A Value-Centered Model of Product Design, Development and Delivery[1]

Srikanth Kannapan
Xerox Corporation
Design Research Institute
Cornell University
Ithaca, NY 14853

S. Desa
Sibley School of Mechanical and Aerospace Engineering
Cornell University
Ithaca, NY 14853

ABSTRACT

A *value-centered* model of product design, development and delivery (PD^3) can enable the proper assessment and allocation of resources in order to maximize the value of the product. To develop such a model, a two-dimensional grid that unifies the function and process elements of PD^3 is described. The grid leads to a rational definition of enterprise resources. Then, useful attributes - strength, importance, cost - of a resource are defined, and used to develop the notion of resource value. The determination of the resource attributes, including value, is illustrated by an elementary example.

Motivation: The success of technological enterprises in competitive environments crucially depends on the productivity of *product design, development and delivery* (PD^3). Better alignment between the results of engineering design research and the needs of PD^3 in industrial practice can potentially maximize both the value of research effort and productivity of PD^3.

Needs: In order to properly understand how design research results fit together and impact practice, it is necessary to stand back, review and comprehend product design, development, and delivery (PD^3) within the context of a technological enterprise. As a step in this direction, what is required is a simple generic model that is capable of capturing the essence and richness of product design, development, and delivery in real enterprises. This model must present an integrated view of the enterprise that permits assessment of PD^3 productivity.

Objectives: From the aforementioned standpoint, the paper has the following specific objectives:

1) Distill the key elements of product design, development and delivery (PD^3).

2) Structure PD^3 into a simple *resource* model that enables a technological enterprise to be viewed in an integrated manner.

3) Define key attributes of resources that determine the "success" of PD^3 in an enterprise: strength, importance, cost, and value.

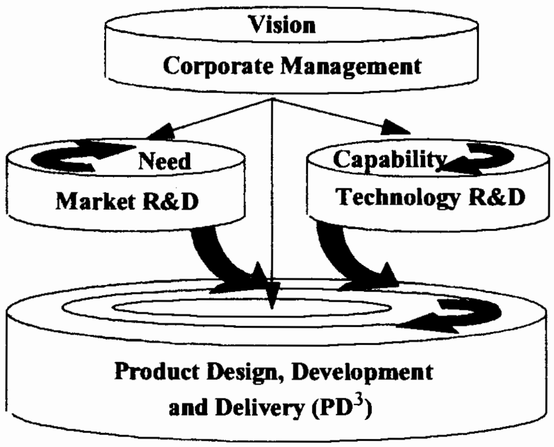
The *central idea* of the resource model is that a value-centered view of product design, development and delivery can be simply represented as a two dimensional *grid*, each dimension of the grid containing a group of related elements that are *invariant* with respect to the specific nature of the enterprise. This grid forms the basis for assessment of strength, importance, cost and value of the resources. Value assessment can then be used to optimally allocate investments to maximize the productivity of PD^3.

Paper Format: In order to enable quick reading and assimilation, this paper is deliberately presented in a sequence of interconnected frames with a central diagram and sufficient but limited explanatory text. The text (on most pages) is in two parts: a "story line" in italics that enables a quick "reading" of the diagram, and text explanations and elaborations in bulletized form.

---

[1] The order of author names is arbitrary.

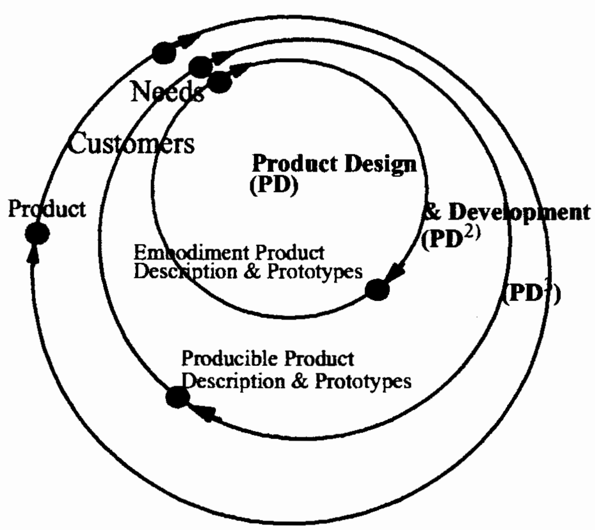
Setting the Context: The Enterprise



PD^3 is positioned in an enterprise that includes corporate management, market research and development, and technology research and development. Cycles of activity in Market R&D and Technology R&D feed into PD^3.

