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Engineering Product Design for Ease in Assembly Planning

*[1] **Error! Bookmark not defined.**WhyteAsukwoAkpan[2] Awaka-AmaEmediong Johnson[3] V. A. Amba[4] NdifrekeIkemesit Effeng**Error! Bookmark not defined.**[5] Iniobong Okon Nyah

[1] *Department of Mechanical Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Ikot Abasi, Nigeria.*

[2] *Department of Mechanical Engineering of Mechanical Engineering, Faculty of Engineering University of Uyo, Akwa Ibom State, Nigeria*

[3] *Department of Mechanical Engineering of Mechanical Engineering, Faculty of Engineering University of Uyo, Akwa Ibom State, Nigeria*

[4] *Department of Mechanical Engineering of Mechanical Engineering, Faculty of Engineering University of Uyo, Akwa Ibom State, Nigeria*

[5] *Department of Mechanical Engineering of Mechanical Engineering, Faculty of Engineering University of Uyo, Akwa Ibom State, Nigeria*

Abstract
Product design in Engineering may sometimes be very challenging. The Engineer will also bear in mind the manufacturing process that each component of his design will require at a minimal cost. Above all lying ahead is the task of assembling the product after design and manufacture. Even though a good design and manufacturing have been achieved, not factoring assembly may pose a serious problem and may cause undue delay in throughput of the product to the market. Such delays will increase the cost of production and render the product not competitive. It is imperative for the designer to factor in the assembly challenges of his final product as there exists many ways the product can be assembled. Discovering the optimum or near optimum way of assembling the product will ease assembly and make the entire design, manufacturing, and assembly a complete process at a reduced cost. This research has presented the challenges envisioned and elaborately presented measures to obtain good results.

Keywords: Assembly, compensative, design, ease, planning, product

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I. Introduction

An assembly system is a sub-system of a manufacturing system that involves joining or fixing components together to make a whole. It is also seen as a transformation system. According to [1] assembly system is an open system where collection of elements forms a unit and their interactions form its functions. These elements are broken down into sub- systems or components which include human system, material handling system, work-cell, computer and information system, technical system, building and premises, and management system. [2] stated that the elements of the assembly system are characterised by the organization of work and the choice and arrangement of the physical facilities and human resources. Expanding on observations from other authors.[3] defined the elements of the assembly system as the technical system (hardware directly related to the assembly process), the human system (direct and indirect labour), the material handling system (hardware related to operations at or between stations), the computer and information system (hardware and software to be used to communicate information) and the building and premises.

Assembly elements are for carrying out assembly operations on the product. In assembly operations, two or more separate parts are joined to form a new entity in which the components (parts) are either permanently or semi-permanently connected [4]. Retrieving: picking, orienting, and positioning parts prior to its final transfer to final assembly operations. Handling: transferring a part to its final position with the desired orientation. Inserting: mating a part with one or more other parts. Inserting can further be divided into joining operations (welding, brazing, soldering, and adhesive bonding) and mechanical fastening (clipping, threaded fastening, and permanent fastening).

There are various topologies for arranging an assembly system. One of these topologies employed in arranging an assembly workshop is assembly line. The other topologies include cells (islands), a combination of several lines, or a pure job shop (isolated workstations) [5]. An assembly line typically consists of a few workstations that are connected by transportation links, which move a product between stations in a unidirectional flow. In an assembly line, the assembled product gradually takes shape as additional parts are attached at various workstations that the product visits [5]. The order of assembly operations to produce the final product is specified in the assembly sequence plan. Assembly lines can be generally categorised based on the level of automation in assembly operations and the capabilities of assembly lines in creating product variety.

Flexibility of an Assembly System and Flexible Assembly System (FAS)

Flexibility for an engineering system is the ease with which the system can respond to uncertainty in a manner to sustain or increase it value delivery. According to [6], Flexibility is a competitive priority that offers performance excellence to manufacturing industries. It also supports competitive criteria such as quality, delivery, and price [7]. It is seen as a complementary property to productivity; a company has to be productive and flexible [8]. Flexibility is essential to assembly systems [9]. The flexibility of an assembly system is the extent to which it adapts quickly to product variety, changing demand volume with shorter product lifecycle, decreasing lot sizes and simultaneously achieving quality and productivity [10]. As handling the increased product variety is becoming a high priority in manufacturing systems[10].Flexible assembly systems are gaining significant value due to their practical importance and theoretical challenges in creating product variety[11].

