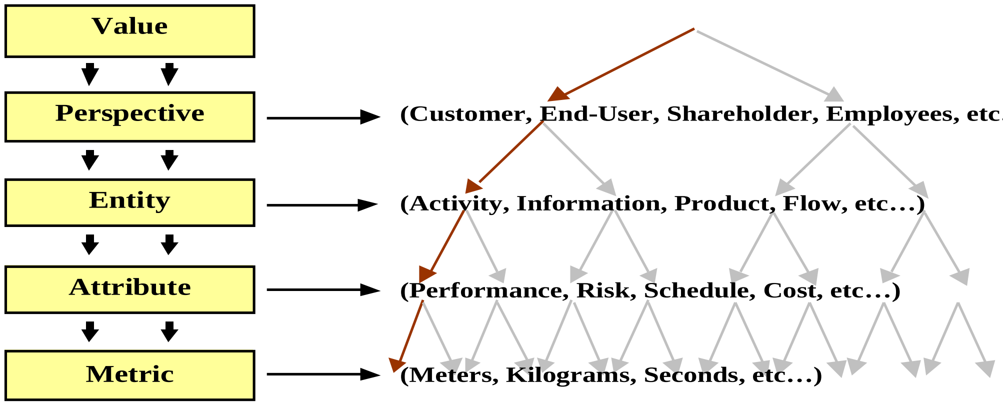

Figure 2: Dimensions of Value (and one sample chain)

The complexity of this situation is illustrated by Figure 2. The challenge clarified by this illustration is that of finding the most influential metrics for the value of PD entities, based on, at best, available general characterizations of value perspectives.

3.0 Methods and Tools

> To solve our basic problem [of improving the product development process], any methodology that is to be developed must be useful in evaluating the partially developed product at any time during its development life. (Sobelman, 1958)

Since 1958, this has been the mantra by which models have been created. Although models are most easily developed by examining old product development processes, they must be applicable to in-process development. Since 1958, little has changed; the LAI PD team in the summer 1999 workshop concluded that data based metrics must be used to drive activities and achieve a lean PD process, and the value associated with a task must be addressed at each step of the process. (McManus et al, 2000)

Currently, there are five models (in various stages of development) that identify value in the PD process, each representing a different perspective. A general methodology would most likely need to use multiple perspectives on value, so it will probably borrow from many if not all of these models. The models are reviewed briefly here and are described in somewhat more detail in Appendix B.

The oldest of the models is represented by the *Economic Value Added Function*. This equation simply states that *the firm's after-tax operating income* minus *the weighted-cost of capital employed* is equal to the *value added*. (Higgins, 1998) The benefit of this definition is that it gives a clear sense of value in terms of the profit from a given PD activity. Unfortunately, applying the model at a level lower than that of a business unit is difficult. The model attempts to address performance, schedule, and risk with a single number of expected profit; an approach that is too general too show *where* value is being gained or lost. Nevertheless, such a model firmly anchors the high level definition of value to a quantitative metric.

In the second method, Slack incorporates other factors (such as risk and time) into his *PD Customer Value Model*. This structure was created in a 1998 research paper (Slack, 1998) based on the work of Shillito and Demarle, but has generally not been used in current industry practice. Its greatest benefit is its rigorous mathematical nature as a utility function. Its primary disadvantage is that there is no accompanying methodology for application. The components of the equation are subjective, and thus there is no clear answer as to the relative significance of the result. The importance of this method is the mathematical method it represents.

The next model involves the *Design Structure Matrix (DSM)* (Steward, 1981 & Eppinger et al. 1994) extended by Browning in his doctoral thesis. This involves the iteration of performance, schedule, and cost to produce risk estimates. Its main advantage is the ability to successfully deal with complexity and iteration, while its primary drawback is a difficulty in modeling performance-activity relationships. An additional benefit is that Browning presents a formalized structure that can be used in other value models. (Browning, 1998)

Browning has also proposed another model described as the *Risk Value Method* that emphasizes measuring value through reducing risk. Essentially, successful PD is the procedure by which uncertainty about product parameters are sufficiently reduced in a planned and systematic way. (Deyst, 2000) The main insight of this method is the assertion that risk and value are inversely proportional, which may be too simplistic for some applications, but is certainly useful for general value characterization. Thus, the method is ideal for activities such as testing, where performance remains the same, but risk is reduced.