- It is important to first establish the context of PD^3 within the overall enterprise wherein current and anticipated market needs are satisfied by delivery of engineered products.
- For our purposes, the overall enterprise is decomposed into four major functional components: corporate management (CM), market research and development (MR&D), technology research and development (TR&D), and, of course, PD^3.
- CM provides the overall driving force by setting direction and vision for the future of an enterprise based on an assessment of internal strengths and potential, and external factors of markets and competition. It also directs and allocates resources to the other functions (thin arrows in figure).
- MR&D is the driving force that essentially determines, assesses, and influences customer needs within the context of the marketplace, and then translates these needs into a market opportunity for the enterprise.
- TR&D is the driving force that develops new or improved technological capabilities to potentially meet market opportunity.

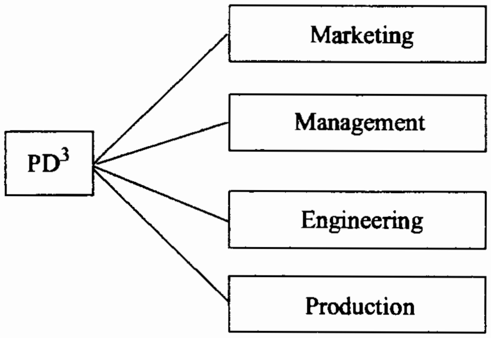
Setting the Context: PD^3



Three embedded cycles of activity or work flow in an enterprise characterize the product design, development and delivery of products to markets.

- PD^3 can be conveniently described as three cycles of activity or work flow embedded one inside the other: Product Design, Product Design and Development, and Product Design, Development and Delivery.
  - Product Design, Development and Delivery (PD^3): The outermost cycle transforms market needs to a product delivered to the market.
  - Product Design and Development (PD^2): The middle cycle is embedded in PD^3 and transforms market needs to producible product descriptions and producible prototypes.
  - Product Design (PD): The innermost cycle is embedded in PD^2 and transforms market needs to embodiment descriptions (detailed descriptions of an artifact) and prototypes.
- We note that the "Customers" and their "Needs" in each cycle may not be identical.
- Only within the entire PD^3 context, which includes all the resources of PD and PD^2, can one identify function and process invariants, and rationally evaluate the resources that determine the success of the enterprise.

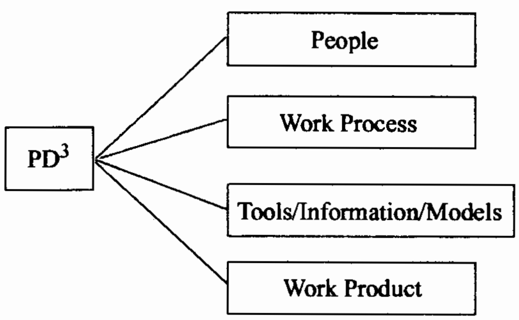
Invariants in the Function Dimension



The function invariants constitute the essential elements of a functional decomposition of PD^3.

- Function invariants are the essential elements that are always present in a standard and natural functional decomposition of PD^3 in every technological enterprise.
- Each of the function invariants correspond to well defined missions of the enterprise, and involve several professional disciplines.
- The function invariants are as follows:
  - Management: organize and supervise PD^3 with the objective of making a profit. This function includes finance, legal, human resources, and other administrative functions.
  - Marketing: continuously monitor market needs and demands, and ultimately sell the product to customers. This includes advertising, sales, customer support and service.
  - Engineering: design and develop the product from need definition to producible prototypes. This includes design engineering, prototyping, and manufacturing engineering.
  - Production: planning, executing and controlling the process of creating products on a large scale from producible prototypes. This includes inventory control, plant engineering, operations planning and control, inspection and quality management, and packaging.

