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DESIGN OF THE ENGINEERING AND DESIGN DEPARTMENT OF A MANUFACTURING ORGANIZATION TO ENHANCE PRODUCTIVITY AND PROFIT: APPLICATION OF THE AXIOMATIC APPROACH TO DESIGN

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Resumen

El objetivo de este artículo es demostrar la aplicación del los conceptos de Diseño Axiomático de Nam P. Suh para diseñar el departamento de diseño de una empresa de manufactura. Se discutirá la independencia de los requisitos funcionales así como el papel del contenido de información en el contexto.

Abstract

The purpose of this work is to show the applicability of Nam P.Suh's concepts of Axiomatic Design to the Design of Manufacturing Organization. The independence of functional requirements will be discussed, as well as the role of information content in the context.

1. INTRODUCTION

Productivity and profit per period of time is a major concern of any Manufacturing business. Every company has a wide variety of goals, however, the bottom line is to provide increasing profit growth.

The author of the present work has chosen to design has chosen to use Nam P. Suh's Axiomatic Design Approach (Refer to appendix I.) to design the Engineering and Design Department of a Manufacturing Engineering Business. In order to attain greater productivity and profit the business must be designed in such a way in which all objective goals are well specified and clear. Once this is done, these goals are converted into functional requirements for the business to operate. Departments or other organizational units that represent the design parameters in the physical domain must implement these functional requirements. Finally, the individuals responsible to accomplish the tasks to reach the goals are the process variables.

Initially the author had the intent of performing an analysis of the entire organization at higher levels in the hierarchy of functional requirements and design parameters (Appendix I). However, after preliminary research, and discussion with Dr. Leonard Albano, experienced user of the axiomatic approach, it was decided to choose depth versus breadth. Dr. L. Albano, PhD from Massachusetts Institute of Technology suggested that the Axiomatic Design approach would be more meaningful if a selected portion of the Manufacturing Organization were selected to be designed in depth via the Axiomatic Approach. This suggests that the study of the whole organization should be addressed one department at a time in order to attain the desired depth.

The use of the Axiomatic approach seems somewhat simplistic and unsophisticated at the higher level of the hierarchy of functional requirements and design parameters, for those who have not gone in depth to lower levels of hierarchy. At the lower levels of the hierarchy, the methodology starts to give an outstanding level of detail and order. It defines all the main tasks to be done and focuses the designer to what is important. The key idea of this work is to illustrate with this example the power of the Axiomatic Framework. More detail can be added to the present work, but the idea has been to keep it simple and understandable. In terms of the Axiomatic Theory, the idea has been to minimize the information content, thus decreasing complexity in order to increase the probability that the reader understands the potential of the Axiomatic Approach.

JUSTIFICATION

The author is interested in the area of Profit enhancement of Manufacturing Operations. This work represents important background in order to identify the key elements in Manufacturing Business by using the Nam P. Suh's Axiomatic Design Approach, a disciplined, structured codified and systematized methodology for design (Refer to appendix I) (Suh, 1990). This will serve as background to continue further studies in performance enhancement of Manufacturing Operations.

This preliminary work with Nam P. Suh's approach will derive the functional requirements, and design parameters for the Engineering and Design Department of a Generic Manufacturing Organization, more specifically for the Design component.

The Axiomatic Design methodology will insure that every functional requirement of the organization have a physical entity (Department, the design parameter) that will accomplish it, and a person within that entity to be held accountable. The author has chosen the Product level, i.e., the mapping between functional requirements and design parameters. The mapping between design parameters and process variables, will not be discussed in depth since at this point we are more interested in the activities that must be performed to enhance profit of the company rather than who (process variable) who is going to perform the task. The beauty of the Axiomatic Theory is its consistency if properly applied. The Axiomatic theory requires that customer needs be translated into functional requirements, these requirements translated to design parameters, and ultimately to process variables.

The latter just supports management theory that requires specifying goals and persons responsible to accomplish these goals. The important aspect is how Nam Suh explains by means of the information Axiom how independence of functional requirements guarantees a good design to start.

SUMMARY OF DESIGN

This work will take the preliminary steps to describe the design activities manufacturing company that enhances productivity and profit. A Company that has very clear goals (Functional Requirements) and clearly assigned responsibilities to departments or units (design parameters) and to individuals (process variables) is an ideal. This company has set very clear tasks to all personnel so that the tasks that every individual performs are directly related to the corresponding functional requirements and design parameters. Because of the scope of this work the process variable level, i.e. personnel involved will not be discussed in depth.

