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Design Integrating and Process in Engineering to Reduce Production Cycle Time in Development of Product

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Abstract: ***Product development teams employ much method's and tool's as they design, test, and manufacturing a new (or improve) product. It is important that the product development team understand how their design and decisions affect manufacture system performances. Having this feedback early in the design processes avoids rework loop's needed to solve problems of manufacturing capacity or cycle time. The team can incorporate this information and associated costs into a design decision problem aimed at choosing the best possible product design. It is clear that the product design, which requires a specific set of manufacturing operations, has a huge impact on the manufacturing cycle time. Reducing manufacturing cycle time has many benefits, including but not limited to lower inventory, reduced costs, improved product quality, faster response to customer orders, increased flexibility and a reduced time-to-market. Design for Production (DFP) refers to methods that evaluate a product design by comparing its manufacturing requirements to available capacity and estimating manufacturing cycle time. DFP can be used to design the product in a way that decreases required capacity, reduces the manufacturing cycle time, or otherwise simplifies production. To understand how a product design impacts manufacturing system performance, this research develops analytical (not simulation) models to quantify how introducing a new product increases congestion in the manufacturing system. It presents approaches that use this information intelligently and make suggestions on product redesign and manufacturing system improvements.***

Keywords: Design for Manufacture, Design for Production, Queuing, Product Design, Product Development, Manufacturing Cycle Time

1. Introduction

Product variety is continuously increasing in today's world market. In such an environment, the required philosophy for a company's survival is the constant replacement of old products with new ones, improved variations of current products and completely new products. Product development has thus become a very crucial aspect of corporate competition. The design and development of a product is a complex process involving numerous considerations such as market analysis, requirements definition, conceptual design, detailed design, materials and process selection, optimization, process control, testing and evaluation, costing, manufacturing and production, and marketing.

2. Literature Review

1. There is a loss of abstract and implied information as the product passes from one phase to another. Each phase receives a different interpretation of the customer requirements. Thus there exists some risk that the final product will not completely satisfy the customer requirements.
2. There is significant loss of time and effort in returning the designs to the design phase from the post-design phases to correct any mistakes or shortcomings discovered in these phases.
3. By finalizing the designs in the design phase, the designer utilizes only his knowledge of the design scenario. The knowledge of the post-design operations such as manufacturing cannot be incorporated into the designs. As a result, opportunities for product optimization over all the processes are missed due to the lack of effective communication between the two operations.

Product development is a complicated process starting with a detailed target assessment, comprising an extensive research of the current market scenario, available products and understanding product customer requirements. This is followed by various steps from defining product specifications based on these requirements to packaging and dispatching the final product to its final destination. An effective product development process *has a number of benefits* such as:

1. Increased Revenue

(a) Increased product life-cycle revenue
(b) Increased market penetration as a result of being first to market
(c) Success in time-sensitive markets
(d) More successful products

2. Improved product development productivity
(a) Shorter development cycle times
(b) Less development waste
(c) Better resource utilization
(d) Better ability to attract and retain technical talent

3. Operational Efficiencies

(a) Design for manufacturability, serviceability and other characteristics
(b) Higher-quality products
(c) Lower engineering change order costs
(d) Improved predictability of launch

3. Problem Description

The Design for X (DFX) approach to designing a product aims to alleviate some of these problems by designing the product while keeping under consideration the performance of the design during other phases of its life cycle. The DFX methodology evaluates product designs along with associated life cycle requirements such as those associated with manufacturability, schedulability, recyclability, dis-assemblability, producability and so on, to determine the product performance during these phases. It attempts to identify possible problems and shortcomings in the designs. DFX searches for solutions to these problems, proposing changes to the product or processes and prioritizes these ideas based on evaluation of the effects of these suggestions on the anticipated performance of the product, thereby avoiding redesigns later in the process.

This research studies situation where a new product, which may be an improvement of an existing design or a completely different product, will be introduced into a given manufacturing system already processing a set of products. This dissertation presents models for understanding how introducing a new product into an existing manufacturing system affects the performance of the manufacturing system, understanding how changes in the product design affect manufacturing system performance, and understanding the economic implications of reducing manufacturing cycle time.