The final model, under development by Deyst, is a mathematically rigorous integration of the Browning's *DSM Modeling* and the more recent *Risk Value Method*. The analysis models the decreasing uncertainty that projects undergo, along with the major components of performance, risk, schedule, and cost.

4.0 A Conceptual Framework for Value Creation in PD

Each of the previous models offered a perspective that can be incorporated into an overarching description of value development. Here, a conceptual framework is presented that will organize this ongoing research on how value is created in PD and hence how it can be measured. Figure 3 illustrates a *value creation model* for PD.

Product development activities are shown creating information and reducing the risk and uncertainty of the project. To proceed, these activities need both internal inputs (from previous activities) and external inputs (knowledge and resources). Furthermore, each activity contributes something to the information package necessary to define the design, and/or contribute to lowering the risk and uncertainty to an acceptable level. Finally, the activity passes information to the following activities, hopefully in a form useful to them.

This is a simplified picture. In real PD processes, the interaction between the activities is often much more complex. Tools such as DSM exist for tracking this complexity, so this aspect of the problem will not be further discussed in this paper.

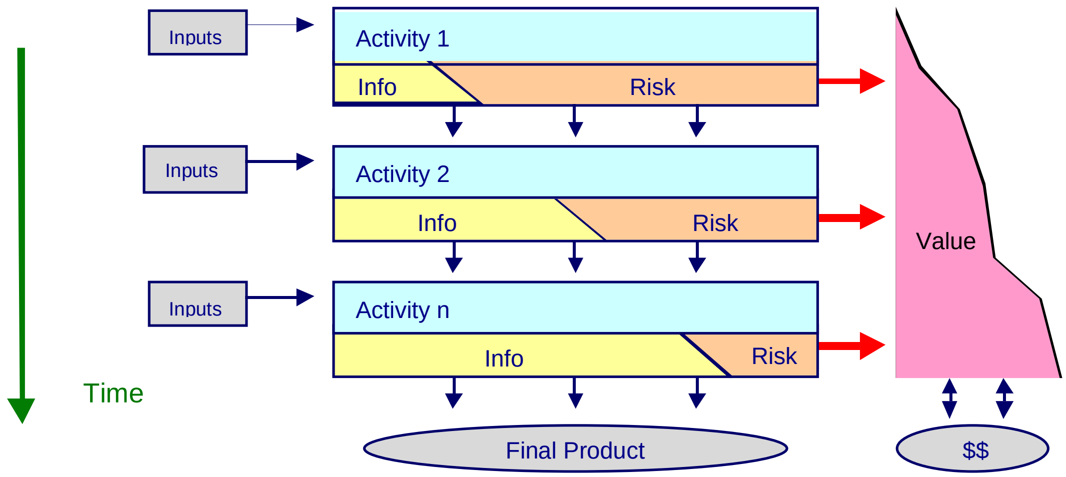

Figure 3: The Value Creation Process

Just as information is collected to produce the final product (typically a build-to package or similar manifestation of the design), one can imagine value accumulating. A number of *entities* are contributing to value, including the activities themselves, as well as the information and knowledge of risk that they create. There is also a final metric of the end value of the final product, expressed in terms of final value to the customer, traditionally associated with either price (customer perspective) or profit (corporate perspective).

The challenge lies in determining the relationship between the PD entities and the accumulating value. The quality and efficiency of the activities will determine the quality of the information produced and the time and money consumed. A decrease in risk correlates with an increase in value, while an increase in information also signifies an increase in value. The outside inputs, which can be as simple as money or as complex as a corporate core expertise, contribute to all of the above. The flows will determine the quality and efficiency of the linked activities, and the delays or lack thereof, in switching from one activity to another. Figure 4 illustrates this.

As previously mentioned, the critical problem is determining the relationship between the PD process and the associated value (represented by the horizontal arrows feeding value in Figure 4). A method is proposed here for capturing this relationship by decomposing it into specific associations between activities, information and value added. At each step, the activity and the information created by it (including information about risk) is mapped into locally available attributes and/or metrics of value.

A list of value attributes is shown in Appendix A. From this list, the list shown in Table 1 was selected as being typical of information that might be available locally during PD, and quantifiable (hence, units are included). This list is intended more as a thought-provoking example than as a finished product.