A fully integrated production system consisting of computer numerically controlled assembly stations, connected by an automated material handling system, control by a central computer is known as Flexible Assembly System (FAS). A FAS is capable of simultaneously assemble a variety of product types in small to medium-sized batches and at high rate comparable to that of conventional transfer lines designed for high volume, low variety manufacture. In other words FAS is an automated assembly system. Automated assembly technology has been one of the key technologies [12]. As an important part for industrial production, the automated assembly can decide the total cost of production and productivity. The operation of FAS is like that of a flexible manufacturing system (FMS) which runs on Computer numerical control (CNC) machines. These flexible systems have capacities to handle variance operations but good programme capable of running the system are required in correct semantic and syntax.

The problem of FAS is lack of comprehensive programme for the system and the cost effectiveness of automating the whole operations. An offline programme is not enough to run a flexible assembly system that is dynamic in nature and prone to error caused by external forces or conditions not accounted for during planning. Online programmes known as agent based are emerging but still lack the cognitive, intuitive and thinking of humans that is required in an assembly system.

Dimensions of Assembly Flexibility

Flexibility dimension is a circumstance in which flexibility is required [13]. Each operation in an assembly system and manufacturing is identified to suggest a certain dimension of flexibility that is needed to accommodate it [14];[15]. Accordingly, various dimensions of assembly flexibility have been presented but different names have been employed to refer to the same dimension of flexibility [16], no consensus regarding the underlying dimensions of flexibility has been achieved. The following dimensions were summarized by [10]: machine flexibility, operation flexibility, routine flexibility, volume flexibility, expansion flexibility, process flexibility, product flexibility, production flexibility, market flexibility, material handling flexibility, labour flexibility, mix flexibility and new product flexibility. This can be expanded to all activities in assembling system.

Volume flexibility for instance, is not achieved through a single factor; rather, it is created through a combination of factors as sources of flexibility [17]. The factors or sources that contribute to achieving or creating flexibility are referred to as the enablers of flexibility in this dissertation.[13] Be regarded flexibility as a product of several important enablers: corporate culture, management structure, process technology, facility layout, and information systems.

Assembly System and Product Modularity

Modularity, modular development, modularisation, or modular design is used interchangeably by many researchers[9] . The word modularity is coined from the word module. Module is a set of standardized parts or independent units that can be used to construct a more complex structure. According to [18], modules contain components that have minimal dependencies upon same modules and minimal similarities on other components not in the module during their life cycle. Modularisation connotes combination, changeability, and substitutability as well as standardization of modules with which various parts can be fabricated in the firm to meet individual needs. Each component of a modular product is expected to carry out a particular function independently and its design should not be similar with other components of another module. This is the major difference between Modular and integral architectural design.

Many authors view modularity as the key to achieve low cost mass customization.[19] argues that products built around modular architectures can be more easily varied without adding too much complexity to the manufacturing system. Also, modules are seen as physical structures with one-to-one correspondence with functional structures. They can be thought of quite simply as building blocks with defined interfaces [20]. Modular products may be defined as machines, assemblies or components that accomplish an overall function through combination of distinct building blocks or modules [21]. A modular product development is one in which the input and output relationships between components, that is, the component interfaces, in a product have been fully specified and standardized [22].

There are so many ways developed to modularize a product. A modular design splits a system into modules that can be built independently, so that a variety of different system can be assembled from them. Two companies manufacturing the same type of product could end up with different modularized product structures, depending on their strategies.[23] and[24] introduced methods to cut out a module from function structures using module heuristics. These methods identify modules from a functional model of a product creating rough geometric layouts and group products into families based on function. [25]presents Modular Function Deployment (MFD) which is also based on functional decomposition, but other modularity drivers than functionality considered. Other ways for formulating modules are component swapping; this is achieved when two or more alternative components can be framed to form different products. Also, identification of modules can be achieved through clustering existing carriers into modules. Design with Modules; design product out of existing modules and Design of Modules; design groups of function carriers and define interface.

Moreover, there are Modularity drivers which are interfaces, functions, interchange ability and standardization. Interface is further divided into spatial interfaces of components in a product architecture, that is, the space a component will occupy in a product design, the user interfaces defines how a user will interact with a product, attachment describes how a component is fixed into a body or frame, transfer deals with movement, control is about the way of regulating, giving and accepting commands and monitoring the system, communication , and environmental interfaces for components in a product architecture.