Design for manufacturing methodologies is used to improve a product's manufacturability. Three important issues dominate the discussion of design for manufacturing (DFM), also called design for manufacturability.

- Can the manufacturing process feasibly fabricate the specified product design?
- How much time does the manufacturing operation require?
- How much does the operation cost?

(For discussion, this body of work uses the term manufacturing to describe both fabrication and assembly, and includes design for assembly as part of design for manufacturing.)

4. Experimental Part

Researchers have developed several different approaches to evaluate manufacturability of a given design. Existing approaches can be classified roughly as follows:

1. Direct or rule-based approaches evaluate manufacturability from direct inspection of the design description; design characteristics that improve or degrade the manufacturability are represented as rules, which are applied to a given design in order to estimate its manufacturability. Most existing approaches are of this type. Direct approaches do not involve planning, estimation, or simulation of the manufacturing processes involved in the realization of the design.
2. Indirect or plan-based approaches do a much more detailed analysis; they proceed by generating a manufacturing plan and examine the plan according to criteria such as cost and processing time. If there is more than one possible plan, then the most promising plan may be used for analyzing manufacturability, and some plan-based systems generate and evaluate multiple plans. The plan-based approach involves reasoning about the processes involved in the product's manufacture.

The direct approach appears to be more useful in domains such as near-net shape manufacturing, and less suitable for machined or electro-mechanical components, where interactions among manufacturing operations make it difficult to determine the manufacturability of a design directly from the design description. In order to calculate realistic manufacturability ratings for these latter cases, most of the rule-based approaches would require large sets of rules.

DFM has been very useful for reducing the unit manufacturing cost of many products, and successful product development processes require tools like DFM.

Design for Time-to-Market

Time-to-Market is the time from product conceptualization to market introduction. Short time-to-market means that a product reaches the market early, which in turn provides the corporate organization with the opportunity to enter the market during the growth phase of the product life-cycle, when the profit margins and potential for growth are higher and the product has a longer market life.

Some of the advantages of achieving the objective as:

1. Reduced time-to-market implies reduced product development time, which in turn reduces the development costs since less funds are allocated to late engineering changes, rework and delays due to bureaucratic tarries.
2. The design related cost reductions are applied early in the development cycle.
3. As a consequence of being the first to introduce the product into the market, the company can be assured of an increased market share and the distribution and retail network confidence. This in turn increases the life-cycle of the product. Figure 2.5 compares the life cycles of products under normal and reduced development times.
4. Typical product delays that are associated with the introduction of a new product are reduced due to the reduced introduction time of the product into the market. These may include unforeseen changes in the market conditions necessitating design changes and changes in the development team members and the competence of these members.

Design Refinement

One of the important components of the concurrent engineering and DFX philosophies is design modification or design refinement. The aim is to modify the designs during the design phase itself before indulging in more expensive and resource intensive processes like manufacturing, while anticipating the problems that may be encountered in these stages. In order to achieve this, the redesign systems may act in a feed-forward capacity (design guidance) or in a feedback mode involving completed product design.

Product life-cycle curves with normal and faster time-to-market

Depending on the complexity, technical or otherwise, the process of introducing the new product may be very complex and identifies the following target areas for strategic initiatives by the product introduction project management in order that this complexity may be minimized as much as possible:

Types of Manufacturing Cycle Times

At this point two types of manufacturing cycle times are of interest to DFP approaches. First, consider a manufacturing system that will complete a large number of work orders of the new product. The size of these work orders may be fixed or have some variability. In this setting, the product development team will need to estimate the *average manufacturing cycle time* of these work orders. Second, consider a manufacturing system that will complete a small number of work orders of the new product. The product development team needs to determine the *total manufacturing cycle time* from the time the first work order starts to the time the last work order finishes. This will apply to an engineer-to-order or make-to order manufacturer that wants to respond to a particular customer request and needs to estimate when the complete customer order (which may be one or more work orders) will be done. Note that this is similar to due date determination methodologies.