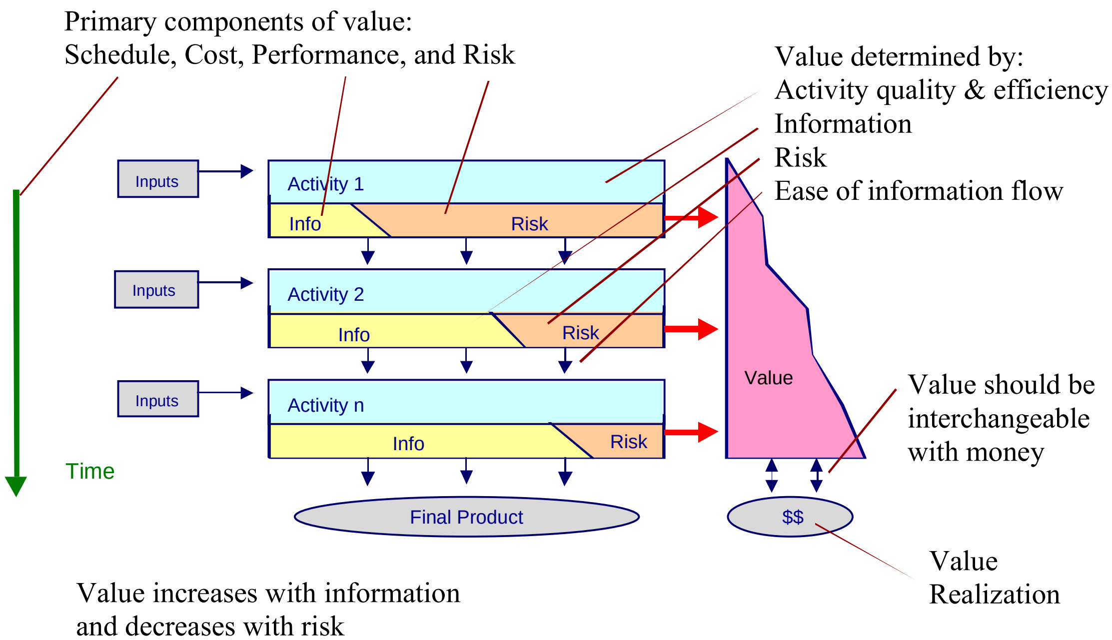

Figure 4: Components of the Conceptual Framework

Table 1: Value Attributes for PD Activities

Type	**Attribute**	**Units**
Performance	Performance specification n	% increase of n due to task
	Overall performance	% increase weighted to customer desirability
Risk	Risk specification n	% decrease of n due to task
	Overall risk	% decrease weighted to customer desirability
	Predicted future iterations	#
Schedule	Set-up time	hours
	Cycle time	hours
	Integration time	hours
	Dissemination time	hours
	Total time	hours
Cost	Fixed overhead cost	$
	Variable cost	$
	Total cost	$
	Future cost – development	$
	Future cost – manufacture	$
	Future cost – operation	$
	Future cost – support	$
	Future cost – retirement	$
	Total future cost	$
Form	Information retained	% of information captured
	Time spent reformatting data	hours
Fit	Necessity of information	% of information actually used
	Depth of information	% of information present that is needed
Function	Complexity of information	(1 – 10)
	Time spent handling info	hours
Timeliness	Time before first access	hours
	Time before last access	hours
	Times accessed	#

If the relations of an activity and the information it produces to all of the local attributes of value can be determined, then perhaps the value of that activity can be ascertained. If Table 1 is taken to represent an accurate picture of the local attributes of value, completing it for a given activity and information would capture a measure of value for that activity. If all activities in a PD process are mapped against all available value attributes and metrics, the result would be a value mapping tool. This proposed tool is dubbed the *value-activity map.*

A *value-activity map* is a matrix that relates PD activities and information to specific value metrics (see Figure 5). The rows of the matrix list alternating activities and information ordered as sequentially as possible. The list of activities can typically be found from a *contract book* or process flow chart. It might also be borrowed from an existing decomposition such as a DSM model. The columns contain the value attributes with their associated metrics. The size of the map will depend on the level of detail to which the PD process is decomposed. A balance will have to be struck between the desire to model in detail and the obvious possibility of the map becoming intractably large. In addition, it should be noted that Browning used a similar procedure to map performance metrics to attributes. (Browning, 1998)

	Pr. #	Value Attributes & Metrics															
		Shedule				Cost				Performance				---			
		A	B	C	...	A	B	C	...	...	...	...	...	...	...	...	...
Activities & Information	A1																
	I1																
	A2																
	I2																

