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CONCURRENT ENGINEERING APPROACH FOR MODELING TO THE LOGISTICS

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ABSTRACT

This paper advocates logistics involvement in the early phases of product design and development in a concurrent engineering environment. A concurrent engineering environment and the benefits of such involvement are explained in detail. The paper focuses on facilitating an interface and collaboration between the designer and the logistician. A conceptual interface for design for logistics is presented. Four areas of interface are considered: (a) Logistics engineering (b) Manufacturing logistics (c) Design for packaging, and (d) Design for transportability. A set of detailed design factors pertaining to each area is represented. A modeling approach, Bond Energy Algorithm, is used to accomplish the design for logistics concerns developed throughout the paper. An example is provided to test and validate the algorithm. The results are analyzed and appropriate perspectives for managerial implication of the methodology are provided. Finally, some conclusions and assessments are presented.

Keywords: Concurrent Engineering, Design for Logistics, Manufacturing Product Design, Bond Energy Algorithm.

1. INTRODUCTION

Product design in a concurrent engineering environment focuses on an interdisciplinary approach that utilizes methods procedures, and rules to plan, analyze, select, and optimize the design of products. In the early stages of the design process concurrent engineering considers and includes various product design attributes such as aesthetics, durability, ergonomics, inter changeability, logistics, maintainability, marketability, manufacturability, procurability, reliability, remanufacturability, Safety, schedulability, serviceability, simplicity, testability, and transportability. The greatest impact and benefits of concurrent engineering are realized at the design stage of product development.

Fig. 1 depicts the system approach to the design of a product. This figure provides a conceptual framework where interactions among various functional areas in a concurrent engineering environment can be explored and analyzed. It encompass all relevant areas pertaining to product life cycle from product inception to disposal. This includes business, production, and support requirements. The paper focuses on the linkage between product design and logistics as highlighted in Fig.1.

1.1 OBJECTIVES

- To demonstrate the importance of early logistics involvement in the product design process.
- To present a conceptual as well as an analytical basis for integrating logistics concerns, constraints, and contributions in the design process. The conceptual and analytical bases are not an end in themselves, but are used to facilitate the design for the logistics process.
- To provide a framework where managerial implications of design for logistics can be explored. Furthermore, the efficiency and effectiveness of the methodology, results, and their managerial implications are analyzed.

1.2 SYSTEM APPROACH TO CONCURRENT ENGINEERING

There are two issues at the core of successful implementation of concurrent engineering:

- All activities related to the development of a product should be focused in the early stages of product design (conceptual design) so that the greatest benefits of such integration are achieved. The information requirements and exchanges at the conceptual design are not well defined and usually fuzzy. This poses a challenge for implementing concurrent engineering.

- The impact and constraints associated with various functional requirements should be communicated to the designer on a timely, accurate, and relevant basis.

Fig. 2 represents an integrated logistics system as it relates to product design. An effective design for logistics cuts across a number of functional areas as illustrated in Fig. 2. These activities converge to product design as the embodiment of all future activities. As the design for logistics affects Fig. 2. Integrated logistics system for product design. Other functional areas, other areas in turn affect logistics considerations. This process is inherently a dynamic one requiring negotiation and trade-off among the functional areas in a concurrent engineering environment.

2. A CONCEPTUAL FRAMEWORK TO DESIGN FOR LOGISTICS

A system approach to design for logistics essentially includes a designer's functional requirements as well as a logistician's requirements of availability, supportability, cost, quality, volume changes, timely delivery, order frequencies, and the like. The design for logistics in Fig. 3 is decomposed into four subsystems. Fig. 3 suggests that the design for logistics has four essential subsystems whose presence and interactions largely determines the content of design for logistics.