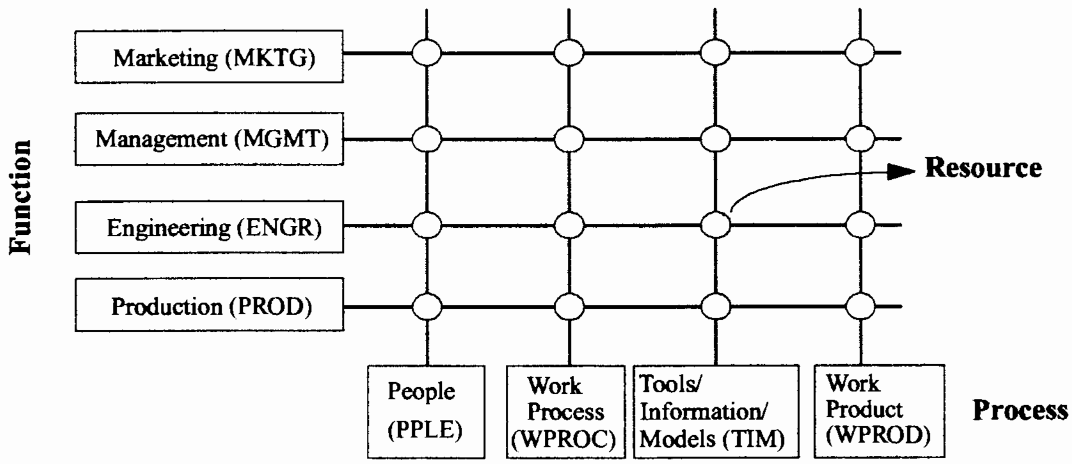
Invariants in the Process Dimension



The process invariants can be regarded as participants in the following flow: people engage in a work process using tools, information and models to create a work product.

- Process invariants are the essential elements that are always present in a flow decomposition of PD^3 in every technological enterprise.
- The process invariants can be regarded as participants in the following flow: people engage in a work process using tools, information and models to create a work product. The process invariants are as follows:
  - People: education, personality, experience, work style, etc., that individuals bring to the enterprise.
  - Work process: task and job content, information flows, task dependencies, etc., that describe the actual activities involved in realization of the work product.
  - Tools/Information/Models: Hardware, firmware, software and knowledge that are part of the infrastructure that facilitates the work process.
  - Work product: Models, plans, and prototypes that are outputs of the flow, and that span a spectrum of representations from abstract to concrete.