Figure 5: The Value - Activity Map for a Given Project

There are a variety of benefits to this approach. Simply comparing the boxes where a relationship exists to the "white space" in the matrix will graphically illustrate how value is evolved throughout a PD process. If several projects are analyzed, then a global look will capture *best practices*. The time and location that specific types of value are introduced may differ between different projects. Successful projects may illustrate a successful approach of introducing value. Another benefit will be the integration of the matrix into a systems dynamics model. The matrix will directly correlate with the relationships used in the model, and the system dynamics model should then contain an accurate portrayal of the PD process. The model could then be analyzed for optimization and sensitivity. A simple modification would combine the value attributes into a single value metric. This will produce a chart that shows the increase of value with time.

5.0 Key Problems and Questions

> Customer-based measures are important [direct measures of customer value], but they must be translated into measures of what the company must do internally to meet its customers' expectations….Managers need to focus on those critical internal operations that enable them to satisfy customer needs….Managers need to decompose overall cycle time, quality, product and cost measures to local levels. (Kaplan & Norton, 1992)

The above statement precisely addresses the central issue with product development models, namely the inability to capture value creation on a local level. For example, the current DSM models do an inadequate job of determining the performance value because they either ignore accumulation of product information or reduce it to a "performance level", a single subjective number. Since performance is a critical part of the entire set of information associated with a project, the DSM models do not satisfy the above need.

Another problem is that product performance and risk are extremely difficult to evaluate early in a design process and their evolution is difficult to forecast. (Browning, 1999) Performance and risk have been identified as key attributes of value. Therefore, their difficult incorporation has been problematic for creating an accurate model. Even if one is to assume that the attributes listed earlier could be properly modeled, there are still other more complex situations. For example, what is the value of a failed project? It may not be zero, as most structured methods would suggest, due to significant amount of latent knowledge that has been created. The answers to these questions are rarely found in models, yet they would be quite valuable for setting up an optimal PD process.

From this discussion, five primary questions appear:

- What are the primary attributes of lifecycle value within PD?
- How can one model the creation of value in a specific PD process?
- Can a useful methodology be developed to quantify value in PD processes?
- What are the tools necessary for application?
- What PD metrics will be integrated with the necessary tools?

6.0 Research Design

The previous questions indicate an initial research direction to pursue with the first step to determine the primary attributes of value. The proposal below uses *value-activity maps* to emphasize a technique of mapping value to specific activities and information. This method proceeds directly to a methodology that will hopefully result in useful PD tools.

Collection of Value Attributes and Activities *(completion by September, 2000)*

Research emphasis will initially be placed on gathering information from industry sites. Initial attention will be paid to projects where the PD process is reasonably well understood; processes that have already been examined by leaning exercises would be ideal. Information that will serve as the foundation for defining value within product development will be collected. It will consist of three main types: value definitions and uses, value attributes, and typical PD activities and information. Both past projects and current projects will be studied, and metrics on their relative success will be recorded. An estimated five to ten sites will be visited to examine a number of specific projects. Attempts will be made to construct *value–activity maps* from the data collected. These attempts will serve to validate and improve the methodology. The maps will be examined to evaluate the relationship between the primary value attributes found and the PD activities that they are most closely associated to. It is hoped the maps will illuminate the relationship of value per project and also across projects. Finally, the overall success of the projects will be correlated with the nature of their value–activity maps.

Development of Value – Activity Methodology *(completion by October, 2000)*

Once the value–activity maps have been finished, the next phase will be to develop concrete associations between specific types of values and activities across projects. The basis of this will be the patterns of information that the maps illustrate. For example, clear markers should appear to show what types of value are captured during what periods of development. This will vary across projects and will additionally be recognized as contributing to the success or failure of a project.

Testing and Refinement of the Methodology *(completion by January, 2001)*

Following the introduction of a methodology, the third phase of research will be the testing and refinement of the methodology. To successfully prove its potential, it will need to be used in new project studies. Ideally, a few additional projects will be studied under these circumstances.

Tool Development *(to be done in parallel with the above task, completion by March, 2001)*

The value-activity map methodology provides a framework for assessing the value of individual activities in PD. This framework can be combined with a PD process analysis tool such as DSM modeling to extend the capabilities of the tool to include the consideration of value when improving PD processes. In addition, the information captured in the value-activity maps can be directly used to provide the necessary input to such a model. This task will select an appropriate tool (DSM is anticipated), incorporate value assessment, and use collected case study data to run sample problems.