Fig. 4 shows the entire decomposition process of design for logistics and, as such, provides a conceptual framework for the inclusion of logistics concerns, constraints, and contributions in the design process. Each module addresses a specific, manageable and homogenous aspect of design for logistics. The logic is that modules are easier to develop, manage, and implement than a monolithic system with all the complexity it offers. The modules presented in Fig. 4 are intended to be generic, yet comprehensive, for the design for logistics and it may be used as a suitable conceptual framework for any design for logistics of mechanical products. Additionally, design factors are the driving force behind the modules. Design factors are the smallest functional requirements in the overall design of logistics.

2.1. LOGISTICS ENGINEERING

Logistics engineering is a field of logistics that deals with the supportability of product and systems throughout their life cycle. Logistics engineering is concerned with the design process in that it establishes requirements to which the ultimate design configuration must comply. Logistics must be intuitively an integral part of the design process along with performance, size and weight, reliability, safety, manufacturability, cost, and the like. The design factors associated with the logistics engineering subsystem are Design for Supportability (a_1), Design for Manufacturability (a_2), Product lines (a_3) and Design attributes (a_4)

2.2. MANUFACTURING LOGISTICS

The characteristics of the manufacturing processes and activities are a major determinant of the logistics activities and logistics system design. Manufacturing processes and activities often create a number of constraints and opportunities for a logistics system. Manufacturability, as a main feature of product design, is a significant contributor to the design for logistics. The design factors associated with the modules of the manufacturing engineering subsystem are Manufacturing Processes (a_5), Production Planning control (a_6), Materials (a_7) and Plant Location (a_8).

2.3. DESIGN FOR PACKAGING

This area addresses the issues related to packaging requirements in the product design process. Packaging is an important feature of a product as it creates or enhances the product's image. Product packaging is an important marketing tool and has a significant impact upon overall product cost, its ease of use, and its perception to customers. Packaging also protects the product from breakage, spillage, etc. Logistics requirements for packaging must be incorporated at the design stage with those of marketing and manufacturing requirements. The design factors associated with the modules of the design for packaging subsystem are Packing Materials (a_9), Package testing (a_{10}), Package design Features (a_{11}), and Functional Package requirements (a_{12})

2.4. DESIGN FOR TRANSPORTABILITY

Transportation costs represent the most single important element in logistics costs for most firms. An effective design for transportability stimulates direct competition among firms at different locations; creates greater economies of scale; and reduces the price of goods and services. The design factors associated with the modules of the design for transportability subsystem are Transportation Mode (a_{13}), Design Criteria (a_{14}) and Transportability issues (a_{15})

3. A MODELING APPROACH TO DESIGN FOR LOGISTICS

This paper utilizes Bond Energy Algorithm (BEA) - a clustering approach - to the design of logistics systems. The clustering algorithms have been widely used in the decomposition of complex design problems. The purpose of clustering algorithms is to decompose a large system into subsystems and then cluster them into manageable modules and activities. BEA is concerned with the grouping of objects into homogeneous clusters (groups) based on common features or activities. Clustering Analysis Methods have been widely used in various disciplines such as biology, data recognition, medicine, pattern recognition, production flow analysis, task selection, control engineering, automated systems, market segmentation, and expert systems.

3.1. SOLUTION PROCEDURE FOR BOND ENERGY ALGORITHM

BEA is an interchange-clustering algorithm that seeks to create a lock diagonal form by maximizing some measure of effectiveness. The purpose of BEA, in general, is to identify and display natural variable clusters that occur in complex data arrays. In particular, the objective of BEA in a logistics design is to group design factors into Design Factor Families (DFF) and modules into Module Families (MF). The forming of these families allows a designer to simultaneously consider and design the design factors common to a set of modules. This modularized approach increases the efficiency of the logistics design.