Models of Steady State Performance

This section describes types of models that can be used to estimate average manufacturing cycle time in a manufacturing system in steady-state. That is, the product mix, including the desired throughput of the new product, does not change, and the key resources of the manufacturing system are given and fixed. Most of the works referenced here consider the cycle time of a product with a simple routing, that is, the product requires a given sequence of operations.

Fixed Lead Times

In this model, completing a work order requires a fixed amount of time. This time does not depend upon the system's throughput or the available capacity. This model is the one used by material requirements planning (MRP) systems. A version of this model specifies a fixed lead time (based on past performance) for each workstation in the facility. This model is most appropriate for a facility where parts and assemblies are all very similar, and the product mix does not change very much.

Conveyor Model

This model, estimates the manufacturing cycle time W for a job released to a CONWIP line that already has n jobs waiting to start processing. T_P is the minimum practical lead time, and r_P is the practical production rate:

$$W = \frac{n}{rp} + \mathrm{Tp}$$

This can be applied for estimating the manufacturing cycle time W of a job with n parts that requires processing on a line that processes one part at a time.

If the line produces rP parts per time unit, and each part takes T_P time units on average to move down the line, then W is approximated as follows:

This model is also useful for estimating the total manufacturing cycle time T of a set of s jobs. If W is the average manufacturing cycle time of a job and the release rate is one job every t time units, then

$$T = (s-1)t + W$$

Overall Impact of Reducing Manufacturing Cycle Time

This chapter addresses the overall economic benefits of reducing manufacturing cycle time for a product. These benefits range from reduced inventory to improved product supply predictions. There are economic incentives associated with each of these benefits and this chapter presents models to estimate these economic benefits. These benefits can be compared to other costs or metrics that change as a result of modifying the product design. Describes how reducing the manufacturing cycle time contributes to the main goals of any manufacturing enterprise:

- Reduced costs,
- Greater revenue, and
- Higher profit

Relating Manufacturing Cycle Time to Economic Gain

Manufacturing cycle time is composed of processing times and non-processing times. The processing times depend on the manufacturing operations involved.

These are governed by the type and properties of material, and the type of workstations used. Considerable work towards reducing processing times has been conducted in DFM research. Minimizing setup times has also been the focus of many researchers.

Reducing manufacturing cycle time for a product results broadly in the following benefits:

1. Lower inventories,
2. Process improvements,
3. Product improvements, and
4. Better order fulfillment

5. Contributions

This section discusses the significant research contributions of the work reported in this dissertation.

Understanding the product design - manufacturing cycle time relation

This research has presented novel approaches to estimate the manufacturing cycle time for a product before the product designs are finalized. Manufacturing cycle time has significant economic implications and contributes to total product development time. Confirming feasibility of making the product in the present manufacturing system before the designs are released for production eliminates the need for expensive re-design efforts later in the development cycle. Having reasonably accurate estimates of the manufacturing cycle time aids the product development team in developing better products. The DFP approach gives the development team the option to modify a proposed product design using this manufacturing system performance information or compare alternatives in a set of product designs. Alternatively, the tool also presents the user with the least preferred option viz. increasing the number of resources for a highly utilized workstation.

Tools developed based on the DFP approach facilitate representation and analysis of existing as well as new products being processed in the manufacturing system. The existing product set serves as a reference against which the product development team can evaluate the new product performance.

The tools combine the manufacturing system models into a unique performance evaluation system. The system combines product design characteristics, process plans and manufacturing information to evaluate different performance attributes. The system includes an innovative scheme to identify the critically loaded resources in the system. The scheme estimates capacity addition requirements and generates suggestions to the effect. Further, the DFP tools dispense advice to the user regarding potential design modifications. A novel combination of resource utilizations, workstation cycle times, and product cycle times is used as an evaluation metric to present such redesign advice.