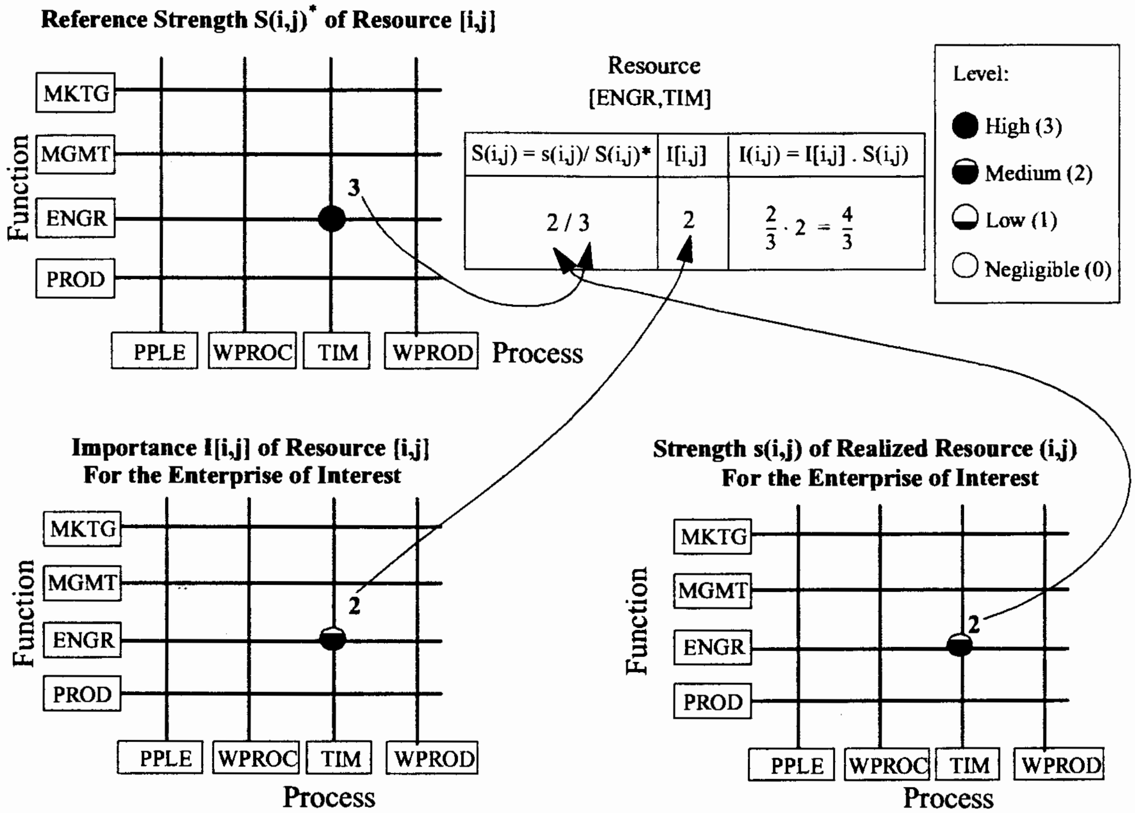
PD³ Resource Grid



Function invariants and Process invariants of the PD³ can be combined to create a grid containing 16 resources.

- Each of the function invariants (management, marketing, engineering, and production) requires process invariants (people, process, information, models, tools, and work product) to support that function.
- The pairing of a function invariant i and a process invariant j will be called a *resource* and denoted by [i,j]. For example, [ENGR, TIM] denotes the resource obtained by pairing the "Engineering" function invariant with the "Tools/Information/ Models" process invariant.
- All possible resources, obtained by pairing of function and process invariants, are conveniently represented by a two-dimensional *grid* that provides a basis for an integrated view of all the resources that underlie PD³.
- The resources can be regarded as the assets of the enterprise that collectively provide the means to achieve the goals of PD³. Examples of different resources are as follows:
  - People in different function invariants are distinguished by their training, expertise, experience etc. in those specific functions.
  - Work processes are specialized according to function (as well as by other dimensions). For example, work processes of production involve acquisition of materials, material handling and processes, inspection and quality control. In contrast, work processes in engineering involve specification development, design of product and manufacturing process, and prototyping.
  - Tools, information and models are distinguished by the type of function they support. For example, management tools including scheduling and work flow tools; marketing tools include customer surveys and focus group interviews; engineering tools include geometric modeling and finite element tools; production tools including machining centers and plant equipment.
  - Work products for management functions include resource allocation, plans, product strategy, and team development. In contrast, for marketing, work products are customer needs and preferences, market analyses, etc. Engineering work products are product embodiment and manufacturing process plans and prototypes. Production work products are products that are deliverable to markets.
- *Strength*, *importance*, *cost* and *value* are four useful attributes of a resource (Desa and Kannapan) (Shillito and De Marle). To see this more clearly, consider the following simplified example. In the heyday of the mainframe computer industry, the strength of the resource R necessary to produce these machines was aligned with the high importance of R to profitability. Hence, R was of high value to an enterprise within the industry even though it incurred significant cost (or investment). With the advent of workstations, while R was still strong, its importance diminished substantially, while still incurring significant cost, resulting in a lower value of R to the enterprise and subsequent losses. A complementary observation can be made about the growth of the desktop computer industry.