The interactions between modules and design factors can be represented in a binary module-design factor incidence matrix. In the formulation of the incidence matrix [a_{ijj}], the entries of 0 and 1 are used. Entry 1 (0) indicates that a particular design factor does (does not) belong to a module. “The designer” accomplishes the binary assignment. The designer may be interpreted as one expert or a team of experts. No attempt is made to define the composition or the working dynamics of the teams. This topic is beyond the scope of this paper. The topic of team decision-making and group negotiations has received considerable attention in current literature. The much talked about rating and assignment techniques (such as the Delphi method) are applicable to this paper as well. The assignment of binary values is inherently a technical task and requires the possession of knowledge and skills as they pertain to a particular logistics design. The methodology presented here allows the generation of multiple incidence matrices. Each of these matrices can be explored and solved, and the results can be evaluated for their effectiveness. On the other hand, the design team members can hold discussions and changes can be made to only one incidence matrix until a consensus is achieved. The opportunities for developing sound incidence matrices abound.

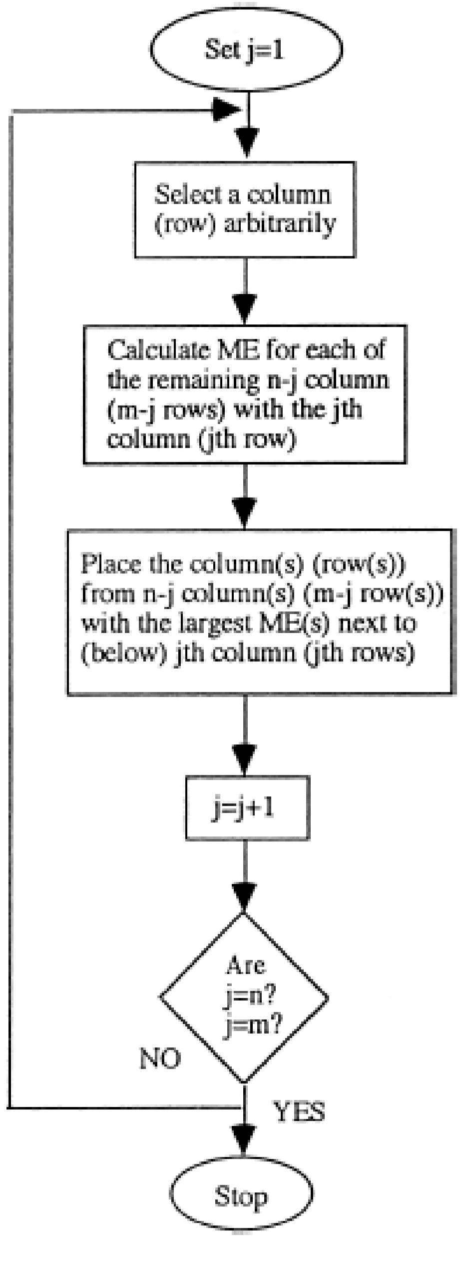

Fig. 5. Flow chart of BE Algorithm.

The Bond Energy Algorithm shown in Fig. 5 outlines the basic algorithm by presenting two basic procedures for the columns and rows. The measure of effectiveness for BEA is calculated as follows:

$$ME = \frac{1}{2}\sum_{i=1}^{m}\sum_{j=1}^{n} a_{ij}\left(a_{i,j-1} + a_{i,j+1} + a_{i-1,j} + a_{i+1,j}\right)$$

The ME measures the density of the bond between any two elements of the matrix. The greater the numerical value of ME, the greater the bond between the elements. The purpose of this algorithm is to permutate the rows and columns and place elements adjacent to one another which have the largest ME values. By using the BEA, an unstructured incidence matrix can be transformed into a new structured matrix with a clear grouping of activities. The clusters (mutually exclusive sub matrices) obtained are considered the building blocks of the logistics system design. For procedural simplicity only two design factors per module were selected for this paper. The incidence matrix (1) represents the assignment of design factors to modules. In the incidence matrix (1), the a_{ij} entries correspond to design factors are presented.

Entry 1 signifies that the inclusion of a particular design factor in a module is a necessary and essential requirement of forming that module. Each module inherently consists of a set of cohesive and bounded design factors whose interactions determine the overall design and effectiveness of the module. The selection and assignment of design factors to the appropriate modules pose a challenge as well as an opportunity for the designer. These decisions are virtually interrelated and must be made with caution. In assigning the binary values of 0 and 1, two issues must be considered. First, not all binary decisions require a similar level of difficulty, skills, and judgment. Some binary assignments are fairly obvious and easy to make.