Nam P. Suh states in his April 22, 1977 Version of Axiomatic Design mentions four domains of the design world. The manufacturing domain applies expressly to the manufacturing area within an organization. The present work should be continued using the manufacturing domain.

The present design entails a Department of Engineering and Design of a Manufacturing Operation. To diminish the complexity of the present preliminary work, for now the organization may be considered a closed and fix system. At this point this means that the system has to satisfy a fixed set of functional requirements at all times and whose components do not change as a function of time (Suh 1990).

THE ESSENCE OF THE AXIOMATIC DESIGN APPROACH

The main advantages of the Axiomatic Theory of Nam P. Suh can be summarized in the following manner:

1- Provides a disciplined approach to tackle design problems of varied nature. It is suitable to design a machine as well as to design an organization or just a vacation trip.

2- Provides an unbiased solution to a problem if done in the rigorous manner it is intended.

3- Forces to prioritize the functional requirements and minimize the number of them to be analyzed at a given level at one given time.

The following summary of the Axiomatic Design Approach is from (Suh 1 990). The Axiomatic Design Methodology is an attempt to provide structure and sequence to the design process. Design has been treated as an "art", and little or no attempts have been made to provide some structure to it. The most important task is to define the problem to be solved. If the methodology is to give just the benefit of focusing the designer into the most fundamental functional requirements, it is already giving the reader a valuable contribution this methodology gives us a way to increase the range of possibilities or viable alternatives to consider in solving a problem. It does not jump into a preconceived solution. If followed rigorously, it can provide a large number of acceptable good solutions to start with. The methodology provides a means to compare the good designs generated with the methodology and decide which one is better. This methodology gives us a way to increase the range of possibilities or viable alternatives to consider in solving a problem. It does not jump into a preconceived solution. If followed rigorously, it can provide a large number of acceptable good solutions to start with. The methodology provides a means to compare the good designs generated with the methodology and decide which one is better.

Dr. N, P. Suh's approach of Axiomatic Design is a first attempt to make design into a science. The idea is to incorporate principles to be followed in design just as early principles in thermodynamics developed into the complete theory. The initial stages of research were made while working at the National Science Foundation, while on an extended leave of absence from Massachusetts Institute of Technology (MIT).

Axiomatic Design allows recognizing faulty design decisions in the conceptual stages of the design process. Early enough in the design process, to make a difference in the final cost. No trial and error is involved here as in traditional design processes. Suh proposes that the methodology is applicable to a broad range of designs and effective for organizational design. The first step is to have a good problem definition. The second step is a subjective an idea creation, a synthesis process. There should be some feedback in order to improve the design. In essence, a feedback control loop is created.

THERE ARE TWO BASIC AXIOMS:

Axiom 1 the Independence Axiom: Maintain the Independence of functional requirements (FRs).

Axiom 2 the Information Axiom: minimize information content. The methodology provides an unbiased creative process with novel ideas and the analytical process based in a finite set of basic principles.

As it stands right now intuition and experience in the design field cannot be transmitted to coming generations because there is no science base to the discipline. The design axioms complement and aid the creative process in the evaluation of ideas, in order to select the best ones. Without the use of the Axioms, there is no way to distinguish the advantages of one design over another without building the system and testing it. The basic premise of the axiomatic approach is that there is a fundamental set of principles that governs good design practice. No one so far has proven the axioms invalid.

Identifying common elements present in a sample of successful design projects created the axioms.

According to Suh, the design process involves four main aspects:

1- Problem Definition, which involves the definition of functional requirements and constraints

2- Creative process of conceptualizing and devising the solution

3- Analytical process to determine whether the proposed solution is a rational solution for the problem at hand.

4- Check if the solution is consistent with the perceived needs.

According to C. Brown (WPI Professor of Design) the following algorithm can be used to proceed in the design:

1- Define the needs (Society-customer).
This must be done in a solution-neutral environment (unbiased). The needs are defined by marketing and tend to be unclear ("fuzzy").

2- Convert the customer needs into functional requirements (FRs). These are more quantifiable. And usually "verbs"

Need----FR------Design Parameter (DP)

Needs must be mapped to FRs and Marketing ideas to Engineering

3- Functional Requirements (FRs) must be prioritized. A hierarchy must be established in order to address the few main FRs. On a high level. determine de DPs at that level, and then proceed to determine the FRs and then DPs at a lower level. A zigzagging process results.

