Design and Development of a Model for Competitive Production Management System through Axiomatic Design – A Case Study

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Abstract- **Manufacturing enterprises consist of *people, things,* and *information*. *Peoples* are hired for performing various functions such as; marketing, design, purchasing, inventory control, inspection, machining, management, safety, service, and security. *Things* range from factories, to machines, materials, transporters, computers, warehouses, vendors of components, and utilities. *Information* is according to marketing requirements, product design, and Production systems and operations, Production processes, human resources, supplier chain systems, and general management. All these elements constitute part of the manufacturing enterprise. A Manufacturing organization as a system can have functional sub-systems, such as a *production sub-system, a marketing sub-system, management sub-system, management and information sub system, and labor sub-system.* The scope of this paper is limited to design and development of a model for Competitive Production Management System (CPMS). A Delphi approach along with '*ANOVA*' has been used to separate out significant and non-significant factors affecting in the models, resulting in a comprehensive, compact sub-system design. Finally, a model designed and developed for CPMS has presented at the end. An *Axiomatic Design* approach selected for design and development of CPMS. At the end, comprehensive Mathematical model for CPMS presented**.

Index Terms- **Axiomatic Design; ANOVA; Delphi technique; Key-Performance-Areas (KPA's)**

I. INTRODUCTION

The purpose of manufacturing, at least idealistically, is to enrich society through the production of functionally desirable, aesthetically pleasing, environmentally safe, economically affordable, and highly reliable top quality products. The Manufacturing also provides a gainful employment to drive the economy. The Production systems classified based on materials input are, *discrete parts producing* and *continuous parts processing*. Process planning entail the specification of the sequence of operations required for converting the raw material into finish parts and then assembling of these parts into products. The finished and semi finished parts are produced with the help of process plans that are set of instructions specifying how the product should be manufactured, including the sequence of machine tools, the tools required, and the machine settings. The major organizations commonly perform the various functions. It is rather viewed these industrial unit as functions instead of departments. Although traditionally each functions may have been a separate departments. India Industries are facing major problems of, Coordination; Need for Control; Fragmented Information Infrastructure; and Insufficient Process ability of Available Information with respect to these functions [1].

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II. LITRATURE SURVEY

Major Challenges that the Auto Industries has to face are [2]: Fewer suppliers to auto Industry with long-term relationship. Demand for 5% to 10% reductions in cost annually when source from developing countries, Responsibility for design development testing quality and research including covering of development costs and shorter innovation cycle. Use of electronic and new-materials emerging modular system, with others as vendors to module supplier. Need for high flexibility and adaptability in view of frequent phasing out of vehicle models. Korgaonkar [3], listed varies problems of industries in developing countries are: Inferior quality; Underutilization of both workers and equipment's, High rate of scrap and defects ,Poor and inadequate maintenance; Shortage of raw materials; Shortage of skill workers; Lack of appropriate supervision; Informal and casual quality control; Low productivity.

III. BOTTLENECKS FOR COMPETITIVE PERFORMANCE IN AN INDIAN INDUSTRY

A basic problem in Production is a problem of coordination, which is stated as follows: After setting off, a Production took into thousands of subtasks, how difficult and costly is it to assure their proper sequencing, scheduling and interaction-over a period. After dividing the task expertise among hundreds of 'incomplete expert' workers, how difficult and costly is it to maintain their coordination, motivation and performance. As we used to divide information in to millions of tiny bits, how difficult and expensive is it to achieve its requisite integration, record and update? As the complexity, cost of integration and coordination becomes too large; on tends to focus on the question of reintegration. As for managing task complexity, coordination is required, likewise to manage market uncertainty, planning and control is required. For instance, a production schedule is optimized to increase system responsiveness to demand, that is, to keep due dates, to reduce total flow-time and, to balance factory loads. This is a planning problem. On the other hand, the control problem

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deals with machine-sharing policy, lot splitting and job sequencing that is: Exploiting resources efficiently, and Respecting due dates in the face of uncertainty. In general, the breakdown of long-to-short term planning decisions indicates levels in the complexity of decisions.