Secondly, the specific requirements of each logistics design, the complexity of the design process, and finally the number of design factors and modules involved largely determine the nature of the binary decisions. The incidence matrix (1) is an unstructured matrix that will be transformed into a new structured matrix by the use of the BEA. First, column 1 of incidence matrix (1) is selected arbitrarily and the measure of effectiveness for each column is calculated and presented in Table 1. From Table 1, columns 21 and 26 with the ME value of 5 (the highest ME value) are placed next to column 1. This procedure is repeated until all columns are accounted for and placed with one another.

The results are represented in incidence matrix (2). By the use of the BE algorithm and selecting row 1 arbitrarily, the measure of effectiveness for all other rows are calculated and presented in Table 2. Rows with the largest ME values are placed together. From Table 2, rows 13 and 15 with the ME value of 8 and 6, respectively are placed next to row 1. This procedure is repeated until all rows are accounted for and placed with one another. The detailed solution for columns and rows are available from the author. The combined results of both columns and rows for the BEA are presented in incidence matrix (3). The clusters (mutually exclusive sub matrices) in incidence matrix (3) present a structured matrix with a clear grouping of activities.

The incidence matrix (3) indicates that the overall design of logistics can be accomplished in four self-contained modules. Module Family 1 addresses transportation issues. It consists of design for supportability, functional packaging requirements, the transportation mode, and transportability issues. Module Family 2 addresses manufacturing issues. It consists of design for manufacturability, materials, and manufacturing processes. Furthermore, Module Family 3 and Module Family 4 address production planning and control and design characteristics, respectively. For example, Module Family 2 focuses on the issues and problems related to manufacturability, materials, and the actual manufacturing processes. In designing this module family, the designer considers only the necessary and relevant design factors. By so doing, the Scope and degree of complexity of the design become more manageable.

The logistics designer simply focuses on such design factors as: standardized parts, type of manufacturing processes, production volume, material properties, type of materials used, and physical properties (width, height, length, center of gravity, etc.). As is evident, this module family not only considers the commonly used manufacturing design factors, but also cuts across other modules (manufacturing processes - a_5, packaging materials - a_9, transportability issues - a_{15}) and includes other relevant and necessary design factors. This simply signifies that the manufacturability module is not an isolated activity and may not be designed in a vacuum-like environment. On the contrary, this modular approach enhances the effectiveness of the manufacturability module by reaching and incorporating other relevant and essential design factors, which may have otherwise been disregarded. The design effectiveness is further enhanced by the manageability and ease of implementation of such a modular design

Similarly, one may consider Module Family 3, which combines five separate modules from three different subsystems of the logistics design. This module family proposes that logistics engineering, manufacturing logistics, and design for packaging are interrelated and must be considered Table 2 simultaneously. By the same logic, Module Families 1 and 4 may be analyzed and explained.

4. ADVANTAGES AND IMPLICATIONS

The following represents a summary of advantages and practical managerial implications of the methodology of design for logistics. The methodology presented here allows the designer to be an active participant in the design of logistics systems. The designer develops the initial incidence matrix. The final solution to the problem is dependent upon the initial matrix. Various solutions can be developed based on differing initial solutions. This capability enhances the effectiveness, as well as the efficiency of the solution procedure, and provides a great deal of flexibility for the designer. This methodology is applicable to matrices of any size or shape. he only requirement is that the elements of a matrix be non-negative. The BEA solutions are finite. This makes the BEA algorithm applicable to new designs as well as currently existing designs. The final solution obtained by using this algorithm is independent of the order in which the rows and columns are presented.