4- Makes a clear distinction between functional requirements and constraints. The functional requirements represent the structured definition of the customer needs. Functional requirements must be independent from each other; DPs do not need to be independent. However, it must be clear that a DP should only be used to address a given functional requirement. Otherwise a coupled system is present and by definition there are many other better designs that could be chosen. Constraints are bounds placed on an acceptable solution. There are input constraints, which represent a bound in size, weight, materials, and cost for example. System constraints are also present and they represent geometric shapes, capacity of machines or perhaps some fundamental principle or law of nature.

5- Design parameters (DPs) to satisfy Functional Requirements (FRs). DPs are usually nouns. Once the Functional requirements that answer the question: What is desired? In the functional domain the designer must define the design parameters that define how the matching functional requirement (goal) will be addressed. For example a bicycle; a human powered vehicle has four functional requirements: to move forward, to stop, to steer, and to support a seated human. These are the goals, or the whats? in the functional domain. For each goal (FR) of the functional domain there is a corresponding design parameter in the physical domain that addresses each goal.

Functional Requirements:

- Move forward
- To stop
- To change direction
- To support one seated human

Design Parameter (Physical)

- Power transmission mechanism

- Breaking mechanism
- Steering Mechanism
- Frame

6- Check for independence and information content. The check for independence is done in the following manner: The FRs and DPs are placed in the form FR=[A] DP where [A] is the design matrix. In order to test Axiom 1 (independence) the design matrix should be ideally a diagonal matrix. If this is so independence is guaranteed. If this is not possible, a triangular matrix form will enable independence as long as certain order of adjustment of DPs is followed. The check for information content is performed as follows. Once several designs have passed the independence test, and those uncouple ones, the ones with diagonal design matrix form are selected. At this point for example: two designs have passed the Axiom 1 test, and guarantee diagonal design matrices. The issue now is to apply Axiom 2, the information axiom, to determine which of the two good designs is better. The requirement here is that the information requirement for each design must be calculated. The design with the lower information requirement will be the best design. This is true because information is proportional to the inverse of the probability of success of a particular event. As a result the higher the probability of success, the lower the information content required developing the design. 7-Return to a lower level of FRs and repeat the same procedure (steps 1-6). This shows the zigzagging nature of the FR-DP hierarchy. First the FRs of level one are determined, then the corresponding design parameters for that level. Once this is done, descend to a 2nd level of FRs and determine their corresponding DP.

7- Return to a lower level of FRs and repeat the same procedure (steps 1-6). This shows the zigzagging nature of the FR-DP hierarchy. First the FRs of level one are determined, then the corresponding design parameters for that level. Once this is done, descend to a 2nd level of FRs and determine their corresponding DP. The Axiomatic Design Methodology will enable the designer to define the problem more precisely by focusing on a few most important Functional requirements firs, and then addressing the others. Customer requirements are usually many, and some of them are less important than others. Suh's methodology enables to map the Customer Requirements to Functional Requirements and prioritize. The main idea is to enable the designer to concentrate on fewer number of FRs at a given moment. There is a hierarchy of FRs and DPs in such a way that Suh's methodology does not leave out less important customer requirements, but rather puts them in a priority in order analyze them at the right time. The designer will choose the main FRs and will define the corresponding DPs. Then he/she will work with lower level FRs to set DPs at this level. Subsequently the designer will address one lower level of FRs and DPs and continue in this manner.

The Axiomatic approach promises to deliver a better design to start with. The way this is done is the following. First of all there are many good designs that can satisfy the given functional requirements. From the Axiomatic standpoint, the functional requirements are selected in such a way so that they are independent from each other and that each DP does not influence more than one FR. If this is obtained the design matrix is a diagonal matrix and there is no coupling. Axiom 1 is satisfied (Ref Appendix I). From all the possible "good designs" there is a way to judge which one is better than the other. Axiomatic design enables the designer to come up with more than one acceptable design that may be used. The methodology has a way to rank the designs according to criteria that will be discussed in the following paragraphs.

Axiomatic Design then becomes a tool to be able to select a "better " design from the start that will reduce the number of iterations prior to final design, and will also reduce the need for incremental improvements that significantly increase the costs of a product in a design stage. The axiomatic approach will discard any designs that have coupling in their design matrices. This implies that all the designs that are coupled have a greater information requirement (lower probability of success) than those designs that have satisfied Axiom 1 and their design matrix is of the diagonal form.