Today the manufacturing industry is still striving for stability of its production system as a major organizational goal. Therefore, in most manufacturing firms, management of change is not considered as a permanent objective. Whether, JIT or CIM, whichever way the task, coordination is managed by an integrated information infrastructure. However, information processing is found to be fragmented even in computerized applications [1]. Therefore, in many companies the decision-making process is still based on traditional information processing-information gathering with ‘paper and pencil’ on request and from inconsistent sources. This process is at the least very time consuming and may yield only insufficient or ever unreliable information. In addition to having a fragmented information infrastructure, most companies are not organized for fast decision-making processes. Departments are still managing their affairs according to their own sub-goals rather than to real enterprise goals.

IV. AXIOMATIC DESIGN APPROACH

Dr. Nam P. Suh developed axiomatic Design in the late 1970. Axiomatic design approach is the one that prescribes the design process and the good design criteria, and therefore, it is selected as foundation of the Production System design methodology. Suh set out to develop "a firm scientific basis for design, which can provide designers with the benefit of scientific tools that can assure them complete success" [4]. Until this time, design was considered purely creative process that could not be formalized. However, the fact that there are good design solutions and unacceptable design solutions indicates that there exist features or attributes that distinguish between good and bad designs. Furthermore, since this creative process permeates all fields of human endeavor ranging from engineering to management, the features associated with a good design may have common elements. These common elements may then form the basis for developing a unified theory for the synthesis process[4]. Axiomatic Design is a formalized methodology to structure the design process and to assess the quality of various designs. The methodology was named "*Axiomatic Design*" because it is based upon axioms. Axioms are fundamental truths that are observed to be valid and for which there are no counterexamples or exceptions [4].

A. *The independence axiom*

The first Design Axiom states: "In an acceptable design, the [Design Parameters (DPs)] and the [Functional Requirements (FRs)] are related in such a way that a specific DP can be adjusted to satisfy its corresponding FR without affecting other functional requirements"[5]. If no DP affects other than one FR, then the design is considered uncoupled. In order to assess coupling, one can write the design equation. The design equation is a mathematical representation of the interactions between FRs and DPs. A design equation has to be written for each transition between domains and at each decomposition level. The design equations have the following forms:

For the transition from FRs to DPs:

$$\{FRs\} = [A]\{DPs\}$$

For the transition from DPs to PVs:

$$\{DPs\} = [B]\{PVs\}$$

The {FRs}, {DPs}, and {PVs} matrices are column matrices with the number of rows corresponding to the number of FRs at the given decomposition level. The [A] and [B] matrices are square matrices. These are termed as design matrices. Examples of the three categories of designs: uncoupled, coupled, and decoupled. An uncoupled design is ideal. Notice that DP1 affects only FR1, DP2 affects only FR2, and so on. In uncoupled designs, Xs appear only along the diagonal of the matrix. Coupled designs are unacceptable. Note that DP1 affects FR1 and FR2; DP2 affects FR2 and FR3; and DP4 affects FR2 and FR4. Visually, one can identify a design as coupled if Xs appear on both sides of the diagonal. Decoupled designs are more acceptable than coupled designs. If Xs appear only on one side of the diagonal, the design is decoupled. Decoupled designs are better, but still not ideal because they are path dependent. The final solution depends upon the order in which the DPs were implemented.

B. *The information axiom*

Axiom 2, the Information Axiom, states: "Minimize the information content of the design". An alternative statement is "The best design is a functionally uncoupled design that has the minimum information content" [4]. Information part is related to the probability that a particular design will satisfy the Functional Requirements. If several uncoupled design alternatives exist, Axiom 2 can be used to choose the best among them.

C. *Mapping and decomposition*

The Figure 1 shows the Axiomatic product Design approach involves mapping through four design domains. Each translation or transition to a new domain represents a refinement of the design. In the Customer Domain, the designer lays out the Customer's wants for the system. These Customer Wants (CAs) are then further translated into the Functional Requirements (FRs) of Functional Domain. FRs, are then mapped to Design Parameters (DPs) in the Physical Domain. DPs are physical realizations of the FRs. Finally, the mapping of DPs in to the Process Variables (PVs) is done. The mapping process involves, zigzagging between different levels of the domains in order to define the FRs, DPs, and PVs [5].