5. CONCLUSION

A concurrent engineering environment provides a suitable venue to consider logistics problems since logistics concerns, contributions, and constraints are best addressed in the early phases of the product design cycle. The advantages outlined for concurrent engineering earlier in this paper can be realized if logistics requirements, as a part of the overall product design, are considered. The conceptual framework provides for an effective tool for the logistician to include the necessary and relevant subsystems, modules, and design factors. This approach allows the designer to become a full participant in the logistics systems design. BEA provides an efficient clustering algorithm for solving logistics problems. This algorithm generates self-contained clusters that can be more easily understood, changed, and implemented. This feature allows for a logistics system to be implemented more effectively and in a shorter period of time since the independent clusters need not be implemented sequentially.

This paper has specifically explored a large number of areas where collaboration and interface of logistics and design activities can result in significant achievements for a manufacturing enterprise. Although these areas of collaboration are equally applicable to a variety of manufacturing logistics, care must be taken that a specific, relevant, and custom-made program resulting from the unique requirements and environment of each firm is selected. This process allows for a better focus on the ensuing issues that require more immediate attention.

The most important and essential prerequisite for an interface between logistics and design, however, remains to be the elimination of the “over-the-wall-design” concept. All collaboration and interface must be done on a long-term basis unless circumstances dictate otherwise. Logisticians should be given an essential role as the key player in the design process.

This process is certain to fail, if legitimate authority and power is not legated to the logistics function. Top management should genuinely encourage logistics involvement. If the design process is viewed as an abstract and vacuum-like process that is performed sequentially rather than concurrently, no significant achievements are expected to occur. The effective dialogue between logistics and design can only occur when the barriers and walls -whether real or imaginary are removed. The support of top management and a positive institutional culture are essential to instill and foster such an environment.

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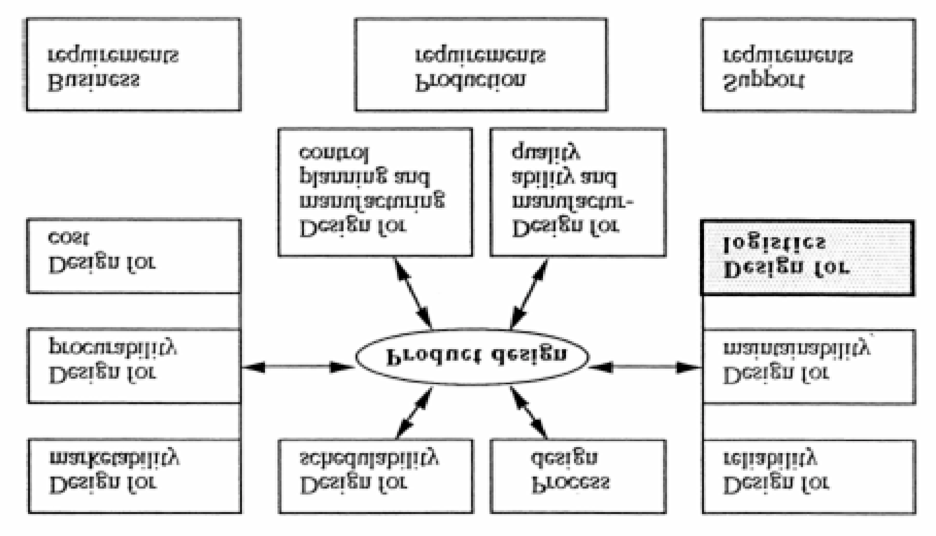