Strength and Importance of a Resource



The importance of a resource and the strength of its realization can be assessed and combined to compute the realized importance of the resource.

- We refine the concepts of *Strength* and *Importance* and formulate their inter-relationships.
- We must first clearly distinguish between the realization of a resource, denoted by (i,j), and the resource [i,j] itself. For example, a potential realization of the resource [ENGR, TIM] might be the following set of well-known tools: ANSYS, MATLAB, ProEngineer, ADAMS.
- Each realized resource (i,j) has a associated *Strength*, S(i,j), that is a measure of its capability in terms of performance, reliability, etc. Strength is an attribute of *realized* resources. We use a scale of measurement from Negligible (0) to High (4).
- Each resource [i,j] has an *Importance*, I[i,j], that measures how essential it is to fulfilling the goals and vision of the enterprise. We use a scale of measurement similar to that of Strength.
- Even though a realized resource may have a high Strength, the resource itself may have a low Importance with respect to the goals of the enterprise.

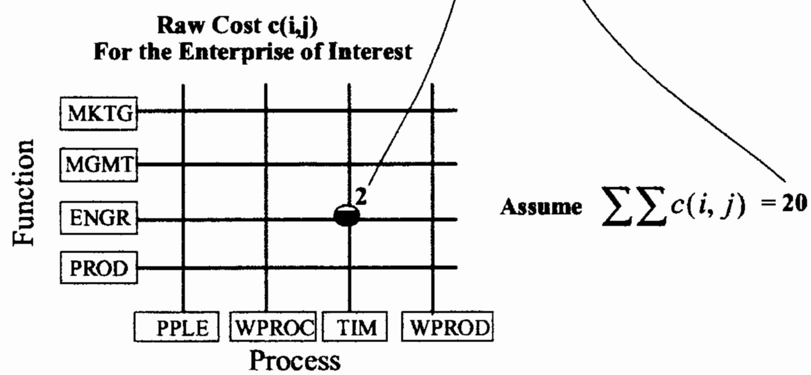
To capture this interaction, we define the *Realized Importance*, I(i,j), of the resource [i,j] as a function of both the Importance, I[i,j], of the resource [i,j], and the Strength, S(i,j) of (i,j). In general, the realized Importance would be a complex function of the form:

$$I(i, j) = f_{i,j}(S(k, l), I[k, l]; \text{forall} k, l); \text{forall} i, j$$

- The Strength of a resource, S(i,j), is obtained by measuring a "raw" strength s(i,j) with respect to a reference Strength $S(i,j)^*$. The reference Strength may be chosen, for example, to reflect the "best practices" of enterprises within an appropriate context of an industry or region.
- To illustrate these ideas, we have graphically shown (above) how S(i,j) and I(i,j) might be computed for a specific resource of an enterprise of interest. The form of the function $f_{i,j}$ has been simplified for purposes of illustration.

Value of a Resource

	S(i,j)	I[i,j]	I(i,j)	c(i,j)	C(i,j)	V(i,j) = I(i,j) / C(i,j)
Resource ENGR,TIM	2 / 3	2	$\frac{2}{3} \cdot 2 = \frac{4}{3}$	2	$\frac{2}{20} = 0.2$	$\frac{4}{3}/0.2 = \frac{20}{3}$



The value of a resource of a typical technological enterprise can be assessed from the realized importance and cost of each resource.