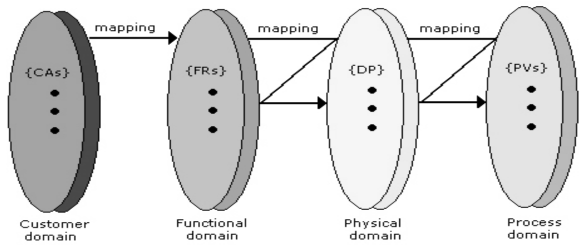

Figure 1: Mapping Product Design Domain

D. Benefits of axiomatic design process

Benefits to the Designers: Axiomatic design helps designers with both new and existing designs. In both cases, designers are more creative and develop better designs in less time **[6]**.

New designs: the designer designs in a systematic way, completing prerequisite tasks before continuing to the next stage. Accordingly, the designer is *more creative by:* understanding a clearly defined problem before design begins, identifying innovative ways to fulfill the functional requirements *saves time by:* avoiding frustrating dead ends, drastically reducing random searches for solutions, minimizing or eliminating design iterations ,using current design tools more effectively. P*roduces better designs by:* selecting the best design among good alternatives, optimizing the design properly, verifying the design against explicit requirements and has a fully documented design for troubleshooting and extensions [6].

Diagnosis of existing designs: For diagnosing an existing design, the use of axiomatic design highlights problems such as coupling and makes clear the relationships between the symptoms of the problem (one or more FRs not being achieved) and their causes (the specific DPs affecting those FRs). While improving the solution, the designer also enjoys the new-design benefits above [6].

Extensions to existing designs: When an existing version needs an engineering change or an upgrade, axiomatic design identifies all of the areas affected by the contemplated changes. As a result, unintended problems are not considered. To summarize, for both new and existing designs, the designer is more creative, turning out better designs quicker. Benefits to Management; Efficient Project Work-Flow; Effective Change Management; Efficient Design Function; Benefits To The Firm; Competitive Advantage; Higher Profit, Less Risk [6]. When searching for axioms it is most important to understand and define what an axiom is. The wikipedia has the following definition:

Axiom (Greek axioma appraisal, assessment, opinion, statement, which without proof is considered to be true), in everyday speech it means an obviously true statement. In science, an axiom is considered as a principle that in it self is not the subject of proof but which is serving as the base for the proof of other statements (Comp. "Postulate"). A scientific discipline is said to be axiomatic or to be developed using a axiomatic methodology if all concepts in use are explicitly defined with the aid of a number of in beforehand defined basic conceptions, so called primitive conceptions, and all statements (theorems) within the discipline are derived as logical consequences from a number of in beforehand stated axioms. The basic statements and the axioms are together delimitating an axiomatic system or an axiomatic theory [7].

V METHODOLOGY OF THE RESEARCH

Following methodology used for development of a proposed Model for CMMS.

Step I: It is propose to use *Delphi* technique [8] for collecting the necessary data with respect to the utilization of manpower, material, machines and equipments, and methods from industries engaged in batch Production such as auto industries and major ancillary units for these industries. After sending preliminary questionnaire to these industries, a revised questionnaire prepared after the receipt of response and was to all selected industries. A consolidated data sheet will be then prepared for further analysis.

Step II: Analysis of variance (*ANOVA*) used to eliminate uncertainty and discrepancy in the compiled data.

Step III: The refined data then used for developing the Model for CMMS by making use of *systems approach*.

Figure 2 shows methodology for identifying the key-performance area (KPA's) along with productivity Index (PI's). *Productivity Index (P.I.) = Effectiveness / Efficiency*

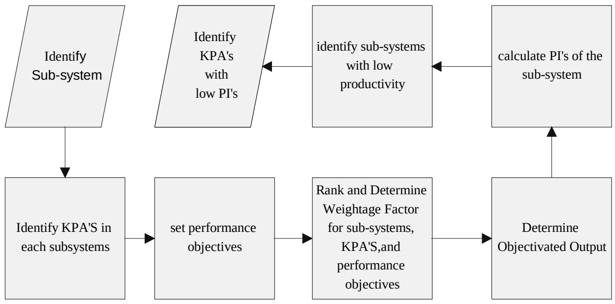

Figure 2: Methodology for identifying the KPA's in each Sub-System

A. Identification of sub-systems

Burns and Stalker [9] suggested that a system or a sub-system has five basic characteristics: A central objective and measure of performance; its environment; its resources; its components; its managements. An organization as a system can have functional sub-systems, such as a *Production Sub-system, a marketing sub-system, management sub-system, management, information sub system, labor sub-system.* These are also part of other sub-systems.