Modularity enables firms to achieve several strategically important advantages in competing in product markets. One on one mapping of function and physical component ensures decoupling of task, subcontracting and network cooperation and ease of maintenance, repairs, and recycling. Other benefits of modularity are production of standardized products, it allows delay design decision, decrease order lead time, interchange ability, share the same assembly structure for many assemble operation, combination of component to form sub-units, produce different products through combination of standard components, component economies of parts and flexibility in designing. Modularity over the years has proven to be great asset in the field of engineering. This has been used in modular product design, modular assembly system, Green Life Cycle Engineering, Sustainable Manufacturing, and process Modularity. With all these advantages, Modularity still has limitations in application and having many parts is a disadvantage in assembly systems as there will be many ways to couple them and more parts entails complex combinatorial problem.

Product Design for an Assembly System

Design is the description of a product to be made in the language understood by designers and producers. Product design is the detailing of the material, shapes, and tolerance of the individual parts of a product [26]. Design and development of a product comprises the transformation of conditions, needs, requirement into a concept or idea able to satisfy it[27] Therefore, from the above definitions design and/or development is the transformation of user's need, manufacturer specification, government regulations and/or environmental and social conditions into a concept or idea able to satisfy them and efficiently describing them in a language that aid manufacturing.

As one of the criteria in design, the manufacturability and assimilability of a product must be considered. A good design is one that considered facilities on ground for processing and assembly as one of the specifications in design consideration. A design is useless if it cannot be processed or assemble into a unit to carryout it functions. [27]identified that activities and tasks are arranged in a logical order, in design process of a product in order to get the best result with minimal effort.. The problem context is often complex and messy and poorly understood. In the process of problem solving, temporal formulation of problem will be feasible, but this is unstable and may change as more information is available. In fact, Cross believed problem and solution goes hand in hand. Refining problem statement or definition is continuous throughout the period of providing the solution.

The core of product development is conceptualization. Here different models or concepts are developed from which an optimal concept is chosen. Different solution can be a respond to a problem, but the best solution has to emerge from various proposed solutions. [27] proposed specification and factor matrix (SFM) as a method of developing models connecting specifications with factors. The designer has several tools to aid decision making. Among them, the hierarchy's analysis and Pugh method of comparing advantages and disadvantages of designs [28],[29]. These tools allow the assessment of different alternatives and the selection of the best valued using appropriate design criteria. In the analysis of hierarchies of Saaty the relative importance of each criterion is defined on a square matrix called "matrix of comparisons". On the other hand, Pugh's method provides an overview of advantages and disadvantages of different design alternatives through a matrix where each column represents an alternative and each row an evaluation criterion.

Detailed drawing followed concept generation. It also helps in analysis and evaluation of the product. To check the functionality and workability of a design, the various parts must be fixed together in a pictorial form and analysis of strength, forces and mechanism must be thoroughly considered. This detailed design of the product can be orthographic, sectioning, isometric, part or all of them. In addition to drawing, annotation such as dimension, limit and fit, and legend are included. It should be noted that with the emergence of Robotic and Numerical control machine, concept can be communicated as strings.

Prototyping and testing is necessary for checking and confirmation of the design. In this era prototyping is done in virtual environment not necessary manufacturing it in the factory. If through this virtual testing the interconnectivity, parts movement and obstruction, force exerted, and behaviours of various members can be tested before mass production.

Assembly Planning

According to [30], Assembly planning is generally considered to be the process of determining a set of instructions for mechanically assembly a product from set of components. A more specific definition considering the nature of assembly system with many parts and several operations is by describing assembly Planning as finding an optimal sequence, schedule, procedure, cost and time of execution but there is no such detailed planning. Virtual planners considered an assembly system planning to be a graph of precedence relations in which nodes represent assembly operations and arcs represent precedence relationship [31]. Assembly planning can also be referred to as task planning. In Task planning, assembling tasks are decomposed into sequence of elementary operations. In an automated system, task planning is the assignment of sub-task to resources and a model for coordination and scheduling of system resources. The various subsystems/features that must be planned individually before achieving a good assembly plan include Sequencing, Scheduling, Work cell planning, assembling line, balancing, buffers, tools and equipment, personnel, robots, grasp, movement, path, resources, feedback, and control.