- We associate *"Cost"* to a realized resource, and relate it to the Realized Importance of the resource in order to assess the *Value* of the realized resource. (The quotes around Cost simply imply that cost need not be limited to economic cost alone.)
- Even though a realized resource may have a high Importance it may involve an exorbitant *"Cost"*, thus making it of questionable value to the success of the enterprise. Therefore, the Realized Importance I(i,j), of a resource must be suitably scaled with respect to "Cost", C(i,j), to obtain the Value, V(i,j), of the realized resource. In general, the *Value* of a realized resource would be a complex function of the form:

$$V(i,j) = v_{i,j}(I(k,l), C(k,l); \text{for all } k,l); \text{for all } i,j$$

- The Cost of a realized resource is obtained by measuring a "raw" cost c(i,j) and normalizing it with respect to the total "raw" costs of all resources of the enterprise:

$$C(i,j) = \frac{c(i,j)}{\sum\sum c(i,j)}$$

- To illustrate these ideas, we have graphically shown (above) how Value, V(i,j), for a realized resource may be computed for an enterprise of interest, from I(i,j), and the Cost, C(i,j), of the realized resource. The form of the function v(i,j) has been simplified for purposes of illustration.
- To be useful, the form of the function v(i,j) must be carefully chosen to reflect the goals and vision of the enterprise. Some useful properties of the function are intuitively obvious. For example, one would expect a high Value arising from a high Strength, high Realized Importance, and a low Cost. Other properties of the function are more subtle. For example, how much Value is there to a high Strength, low Importance resource with a low Cost? In such cases, the relative Value of the resources may also provide useful information.
- One important use of Value assessment is the determination of *gaps* in resources (Desa and Kannapan). To this end, one may assess the *Strength gap* between realized Strength, S(i,j), and Reference Strength, $S(i,j)^*$ through appropriate benchmarking. Then, one may determine the *Importance gaps* (i.e., the importance of closing the Strength gap) by appropriate combination of the Strength gap with resource Importance. Based on this assessment, one can then allocate/re-allocate investments among the resources to minimize gaps, thereby maximizing the Value of resources with respect to the goals and vision of the enterprise.

Related Work

(Hubka and Eder) develop an abstract model of technical systems recognizing the interaction of human systems with technical systems, information systems and management systems. But the top level model almost immediately focuses on technical issues of design theory. (Taylor and Henderson) provide a three dimensional (cube) range representation with elaboration of the abstraction and complexity of the engineering work product. (Tomiyama et al) describe a richer three dimensional (cube) representation of the product model, design process, and design activity somewhat paralleling the elaborations of the engineering work process and product of our model. We have integrated these components into a broader framework that includes the people, marketing and production components of PD^3. This permits a more comprehensive and integrated assessment of the value of all the resources constituting PD^3, thereby providing a rational basis for resource allocation to potentially improve the productivity of an enterprise.

Concluding Remarks

We presented a preliminary model of an integrated value centered view of PD^3. The model represented function invariants and process invariants of PD^3 in a two dimensional resource grid containing 16 vital resources. By associating strength and importance to each resource of the grid, and defining a suitable valuation function, a value can be assigned to each resource.

The construction and use of the resource grid to quantitatively assess the strength and importance of each resource in PD^3 practice is illustrated in (Desa and Kannapan). We are now further testing and refining the framework of this research through active engagement with technological enterprises.

As more resolution is incorporated into the grid, it will be possible not only to see where and how a tool or method fits into the overall scheme of PD^3 but also to clearly understand it value in that scheme. The detailed elaboration of the grid should also provide a rational basis for attempting to resolve typical trade-off conflicts that arise in allocating resources in actual product design, development, and delivery practice. For example, "Should capital be invested in a rapid prototyping capability or a sophisticated solid modeling package?"

References

Desa, S. and S. Kannapan, The Fast Resource Evaluation Grid, Proceedings ASME Design Theory and Methodology Conference, Boston, pp. 571-583, 1995.

Hubka, V., W. Eder, *Theory of Technical Systems,* Springer Verlag, 1984.

Shillito, M. L., D. J. De Marle, *Value: Its Measurement, Design, and Management*, John Wiley, 1992.

Taylor, L. E., Henderson, "The Roles of Features and Abstractions in Mechanical Design", *ASME Design Theory and Methodology Conference,* 1994, pp. 131-140.

Tomiyama, T., D. Xue, H. Yoshikawa, "Developing an Intelligent CAD System", *April 1993- March 1994, Publications report*, University of Tokyo.