The axiomatic approach may diminish the problem of specifying tolerances that the machinery may not meet since tolerances are specified in the functional requirements, and constraints should be considered. Also, the methodology disciplines the design engineer to approach a problem in a more systematic and scientific way. The problem definition is the key initial element. Significant time must be taken to define the "problem". When a problem is brought to light, engineers should not have a biased/predetermined solution. In this way the methodology allows the engineer to have a broader perspective to solve problems.

The second step is to convert the customer needs into functional requirements (FRs) and to select a set of plausible first level FRs. At this point the designer must be sure to select the DPs for FRs that do not cause coupling (independent of each other). The design matrix for each design is checked. If it is not diagonal or triangular, the designer must go back and redefine the FRs, find plausible DPs, and select the best DPs for the FRs. At this point a check on the design is made. The design is asked if the apparatus meets the original needs of the customer (back to creating the FRs).

With this iterative process at the design stage, the Axiomatic Design Methodology enables refinement of the design ideas prior to the prototype/test stage. By doing this the design process will be less costly, and the resulting design is more likely to be a better design since strict criteria for a "good design" are followed as defined by Axioms 1 and 2. The principle, or concept behind the axiomatic approach is based on well defined customer needs that are translated into specific functional requirements. Once the functional requirements are determined, constraints (bounds of the design or system) should be specified. The functional requirements must be in a form of a verb indicating what is desired. The corresponding, design parameter (unique in the best case) will be in the form of a noun answering how, or with what the functional requirement will be satisfied. The designer must "travel" from the functional domain of the customer requirements to the physical domain of the design parameters.

To understand the process, the designer has hierarchies of functional requirements and design parameters. At a given level the designer traverses to the design domain. Subsequently the designer must "travel again" back to the functional domain, but now he/she is going down one level of the functional hierarchy in order to determine the second level functional requirement. Once this is done the designer must "travel" to the physical domain at the same level as the functional domain he finds himself at. This zigzagging process that enables decomposition terminates when no further decomposition is possible. The Axiomatic Approach is a disciplined approach to define a problem, prioritize the needs, and provide an unbiased solution.

3. COMPOSITION OF THE TYPICAL MANUFACTURING OPERATION

There are a wide variety of models used for to describe the composition of companies. This work makes no attempt to be rigorous about the composition of the organization. The idea is to have in mind the main processes that take place.

3.1 FUNCTIONS OF A MANUFACTURING OPERATION

The basic functions of a manufacturing facility for small and medium size production lots have been summarized from (Rembold, Nnaji et.al. 1993).
Axiomatic Design Methodology should be applied in the design of each one of the func-

tions-processes in order to increase the productivity of the firm and thus increase its profit. The basic functions of a manufacturing facility for small and medium size production lots have been summarized from (Rembold, Nnaji et.al. 1993).

Axiomatic Design Methodology should be applied in the design of each one of the functions-processes in order to increase the productivity of the firm and thus increase its profit.

I- STRATEGIC GOAL SETTING

1- Capital Equipment and facility planning

2- Long Range Planning and Forecasting

3- Market Research

II. TECHNOLOGIC PLANNING

1- Manufacturing Process Planning

2- Engineering and Design

3- Customer Order Servicing

III. ORGANIZATIONAL PLANNING AND SCHEDULING

1- Purchasing

2- Production order scheduling, monitoring and control

3- Marketing

IV. MANUFACTURING CONTROL AND MONITORING

1- Receiving
2- Raw Material Inventory

3- Purchased Parts Inventory
4- Parts Manufacturing

5- Finished parts inventory

6- Assembly

7- Quality Control

8- Finished Goods Inventory

9- Spare Parts Inventor

10- Shipping

V. BUDGETING AND ACCOUNTING

1- Credit Accounting

2- Profit and Loss calculation

VI. BUDGETING

1. Debit Accounting

The author believes that if every item listed in this list is addressed with the Axiomatic Theory of design, with the goal of productivity and profit in mind, the result will be a model company that has very specific goals, and very well defined responsibilities. If the functional requirements are selected consistent to the goal of productivity and profit, the model will yield a model company that can be used as a benchmark for performance comparisons for of businesses. At the present time, for sake generality no specific industry has been cited. The next section will address the rationale used to select the Engineering and Design activities.