Models and Framework for Planning

Ease in planning of assembly system starts from sequence planning using graphs through computer aided assembly planning, virtual reality, path planning to assembly planning using product design.

Models for Assembly Planning

The combinatorial nature of assembly system makes planning with theoretical analysis complex and almost unachievable as there are so many ways of coupling or assembly parts. [32]agreed with the above statement and stated that there are no formal efficient ways for tackling dynamic system of combinatorial nature. A product consisting of 14 parts can be assembled in fourteen (14) factorials, which is over 87 billion different ways. Enumerating these plans to determine the optimal assembly plan can be prohibitive. To neutralize the difficulty in optimization of assembly system planning,[33] formulated groupings for planning assembly system. This has reduced the number of components in the system thereby reducing number of ways to combine the various parts to form the required unit.

Grouping parts and treating each group as a single part has been proposed to speed up the search for an optimal plan. The implicit result of group representation is the reduction in the number of reorientations in assembly plan which is one of the optimality criteria in assembly planning. An ad-hoc approach to grouping based on user-supplied 'features' listed in the part inventory. They loosely define a group as a set of parts that must be assembled without interruption by any parts outside the group. They identified three types of groups: sort, stack, and layer. A sort of group contains parts that have identical shape (such as screws) as determined from a part database and similar relative positions in the assembly. A stack group can contain parts of different shapes that contact a single assembly direction. A layer cluster is a set of parts sandwiched between two parts. A layer cluster can be disassembled after removing one or both "sandwich" parts.

Also, there are many attempts in generation of models for the realization of an optimal assembly plan. First, researchers were interested in producing an optimal sequence for assembly system.[34] describe an acquisition method based on structured set of questions and introduced a contact graph known as Liaison Graph. This graph decomposed an assembly system into sub system or sub-units known as state. [34] used state tree representation for the sequence and is based on forward planning approach. This method could generate an assembly sequence but is difficult to obtain an optimal sequence. [35] improved on liaison graph by introducing a Diamond Graph. His input was the introduction of non-history dependent non-restrictive assumptions. [36]

proposed AND-OR graph, a very compact representation for both assembling and sequences. [37] interest was on automated system, they proposed two graphs: feature mating operation graph (FMOG) and geometric mating graph (GNG). The first represent components and mating operations and allow manipulation of sub-assemblies. Also, backward assembly planning (BAP) was introduced by

[38] stated that an autonomous and closed to reality planning is required to replace history and non-history dependent. History dependent planning is generated based on experience or past procedure while non-history dependent depends on algorithm. Both approaches looked at information relating to components and relationship between them or mounting sequences as a veritable tool for planning.[38] introduced forward assembly planning that applied hypothetical reasoning technique that will not request a planner considering all aspects before deciding an optimal sequence. A dynamic tree expansion performs selection without calculating all the possible sequences; it utilizes a knowledge-based system that uses hypothetical reasoning and forward chaining as inference method.

Computer Aided and Virtual Assembly Planning

The Attempts to accelerate assembly system through the development of computer aided assembly planning (CAAP) systems have not been successful even when the design has been carried out using a modern CAD system [36]. The very reason for this lack of success is that assembly is dependent on expert knowledge and experience which is difficult to formalize [39]. This called for a more holistic and multidiscipline approach which the significant advancement in virtual reality technology enabled notably virtual mechanical assembly operation and planning. Instead of abstract algorithmic assembly planning, an engineer can perform the assembly intuitively in virtual environment using VR hardware and software [40].

There are many advantages in this approach of Virtual reality including information feedback to the designer in order to refine the product design based on the information obtained from the assembly trials, testing the feasibility of the design and assembly sequence generated from the interaction with virtual environment. Planning with virtual reality (VR) requires creation of the various parts in AutoCAD and transmitting the same to virtual environment for simulation. The virtual assembly environment incorporates virtual representations of components and the assembly shop floor, produces auditory and visual responses when two parts collide, and enables the user to interact with virtual objects to build assemblies. The operator picks the part to be assembled with the virtual hand, and then he moves towards the base part and drops it to the desired position and orientation. Securing the part in its assembly location is made by imposing geometric position and orientation constraints when the moved part is dropped to its assembly location [41]. When the operator generates the assembly plan by performing assembly trials using real parts, he uses his experience and intuition that cannot be represented by any programming language. Virtual assembly system allows testing the product assimilability at the design stage to provide information feedback to the designer.