Quick Analysis Mechanism

The mathematical models developed to represent the product and processing parameters, though based on certain approximating assumptions, provide a mechanism to the product design team for real-time analysis of the product design performance. Previously proposed approaches employed more simplistic manufacturing system models. This research has presented an approach based on a more realistic queuing system based model for estimating product and manufacturing system parameters. These approximations used are acceptable for preliminary design analysis especially since the time taken is much lower than simulation-based procedures. The time taken for building the corresponding simulation model is much higher than for building an alytical model. The running time for the simulation models is also greater.

(Simulation can be more accurate if sufficient time is allowed and care is taken to create a valid model.)

The low analysis time requirements mean that the development team can quickly analyze multiple product design alternatives. In addition, the team can easily analyze the product and process parameters for varying product mixes, multiple order release schema and dynamic production scenarios. The models also include sensitivity analysis for the manufacturing cycle time with respect to the processing times at the various stations. This analysis can be used by the development team to better understand how their designs affect the manufacturing system performance. Though queuing network models have long been used for various analyses including representing manufacturing systems, this research effort is the first to consider the relationship between product design and a queuing network based manufacturing system and to use the queuing network parameters to suggest improvements to the product design.

Manufacturing cycle time affects product profitability

This research studied and clearly presented how reducing manufacturing cycle time for a product results in economic benefits for the manufacturer. This compilation supports the arguments for reducing manufacturing cycle time for a product. Relating manufacturing cycle time to greater profitability is a difficult but important undertaking. No comprehensive presentation for this relation previously existed.

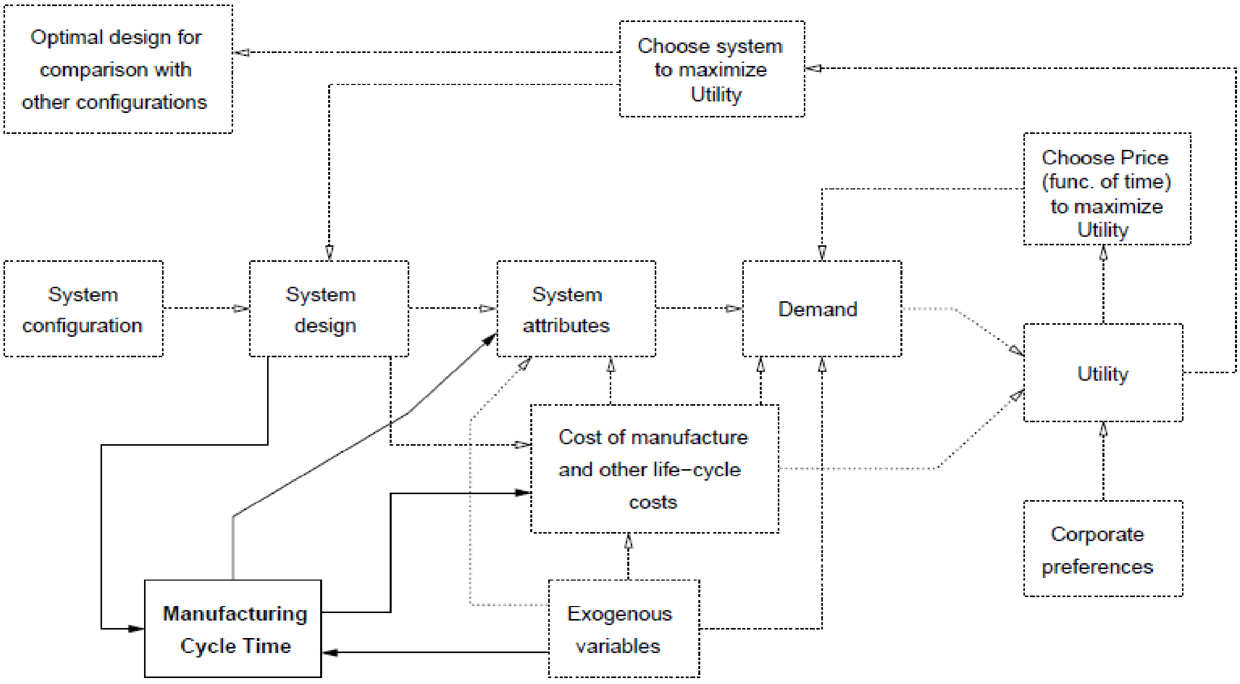
New product introduction literature and product cost analysis literature do not present comprehensive models to understand the economic implications of reducing manufacturing cycle time.