Selection of the Engineering and Design Department

The Engineering and Design Department, more specifically, design activities, was selected as a starting point to apply Nam.

P. Suh's Axiomatic Theory for the following reasons:

1- Engineering and Design costs for products can be reduced significantly if The Axiomatic Approach is implemented. Cost savings go directly to the bottom line: profit.

2- The present work reviews the activities performed by the Engineering and Design Department and introduces in the design the cutting edge tools and concepts for performance and productivity improvement.

3- The study will allow focusing on Concurrent Engineering, Axiomatic Theory, and Design for Manufacturability and Assembly as key elements for the Design and Engineering Department. As mentioned before in this work, the Engineering and design of a Product constitutes a high portion of the product cost, close to 70% (Boothroyd, 1994). For this reason this Department of Engineering and Design has been selected.

DESIGN OF THE ENGINEERING AND DESIGN DEPARTMENT FOR ENHANCED PRODUCTIVITY AND PROFIT.

The design of the Design and Engineering Operation of the Engineering Department must follow the cutting edge concepts that involve productivity improvement, and hence profit potential. The design activities are addressed here.

FUNCTIONAL REQUIREMENTS AND DESIGN PARAMETERS

Functional Requirements and Design Parameters for the Engineering and Design Department.

The top level; **Level 1**, functional requirement is:

FR1=Employ Concurrent Engineering Design Principles for Productivity and Continuous Improvement.

DP1=Engineering and Design Department Group or Unit.

The goal of the Company is to enhance profit. In order accomplish this the productivity must increase. Efficiency and effectiveness of operations must be improved.

Concurrent Engineering is placed as the highest-level functional requirement because successful design is the result of teamwork between engineers and other professionals involved in the product design and production process. Each participant looks at it from different perspectives such as design process and inspection planning, manufacturing, as assembly, maintenance, and cost or market demand. (Dormazet, 1 992). This cooperation will result in lower costs.

Level 2

FR11=Control entry (storage), retrieval, and dissemination of customer need information.
DP11=Customer perceived needs database.
FR12=Know the customer needs and requirements for design.
DP12=Product Development Teams. These teams are made up of personnel from:
Marketing Dept, Engineering Design, Quality Assurance, Manufacturing, Manufacturing, Engineering, Finance, and product support. (Backerjian, 1 992).

At this second level, the requirement is: to control customer need information (FR11) by means of a database that should be part of the company database, integral part of the Computer Integrated Manufacturing (CIM) system of the business. CIM results when the computer has become a mayor component of a manufacturing system and helps to plan and operate it. CIM conveys the concept of all processes leading to the manufacture of the product are integrated and controlled by computer. It includes Computer Aided Design (CAD), Computer Aided Process Planning (CAP), Production Planning and Control (PPC), Computer Aided Quality Control (CAQ), and computer aided manufacturing (CAM). (Rembold, Nnaji et al., 1993). The author found no benefit in decomposing FR11 any further for the scope of this work.

Since CIM in a modern company involves every aspect of the business, it can be considered a constraint for the Engineering and Design Department. It is a bound that must be respected and supported.

Matrix:

$$\begin{matrix} FR11 \\ = \\ FR12 \end{matrix} \begin{vmatrix} X & X \\ & \\ O & X \end{vmatrix} * \begin{matrix} DP11 \\ \\ DP12 \end{matrix}$$

Decoupled matrix: Lower triangular. The order of adjustment is adjust DP12 to fix FR2 and adjust DP11 to fix FR11.
A11 represents the effect or influence of DP11 on FR11. If there was a way to demonstrate a relationship by a graph, then one can use the partial derivative (rate of change) of FR11 with respect to DP11.

A12 represents the effect influence of DP12 on FR11. If there was a way to demonstrate a relationship by a graph, then one can use the partial derivative of FR11 with respect to DP12.

A21 represents the effect of DP12 on FR12. If there was a way to demonstrate a relationship by a graph, then one can use the partial derivative of FR12 with respect to DP11.

A22 represents the effect of DP12 on FR12. If there was a way to demonstrate a relationship by a graph, then one can use the partial derivative of FR12 with respect to DP12.

In summary, a change in the Product development team does not affect customer needs.

The Product Development Team becomes the physical entity that will perform the product or process design within a Concurrent Engineering environment.