B. Development of questionnaire

The following methodologies applied for the development of a questionnaire. Key-performance areas identified in the Production sub–system were incorporated in the model. Mc-Conkey and Dale D. [10], recommends that KPA can be in one or more of the following four categories. Quantity, Quality, Timeliness, Cost. Figure 4 shows these KPA's.

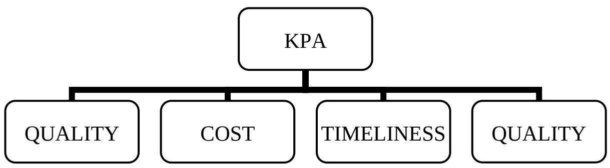

Figure 4: Dimensions of Key-Performance-Areas (KPA)

McConkey recommends that, while identifying the Key-Performance-Areas, the two more considerations are vital. Firstly, identified KPA's should be those, which are associated with the sub-system. There is possibility of overlaps and some areas of system would appear to be belonging to more than one system /sub-system. Secondly, the KPA's should have basis and relevance to the organizational objectives. As the objectives of organization vary form one organization to another, the KPA's also vary accordingly.

C. Hypothesis Testing

In the present study the one factor ANOVA–test is used. This test is used for evaluating the differences of mean of the dependent variable for various categories of single independent variable. The data then processed on *Minitab* software [11]. The process of one variable ANOVA is as follows:

Step 1: Formulate the hypothesis
Step 2: Obtain the mean of each sample
Step 3: Find the mean of the entire means i.e. grand mean
Step 4: Calculate the variation between samples denoted by $SS_{between}$
Step 5: Obtain the mean square of the variation between samples denoted by $MS_{betweem}$ using $SS_{between}$
Step 6: Calculate the variation within the samples denoted by $SS_{wIithin}$
Step 7: Calculate the mean square of variation within samples denoted by MS_{within} using SS_{within}
Step 8: Calculate the total variance denoted by SS_y. Determine F ratio using the formula given below
F–ratio = $MS_{betweem} + MS_{within}$
Step9: The F-ratio then compared, with corresponding value in the F- distribution table

If the F-ratio is less than the table value, then we accept the null hypothesis that there is no difference between population means. However if the F- ratio is equal to or above the table value, we reject the null hypothesis and accept the alternate hypothesis that there is a difference between the population means. The Production sub-System decomposed further with respect to the KPA's of the sub-System [12] *i.e.* Manpower utilization, Asset utilization, Material utilization, Schedule of completion, Quality of production, Production Planning and Control (Figure 5).

D. Decomposition of Production Sub-System

Next stage is to decompose each sub-system in details. Yien Tsang Sum [13] suggested a method to decompose different domains of product design and manufacturing system design.

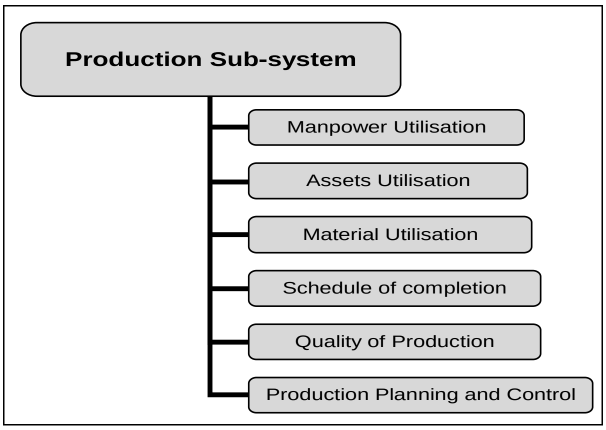

Figure 5: KPA of Production sub-System

Figure 5 shows the Production sub-System. It is decomposed further with its KPS's. After decomposition with respect to its KPA's, the mathematical expressions are developed. Table 1 shows First Level Decomposition of Production Sub-System. Table 2 shows the mathematical expression of first level decomposition of the Production sub system. The second level decomposition of the Production sub-system developed with respect to its KPA's. The Table 3 shows the second level decomposition of the production subsystem. Table 4 shows the mathematical expression of second level decomposition of the Production sub-system.