Present Findings at a Conference *(paper due by April, 2001)*

At this stage, the results should be appropriate for the International Council on Systems Engineering (INCOSE) July 2001conference.

Completion of the PD Tool and Submittal of Thesis *(completion by June, 2001)*

The product development tool and thesis will be completed at the end of the academic term in June.

7.0 Summary

"What is value in product development?" is the key question of this paper. The answer is critical to the creation of *lean* in product development. By knowing how much value is added by PD activities, decisions can be more rationally made about how to allocate resources, such as time and money. Moreover, activities can be better classified as non-value added. This paper presents the framework for pursuing the answer to the proposed question, including:

- A brief overview of value
- A list of value attributes
- The five models that have been recently proposed to capture value
- The current problems and questions
- The research design (involving extensive collaboration with industry)

The research design aims for the development of two primary deliverables: a methodology to guide the incorporation of value, and a product development tool that will allow direct application.

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Appendix A – Attributes of Value

Information FFFT (McManus, 1999)

- Form
- Fit
- Function
- Timeliness

Enhanced DSM Modeling (Browning, 1998)

- Cost
- Schedule
- Performance
- Risk

PD Customer Value Model (Slack, 1999)

- Functional and performance properties
- Degree of excellence (level of defects)
- Development of program costs
- Acquisition costs
- Operating, support, and retirement costs
- Product lead time
- Product development time

Life-Cycle Value (Walton, 2000)

- Mission effectiveness and performance
- Scheduling
- Sustainability
- Affordability

General Attributes

- Knowledge
- Effectiveness
- Technical performance
- Amount
- Pertinence
- Price
- Life-cycle cost
- Delivery timing
- Reliability
- Accessibility
- Maintainability
- Suitability
- Functionality
- Manufacturability
- Operability

Appendix B – PD Value Methods and Tools

Economic Value Added Accounting Model (Higgins, 1998)

The *Economic Value Added Function* has existed in similar forms for several decades and is well used in other industries. It states that a company only creates value for its shareholders when its operating income exceeds the cost of capital employed. Higgins defines EVA as follows:

$$EVA = EBIT * (1 - TaxRate) - Kw * C$$

Where: $EBIT * (1 - TaxRate)$ = the firms after-tax operating income
Kw = its weighted-average cost of capital
C = the capital employed by the firm (creditors and owners investment)

In essence, this method looks at the actual profit of each activity. Unfortunately, it is usually very difficult to determine the operating income and operating cost before the conclusion of a product. Nevertheless, a number of processes have actually had to do this in order to justify changes in their PD process; that is, the employees must show a cost savings to change PD methods.

PD Customer Value Model (Slack, 1998)

The second method, *Customer Utility and Risk Function*, has existed for nearly ten years. It uses a systems dynamics approach, for which Slack expands on the theory of Shillito and DeMarle. They proposed that value is defined as being directly proportional to the product of the need for an object (or service) and the ability of this object to satisfy this need, and it is inversely proportional to the cost of the product or service. (Shillito and DeMarle, 1992) Slack further developed the definition by stating that:

> Value is a measurement of the worth of a specific product or service by a customer, and is a function of
> (1) The product's usefulness in satisfying a customer need
> (2) The relative importance of the need being satisfied
> (3) The availability of the product relative to when it is needed
> (4) The cost of ownership to the customer. (Slack, 1998)

Which Slack expressed as:

$$CustomerValue = \frac{\sum \left[N \times (1 - R) \right] \times f(t)}{C}$$

Where: N = the importance of the need for the product or service. The value of N is fully determined by the customer.
R = risk, the probability of a specific product not meeting a specific customer requirement.
$f(t)$ = the availability of the product or service to the customer, relative to the customer need date.

C = the cost of ownership, is a function of product and service attributes as well as the efficiency of the product development process.

Intrinsic in this equation, are the seven value attributes that were mentioned in the Appendix A. These attributes are components of R, f(t), and C. Once all of the individual product characteristics are summed, a customer value is developed. This customer value is relative to a range of values for a given product.