Level 3

FR121= Must define customer needs.
DP121= Quality Function Deployment
FR122= Use Axiomatic Design for new designs (first design attempt)
DP122= Axiomatic Design Methodology
FR123= Create a Drawing of Product or Process.
DP123= CAD Drawing
FR124= Create Bill of Materials (BOM) for product or (material and part list/equipment list) in case of a process.
DP124= Bill of Materials (BOM)

Matrix:

Decoupled upper triangular matrix.

$$\begin{matrix} FR121 \\ FR122 \\ FR123 \\ FR124 \end{matrix} = \begin{vmatrix} X & 0 & 0 & 0 \\ X & X & 0 & 0 \\ X & X & X & 0 \\ X & X & X & X \end{vmatrix} * \begin{matrix} DP121 \\ DP122 \\ DP123 \\ DP124 \end{matrix}$$

The order of adjustment is to adjust DP121 to fix FR121, adjust DP122 to fix FR122, adjust DP123 to fix FR123, and finally adjust DP124 to fix FR124.
The first functional requirement at this level is to know the customer needs, and one way of doing this is by employing Quality Function Deployment, a methodology to determine customer needs.

The second customer requirement is to use the Axiomatic Approach for new designs, and evaluate the need for others based in cost.

The third requirement is to create a draw in of product or process, and the physical embodiment of this FR is the CAD drawing.

The fourth functional requirement is to create a Bill of Materials for a product or a comprehensive list of materials and parts for a process to be designed.

At this level the author has determined that FR121, to define the user needs, will not be decomposed any further. Furthermore, FR122, to use the Axiomatic Approach will not be decomposed anymore since the details of the methodology are given in section 2 and appendix 1.

Functional requirement FR124 involves the creation of a Bill of Materials is not decomposed any further the objective of this work is to describe the design activities. Details on the structure of the Bill of materials are given in (Rembold, Nnaji, et.al, 1993)
It is assumed that the drawing is completed and subsequently the Bill of Materials is made. Decomposition ends at this point. The Bill of materials should be fed into a database that is integral part of the CIM environment of the Manufacturing firm.

At this level additional requirements as numerical control programs and quality control procedures should be included, but have been omitted given the scope of the work. It is suggested that this issues be addressed in further studies.

Level 4

FR1231= Must design for ease of fabrication, assembly, and part count reduction.
FR1232=Must Design for Quality (variability avoidance).
DP1231=Design for Manufacturability and assemblability methodology
DP1232=Taguchi Quality Engineering.

$$\begin{matrix} FR1231 \\ FR1232 \end{matrix} = \begin{vmatrix} X & X \\ 0 & X \end{vmatrix} * \begin{matrix} DP1231 \\ DP1232 \end{matrix}$$

Matrix:

Decoupled lower triangular with adjustment order: first adjust DP1232 to fix FR1232 and adjust DP1231 to fix FR1231.

At this level, the use of Design for Manufacturability and assemblability principles is required. This functional requirement is further decomposed into the basic components of Design for manufacturing. For the illustrative purposes of this work reduction in number of parts, standardization and mistake proofing were selected.

FR1232 should be further decomposed to consider the use of CAE and FEA programs to support the CIM concept.

Level 5

FR12311=Reduce the number of parts.
FR12312=Standardize parts.
FR12313= Make Mistake Proof operations
DP12311=Use three criteria to minimize the number of parts of (Buthroyd, 1994).

$$\begin{matrix} FR12311 \\ FR12312 \\ FR12313 \end{matrix} = \begin{vmatrix} X & X & X \\ 0 & X & 0 \\ 0 & 0 & X \end{vmatrix} * \begin{matrix} DP12311 \\ DP12312 \\ DP12313 \end{matrix}$$

As mentioned before, for the purposes of this paper the decomposition at this level has three items only. The matrix is decoupled. It is a lower triangular matrix so adjustments can be made as long as DP12311 is adjusted first to fix FR12311. DP12312 is adjusted second to fix FR12312 and DP12313 is adjusted last to fix FR12313.
The actual breakdown of DFM is the following according to (Bakerjian, 1992).

1- Simplify and reduce the number of parts,

2- Standardize and use common parts and materials. Group Technology may be used here.

3- Design for ease of fabrication.

4- Mistake proof product design and assembly (Poka Yoke).

5- Design for parts orientation and handling

6- Minimize flexible parts and interconnections.

7- Design for ease of assembly.

8- Design for efficient joining and fastening.