VI. DISCUSSION OF PRODUCTION SUB SYSTEM

For performing the analysis of variance (ANOVA) of the **Production sub system**, One-Way classification used. Analysis of various factors; labor utilization, Assets utilization, Materials utilization, Schedule Completion, quality of Production and production planning and control done independently at 95% confidence interval. The corresponding values of $F_{0.05,}$ $n_{1,}$ n_2 are taken from F-distribution table.

In the analysis of **Manpower Utilization** the various sub factors direct labor utilization, indirect support ratio, cost effectiveness, safety and availability of workloads are analyzed. The analysis of each sub factor is done with another sub factor. From the analysis of sub factors, at 95% confidence interval, by observing the F-ratio ($F > F_{.05,}\, n_{1,}\, n_{2,}$) we can conclude that the sub factor safety has a significant effect on direct labor utilization and availability of workloads has a significant effect on safety. Other combinations of sub factors are not significant. In another words these sub factors have no significant effect on each other. Alternatively, we can say that with the change in one sub factor, there is no significant effect on the other sub factor; hence, the null Hypothesis is accepted.

Table 1: First Level Decomposition of Production Sub-System

Sr. no	Objective	Solution	
	Functional Requirements (FRs)	Design Parameters (DPs)	Process Variables according to key performance measure (PVs)
1.	FR11 Manpower Utilization	DP11Maximize the man-power utilization	PV11 Standard Hours Working
2.	FR12 Asset Utilization	DP12 Maximize The Asset Utilization	PV12 Capacity Planning
3.	FR13 Material Utilization	DP13 Yield	PV13 Value of Materials
4.	FR14 Schedule completion	DP14 Efficiency	PV14 Order execution
5.	FR15 Quality of Production	DP15 Defect free production	PV15 value of Production
6.	FR16 Production Planning Control	DP16 Scheduling	PV 16 Time of completion

Table 2: Mathematical Expression of first level decomposition of Production sub-system

Manpower Utilisation	FR11			X11	0	0	0	0	0		DP11
Asset Utilisation	FR12			0	X12	0	0	0	0		DP12
Material Utilisation	FR13			0	0	X13	0	0	0		DP13
competion Schedule	FR14			0	0	0	X14	0	0		DP14
Quality of Production	FR15			0	0	0	0	X15	0		DP15
PPC	FR16			0	0	0	0	0	X16		DP16

In the analysis of **Assets utilization** the various sub factors capacity utilization, capital cost control, operating cost control analyzed. The analysis of each sub factor is done with another sub factor. From the analysis of sub factors, at 95% confidence interval, by observing the F-ratio ($F > F_{.05,}\ n_{1,}\ n_{2,}$) **we can conclude that the sub factor operating cost control capital has a significant effect on capital cost control, hence alternate hypothesis is accepted .**Other combinations of sub factors are not significant. In another words these sub factors have no significant effect on each other. Alternatively, we can say that with the change in one sub factor, there is no significant effect on the other sub factor; hence, the null Hypothesis is accepted.

In the analysis of **Quality of Production**, the various sub factors index of defect free production, Quality costs and availability of report on quality analyzed. The analysis of each sub factor is done with another sub factor. From the analysis of sub factors, at 95% confidence interval, by observing the F-ratio ($F > F_{.05,}\ n_{1,}\ n_{2,}$) we can conclude that the sub factors are not significant. In another words these sub factors have no significant effect on each other. Alternatively, we can say that with the change in one sub factor, there is no significant effect on the other sub factor hence the *null Hypothesis* is accepted.