Fig.1. Product design in a Concurrent Engineering Environment

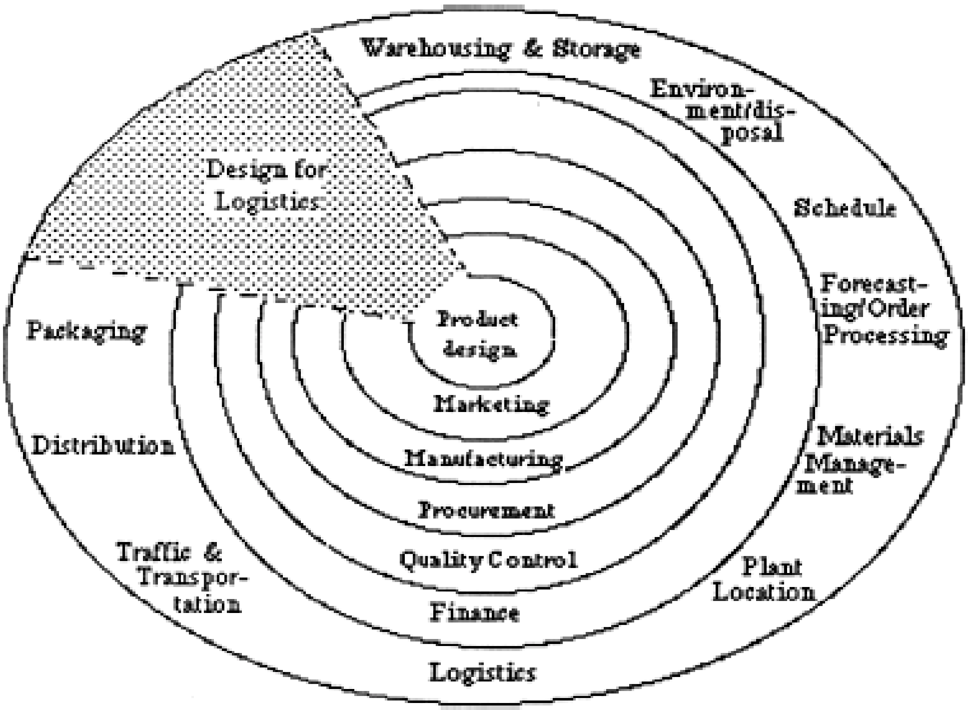

Fig. 2. Integrated logistics system for product design.

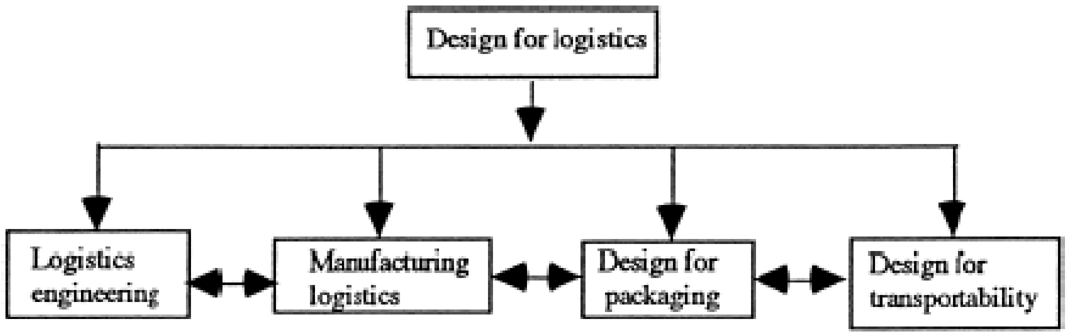

Fig. 3. Design Components for Logistics.