9- Design modular products to facilitate assembly.

Only three very significant characteristics were used as functional requirements. The others because they apply to every design, could be considered constraints.

4.2 CONSTRAINTS

Nam P Suh defines constraints as bounds in an acceptable solution. Input constraints are size weight, materials and cost, while system constraints are bounds as geometric shape, capacity of machine and laws of nature. The difference between constraints and FRs is that constraints do not have to be independent from each other. (Suh, 1990). The precise value of a constraint is not important as long as it does not exceed a limit. The problem with this definition may arise when non-numerical or non-technical designs are attempted. Items 3,5,6,7,8,9 of the previous section may be considered as constraints since they are not independent.

Other constraints applicable in this case are listed below. In order to attain greater productivity and profit additional constraints may be placed in the design so that the designer approaches a better design solution in a shorter time. The department should use Benchmarking to compare itself with the competition. This tool should be used company wide.

Another useful tool that may be used in every area of the business in transactional or manufacturing activities is Six Sigma. Any process or procedure in which a defect per given number of opportunities to obtain a defect can be calculated, may be addressed with Six Sigma for performance improvement.

Continuous improvement also becomes an important constraint that focuses efforts to improve over what has been done before.

To reiterate, CIM becomes a key constraint, which applies to all the business. In order to satisfy it, the Engineering and Design Department for example implements the use of CAD.

Other constraints derived from the implementation of Concurrent Engineering are to involve suppliers and contractors early, to use the standard for the exchange of product model data PDES/STEP. And to integrate CAE, CAD, and CAM tools (Bakerjian, 1992).

DESIGN DISCUSSION USING THE AXIOMATIC FRAMEWORK

The matrices obtained indicate a decoupled nature. Even though it is preferable to have uncoupled matrices, in actual practice this is difficult to obtain. It is quite satisfactory to get decoupled matrices. This means that the adjustment follows a preset sequence as explained in previous sections.

The minimum number of FRs was selected at the highest level, starting from one. Furthermore, the number of levels was kept to a minimum. Further decomposition is possible if more detail is required, but does not add significance to this preliminary study.

The DPs were chosen in such a way that they match their corresponding FR.

CONCLUDING REMARKS AND SUGGESTIONS FOR FUTURE WORK

Even though the design had to be simplified in order not to loose the attention of the reader, the design obtained is consistent with the goal of profit enhancement.

The purpose of this work has been to design the Engineering and Design Department, more specifically, the design activities of a Manufacturing firm so that it attains high productivity and profit. Since about 70% of the cost of a product is determined in the design stage the author thought appropriate to address this department first in what could be a series of Axiomatic Framework applications to all the different departments /functions of a manufacturing facility.

The study initiates the design by specifying the desire to support the concept of Concurrent Engineering, which on the long run will yield significant decreases in development time that has a considerable cost. These cost reductions will impact directly the "bottom line" of the business. The use of axiomatic theory is recommended specially for new designs. Many older designs may not justify a complete redesign. Quality Function Deployment is recommended to obtain the customer needs to be converted into Functional requirements. Design for Manufacturability and assemblability is also proposed in order to decrease development costs, and cost due to parts.

Taguchi quality Engineering may be used to reduce sensitivity to noise due to uncontrollable factors. This will permit reduction in part and assembly tolerances which are mayor drivers of manufacturing cost, and increase the information content of the design thus decreasing its probability of success
(http://mijuno.arc.nasa.gov/dfc/tm.html)..
Product development teams become design parameters to implement the design of the product or process.

The hierarchy is decomposed into drawing in CAD (this functional requirement supports the CIM constraint).

Benchmarking and Six Sigma may be used as constraints in order to enhance productivity and performance. The following paragraph has suggestions for future work.The design can be augmented with more layers of decomposition if some of the assumptions and simplifications are removed. However, the author anticipates that obtaining the triangular matrices will increase the complexity and information content thus decreasing the probability of success of completing the analysis.

The other functions in the Manufacturing firm should be addressed with the Axiomatic Design Framework.

It would be valuable to know all the cost drivers in the department and derive the functional requirements to minimize the magnitude of these drivers. This could be done with Activity Based Costing.