In the analysis of **Schedule Completion**, the various sub factors Order Processing efficiency and work in process control analyzed. The analysis of each sub factor is done with another sub factor. From the analysis of sub factors, at 95% confidence interval, by observing the F-ratio ($F > F_{.05,}\ n_{1,}\ n_{2,}$) we can conclude that the sub factors are not significant. In another words these sub factors have no significant effect on each other. Alternatively, we can say that with the change in one sub factor, there is no significant effect on the other sub factor; hence, the *null Hypothesis* is accepted.

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In the analysis of **Production Planning and Control**, the various sub factors job orders scheduling index, operating cost index and availability of production control reports analyzed. The analysis of each sub factor is done with another sub factor. From the analysis of sub factors, at 95% confidence interval, by observing the F-ratio ($F > F_{.05,}\ n_{1,}\ n_{2,}$) we can conclude that the sub factors are not significant. In another words these sub factors have no significant effect on each other. Alternatively, we can say that with the change in one sub factor, there is no significant effect on the other sub factor; hence, the *null Hypothesis* is accepted.

Production systems must be designed and developed rationally to achieve a set of desire functional requirements. The resulting Production system will be different depending on the functional requirements chosen to satisfy the customer requirements. The functional requirements of a manufacturing system design change over time. In this sense, there is no ideal, time-invariant Production system, since the system design must evolve to deal with the most important manufacturing issues of a given era. The Production system presented in this paper is an ideal Production system design for manufacturing a discrete part, which may be the case with many discrete auto component manufacturers.

Table 3:2nd Level Decomposition of Production Sub-system

2nd Level		Objective	Solution
	Sr. no	Functional Requirements (FRs)	Design Parameters (DPs)
Manpower Utilization	1	FR111 Direct Labor Utilization	DP111 standard hours/attendance hrs
	2	FE112 Indirect Support Ratio	DP112 total attendance hours/ attendance hrs
	3	FR113 Cost effectiveness	DP113 standard hrs. recovery / total personnel expanses
	4	FR114 Safety	DP114 standard hrs. recovery/hrs lost on account of accidents
	5	FR115 Availability of workloads	DP115 standard hrs working/ demand ratio
Asset Utilization	1	FR121 Capacity utilization	DP121 standard hrs. recovery /capacity
	2	FR122 Capital cost control	DP122 standard hrs. recovery / capitalized cost
	3	FR123 Operating cost control	DP123 standard hrs. recovery / operation cost
Material Utilization	1	FR131 Direct Materials (yield)	DP131 value of material used /value of direct materials
	2	FR132 Indirect Materials Usage control	DP132 value of direct materials / value of indirect materials
	3	FR133 Process wastages	DP133 value of wastages / value of direct materials
Schedule Completion	1	FR141 Order processing efficiency	DP141 order execution time / total orders scheduled
	2	FR142 WIP	DP142 standard hrs. recovery / value of WIP
Quality of Production	1	FR151 index of defect free prod.	DP151 value of defect free production /value of total production
	2	FR152 cost of quality	DP152 value of total production / quality cost
	3	FR153 Availability report on quality	DP153 intangible (Scale 0-1)
PPC	1	FR161 job order index	DP161 Job order completion time / ns. of jobs scheduled
	2	FR162 operating cost index	DP162 value of total production / operational expenses
	3	FR163 Availability of production Control reports	DP163 Intangible (scale 0-1)

Table 4: Mathematical Expression of 2nd level of Production Sub-system

	FR111	X111	0	0	0	0															DP111
Manpower	FR112	0	X112	0	0	0															DP112
Utilisation	FR113	0	0	X113	0	0															DP113
	FR114	0	0	0	X114	0															DP114
	FR115	0	0	0	0	X115															DP115
	FR121						X121	0	0												DP121
Asset	FR121						0	X122	0												DP122
Utilisation	FR123						0	0	X123												DP123
	FR131									X131	0	0									DP131
Material	FR132									0	X132	0									DP132
Utilisation	FR133									0	0	X133									DP133
complition	FR141												X141	0							DP141
Schedule	FR142												0	X142							DP142
Quality of	FR151														X151	0	0				DP151
Production	FR152														0	X152	0				DP152
	FR153														0	0	X153				DP153
	FR161																	X161	0	0	DP161
PPC	FR162																	0	X162	0	DP162
	FR163																	0	0	X163	DP163

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