Enhanced DSM Modeling (Browning, 1998)

This model consists of the doctoral thesis of Tyson Browning, in which he evaluates a number of different PD processes. It is primarily based on the idea that information decreases risk and measures value. In other words, information is valuable if it decreases the risk that the product will be something other than what it is supposed to be. Trying, analyzing, evaluating, testing, experimenting, demonstrating, and validating create valuable information. (Reinertsen, 1998) Thus, this model uses the DSM structure from Eppinger; integrates cost, schedule, and performance; and iterates to produce a given level of risk (see Figure 6). Though superficially simplistic, this model contains a fair degree of complexity. For that reason, it has been able to handle several complex PD tasks.

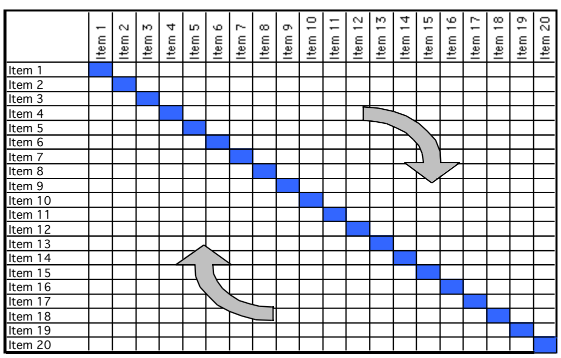

Figure 6: Enhanced Design Structure Matrix (Browning, 1998)

Risk Value Method (Browning, 1998)

In this more recent method by Browning, there is a greater emphasis on measuring value through reducing risk. Browning states that during PD, activities contribute value by creating information that increases certainty about the ability of the design to satisfy requirements. (Browning, 1999) Deyst has similarly stated that successful PD is the procedure by which uncertainties about product parameters are sufficiently reduced in a planned and systematic way. Thus, studies, tests, syntheses, or other PD activities are considered to be of this nature in that they all serve to reduce uncertainty. (Deyst, 2000)

Based on understanding overall product performance risk and its components, the *risk value method* integrates several concepts and methods such as *composite performance measures* (CPMs), customer preferences, *technical performance measures* (TPMs), risk waterfall charts, and uncertainty. (Browning, 1999) These items are captured in the following two figures.

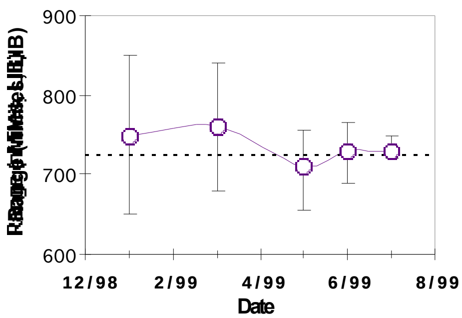

Figure 7: Example TPM Tracking Chart (Browning, 1999)

Figure 7 is an example of a TPM tracking chart. Essentially, as the error bars decrease in size, the value increases. If these measures are grouped together, they can provide *composite performance measures* (CPMs), which are similarly able to provide overall value.

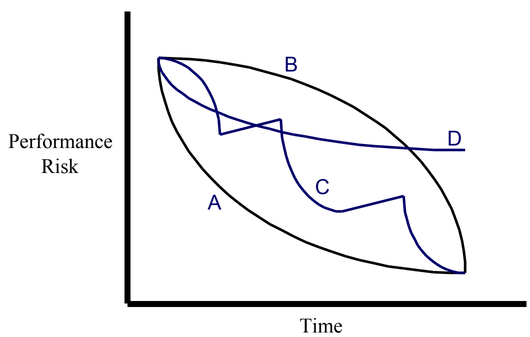

Figure 8: Perf. Risk Reduction Profiles (Browning, 1999)

In Figure 8, a graph illustrates various risk reduction profiles. Actual PD processes probably tend to resemble C. In which case, the method for optimizing the process would be to focus on the areas where risk is flat, or even increases. One additional benefit to this analysis is that each TPM emphasizes the importance of early risk reduction and maintained flexibility. (Browning, 1999)

Product Development Model (Deyst, 2000)

The final model is one that has been recently proposed by Deyst. It is a theoretical model that pursues Browning's model into a more abstract range. Deyst states that the three high level measures of product development processes, (i.e. product performance, cost, and schedule) are all embodied in the *risk value model*. For that reason, the value of each activity can be quantified by the effect that activity has on increasing the joint probability that the cost, schedule, and performance parameter goals will be achieved. (Deyst, 2000) These ideas are developed in vector space and analyzed using techniques of applied mathematics.