It also understands the association between process drift and the need to start more jobs to minimize shortages.

Further, the mathematical model developed to quantify the impact of reducing manufacturing cycle time on inventory holding cost, implicitly models the relationship between shortages and variability in manufacturing cycle time

Contributing to Decision-Based Design

This research studied the impact of a product design on manufacturing system performance and presented the economic impact of reducing manufacturing cycle time for a product. Overall product economics can be used to create better and more profitable products using the ideas in decision-based design.



Design For Production

Contributions of **DFP** Decision-Based Design Framework

The references to "system" in the figure will point to the product when applying the framework to product design. The purpose for the framework is to enable the assessment of a value for every design option in a design alternatives set so that options can be rationally compared and a preferred choice identified. The goal is to make a profit, considering costs and revenues associated with the product. The framework incorporates the effects of things that the designer can control (system design or product design) as well as those the designer cannot control (exogenous variables).

These exogenous variables are usually random variables and can be estimated as distributions. All aspects of the design have associated costs. Demand and revenue are functions of the price. Thus the problem translates to deciding the price for the product while maximizing product utility. Since the revenues and costs are distributed over the entire product life cycle, the decision-based design framework views the design process from a systems context.

Figure illustrates a modified version of this framework that makes explicit the role of manufacturing cycle time (indicated by the solid box and arrows in the figure) in this framework. Manufacturing cycle time is a product attribute and is affected by the product design. This was demonstrated by this research effort. Moreover, there are certain uncertainties associated with estimating the manufacturing cycle time. Some of these uncertainties were modeled here as approximations but more work needs to be done to include others. The economic impact of manufacturing cycle time and the models developed to quantify this impact can be added to the product life-cycle costs.

6. Concluding Remarks

The design for production methodology advocated throughout this dissertation has focused on analyzing the relationship between a product design and a given manufacturing system using performance metrics such as manufacturing cycle time and throughput. There exist a wide variety of products and manufacturing systems and all can benefit from the design for production methodology. The requirements for the DFP approach will vary depending on the type of product being designed and the manufacturing system characteristics.

Tools based on the DFP approach must be designed based on the specific class of target products and manufacturing systems. This in turn requires understanding specific factory or supply chain performance metrics.

The product development team must identify how different design decisions affect these performance metrics and to what extent. One design phase will have the largest impact on manufacturing system performance and should include the DFP methodology. This analysis will help the team develop and validate models that relate the critical design information for the associated design phase to these performance metrics. Identifying key product design characteristics would involve suitably decomposing the design into components and developing modular product architectures.

The development of DFP tools must also take into account the data available for the product and the manufacturing system, the effort involved in making that data accessible to the development team, and the time constraints that limit the amount of analysis that can be done.

It must be remembered, however, that the final goal for the product development team is to design a profitable product. Applying distinct, independent DFX methodologies targeting different aspects of the product life cycle would lead to potentially conflicting design improvement suggestions. Therefore, successfully applying the DFP approach requires coordination with other product design assessment measures, all of which finally contribute towards the ultimate aim of designing a more profitable product.

7. Conclusions

Clearly, product design plays a very important role in product development, significantly influencing the product life cycle, including production. It is important that the product development team understand that their design decisions affect the manufacturing system performance. Having this feedback early in the design process avoids re-work loops needed to solve problems of manufacturing capacity or cycle time. This research has classified previous DFP methods and presented a comprehensive set of models. This will help researchers and manufacturers understand the issues involved, develop better DFP tools and design more profitable products.

This phenomenon of process drifts and developed new mechanisms to model and quantify the effects of process drift in a manufacturing system. Further, it created new models for the relationships between manufacturing cycle time and process drift. Because process drift affects the throughput, these novel models show that a product design affects not only manufacturing cycle time, but also throughput.

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