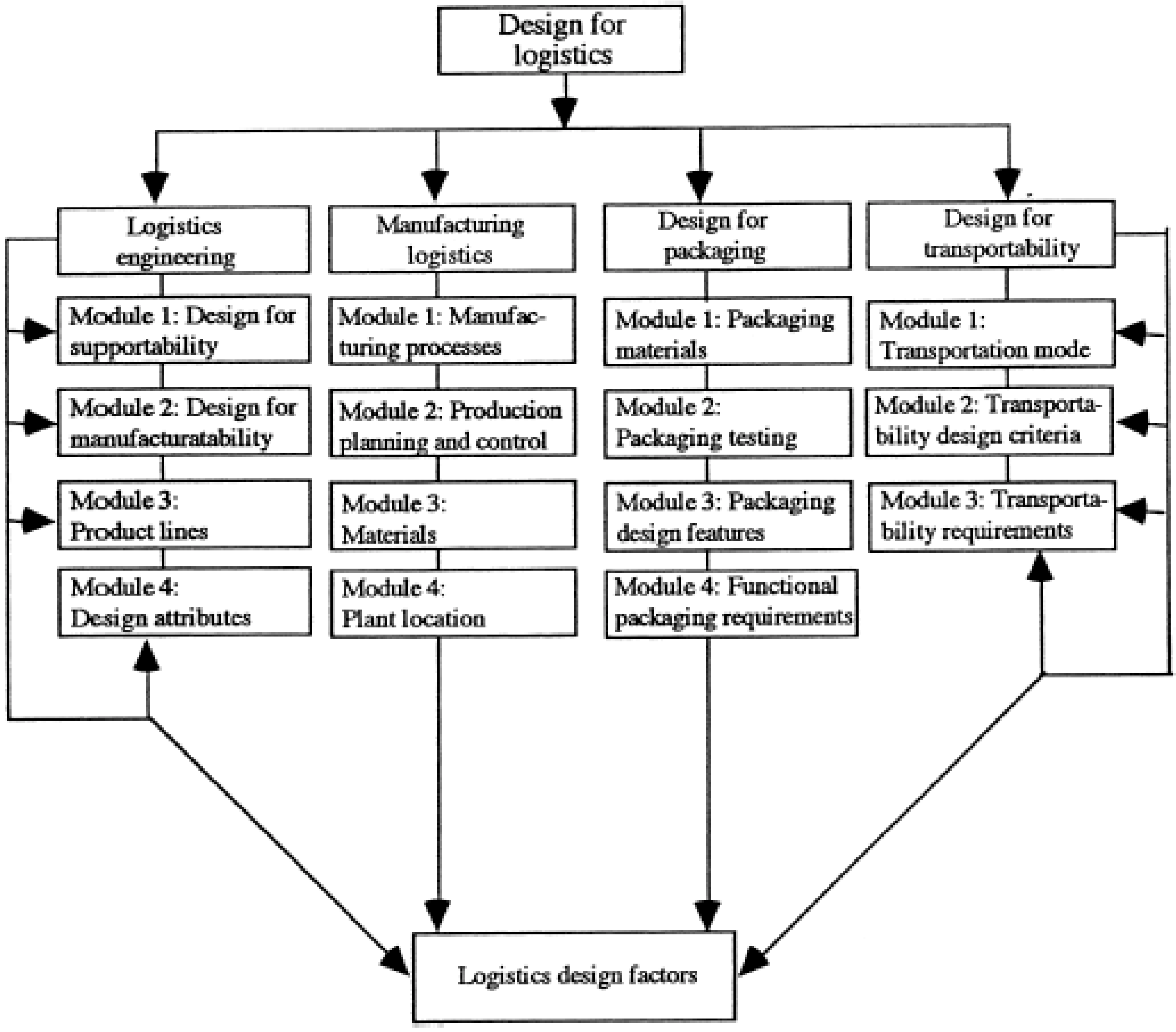

TABLE 1: ME VALUE FOR COLUMN 1

Position	ME			Position	ME		
	J=1	J+1	Value		J=1	J+1	Value
Column Number	1	2	4	Column Number	1	16	0
	1	3	0		1	17	4
	1	4	0		1	18	0
	1	5	0		1	19	0
	1	6	0		1	20	0
	1	7	3		1	21	5
	1	8	2		1	22	0
	1	9	0		1	23	2
	1	10	0		1	24	2
	1	11	0		1	25	2
	1	11	0		1	26	5
	1	12	0		1	27	0
	1	13	3		1	28	0
	1	14	0		1	29	3
	1	15	0		1	30	0

TABLE 2: ME VALUES FOR ROW 1

Position	ME		
	J=1	J+1	Value
Row Number	1	2	0
	1	3	0
	1	4	0
	1	5	0
	1	6	0
	1	7	0
	1	8	0
	1	9	0
	1	10	0
	1	11	0
	1	12	4
	1	13	8
	1	14	0
	1	15	6