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APPENDIX I

Axioms, Corollaries, and Theorems of the Axiomatic Framework (Suh 1990)

The basic premise for Axiomatic Design is that there are some basic principles that govern decision-making in design as in other disciplines. Strict adherence to these principles will guarantee a structured approach to design. Compliance with them will at least guarantee that a viable design is reached from the start. Below are listed the first seventeen Corollaries that are relevant to the present work. Additional corollaries have been developed for Systems.

Axiom 1 The Independence Axiom. Requires that functional requirements (FRs) be independent.

Axiom 2 The Information Axiom requires that the information content be minimized.

THE DESIGN RULES-COROLLARIES

Corollary 1 (Decoupling of coupled designs) Decouple or separate if functional requirements are coupled or interdependent.

Corollary 2 (Minimization of Functional Requirements) minimize the number of FRs and constraints.

Corollary 3 (Integration of Physical Parts) Integrate in a single physical part if FRs can be satisfied independently.

Corollary 4 (Use of Standardization) Use standardized or interchangeable parts if the use of the parts is consistent with FRS and constraints.

Corollary 5 (Use of Symmetry) Use symmetrical shapes/components while being consistent with FRs and constraints.

Corollary 6 (Largest Tolerance) State the largest allowable tolerance in stating FRs.

Corollary 7 (Unccoupled design with Less Information). Seek an uncoupled design that requires less information than coupled designs in satisfying a set of FRs.

Corollary 8 (Effective Reangularity of a Scalar) reangularity of a scalar-coupling matrix is unity. This is a mathematical approach to determine the degree of coupling.

The following theorems, which are propositions that follow from the axioms, are useful.

Theorem 1 (Coupling due to Insufficient number of Design Parameters (DP's)) If the number of DPs is less than the number of FRs, the design is coupled or the FRs cannot be satisfied.

Theorem 2 (Decoupling of a Coupled) If the design is coupled with more FRs than DP's, it may be decoupled by adding new DPs to make the number of DPs equal to the number of FRS, if a subset of the design matrix of n X n elements constitutes a triangular matrix.

Theorem 3 (Redundant Design. When there are more DPs than FRs the design is redundant or coupled.

Theorem 4 (Ideal Design) The number of DPs should equal the number of FRs.

Theorem 5 (Need for New Design)
When a given set of FRs is changed by adding an FR, or substituting an FR, or a new set of FRs, the solution given by the original DPs cannot satisfy the new set of FRs, and a new design solution must be sought.

Theorem 6 (Path independence of Uncopuled Designs) the information content of an uncoupled design is independent of the sequence by which the DPs are changed to satisfy a set of FRs.

Theorem 7 (Path dependence of coupled and decoupled designs depend on the sequence by which the DPs are changed and on the specific paths of change of these DPs.

Theorem 8 (Independence and Tolerance)
A design is an uncoupled design when the tolerance is greater than:
(Summation j not equal to I, j=1 to n (partial of FRI / partial of DPj) X (delta DPj)
In this case the off diagonal elements of the design matrix can be neglected from the design consideration.

Theorem 9 (Design for Manufacturability)
In order for a product to be manufacturable, the design matrix of the product [A] (which relates FR and DP vectors) times the design matrix of the manufacturing process [B] which relates DP and PV vectors for the process) must yield either a diagonal or triangular matrix. If either [A] of [B] is coupled, the product cannot be manufactured.

Theorem 10 (Modularity of Independence Measures)
If a design matrix can be partitioned into square submatrices that are non-zero only at the main diagonal; then the reangularity and semangularity for the design matrix are equal to the products of the corresponding measures for each of the non-zero submatrices.

Theorem 11 (Invariance)
Reangularity and Semangularity for a design matrix are invariant to alternative orderings of FR and DP variables, as long as the FR to DP relationship is maintained.

Theorem 12 (Sum of Information)
The sum of information is also information if conditional probabilities are used for events that are not statistically independent.

Theorem 13
(Information Content of the Total System) If each DP is probabilistically independent of other DPs the information content of the total system is the sum of information of the independent events that are associated with the FRs that need to be satisfied.

Theorem 14 (Information Content of Coupled versus Uncoupled Designs. When the state of FRs is changed from one state to another in the functional domain, the information required for the change is greater for a coupled process than an uncoupled process.

Theorem 15 (Design-Manufacturing Interface)
When the manufacturing system compromises the independence of the FRs of the product, the design of the product must be changed, or a new manufacturing process designed or used to maintain independence of FRs of the products.

Theorem 16 (Equality of Information Content)
All information contents are equally important to design and no weighing factor should be applied.