Virtual Reality too has limitation especially in measurement of its effectiveness in real world. Most of the reported studies use task completion time (TCT) and error rates to measure human performance in virtual environment. From literature available, there is no research aimed at validating the virtual environment by processing the data obtained from the assembly planning activity in virtual world. Most of the published work does not proceed to the validation of the experimental environment before measuring human operator performance when executing the virtual task [42]. There appears to be some confusion whether the virtual environment must be validated before being adopted for performing a task execution or not. However, since the information obtained from the interaction with virtual world will be used to support the task execution in real environment, it is necessary to prove that the synthetic environment represents the real world.

The following approaches can be differed: Roadmap methods; the roadmap approach provides a robot with a collection of path segments leading it around static obstacles. This path is calculated by connecting the initial and the goal configuration of the robot with a roadmap that can be built in several ways. The visibility graph is built by connecting the initial and goal configuration with the edges of all obstacles in the given map. The Voronoi diagram leads through the middle of available corridors between obstacles [43].

Cell decomposition: cell decomposition methods divide the robot's free space into several regions called cells. The connectivity graph is built by connecting adjacent cells. A channel leading from initial to goal configuration through the graph can then be computed. A path can be chosen as, for example, leading through the midpoints of the intersections of two successive cells.

Potential field: potential field methods divide the free space into a fine regular grid and search this grid for a free path.

Nonholonomic planners: in a nonholonomic planner, the path is created as a set of manoeuvres, which consider the geometric and kinematic constrains of the robot. Different approaches have been developed using a random planner or nonholonomic graphs.

Flexibility in Assembly System Using Product Design

[9] defines flexibility in an assembly system, identifies its dimensions, and pinpoints its enablers. Additionally, three requirements of a flexible assembly system for product design were identified: a common assembly sequence, similar assembly interfaces, and common parts. These requirements, if fulfilled in product design across distinct product families, reduce the perceived complexity and support various flexibility dimensions in the assembly system. Moreover, this research study describes the development of a common assembly sequence and similar assembly interfaces as the two key requirements of a flexible assembly system for product design.

The introduction of flexibility in manufacturing system by both the industrialist and researchers is aimed at replacing the inflexible systems with flexible ones either gradually or instantly but problems encountered in the process reduced the pace of actualization. Consequently, more, and far-reaching research by many scholars are embarked on leading to discovery of dimension, enablers and propositions. In fact, there is no holistic solution to this problem rather different aspects are treated separately leading to more knowledge and discoveries. There is a need to collect these discoveries and harness them into achieving the initial aim of replacing the inflexible system, this is called utilization flexibility.

Previous research before [9], were stereo type towards replacing the inflexible system but introduced another aspect of flexibility that treats two systems at the same time in the quest to utilize the inflexible system alongside with flexible system. In that research, as a requirement that must be fulfilled by the product designer, named three enablers of assembly system which were; a common assembly sequence, similar assembly interfaces, and common parts.

Though her work exposed collaboration of systems in achieving flexibility, the paper was bias towards assembly system; hence the inability to reconfigure most assembly system is a great limitation to the success of the work. This is what this dissertation is intended for as planning of assembly system and product design in industry flexibility will explore and utilize compensative and utilization flexibility to bring about flexibility of the system.

Development of Compensative Flexibility

Compensative according is to offset, counterbalance. As applied in this work, the three (3) manufacturing processes; product design, processing and assemble are in tripod function each contributing it flexibility to achieve an optimal flexible system/process in the introduction of a new product. Though this work includes only two (2) aspects of manufacturing, it is of great importance to note that the application of this work can be extended to other aspects especially in automotive industries as processing and assembling cannot be completely segregated.

Characteristics of Compensative Flexibility

One of its characteristics is handling assembly planning and product design simultaneously; the approach is known as concurrent engineering. This is possible as the result and support to industry 4.0 (smart factories), networking, digitalization and intellectualization. In industry 4.0 there are continuous interactions between different departments including the customers in the process of introducing new products to the market. Compensative flexibility is for effective control and coordination between product designs and planning, both must be operated as a unit or under common management. This is necessary for inclusion of the latest technology, responding to feedback, access to assembly requirement, adoption of new models and synchronization of the two departments.

Another quality of CFM is solid modelling and simulation. Components are modelled and assembled in 3D and simulated using available tools such as AutoCAD, AutoCAD inversion, Solid works, FEMAP, Promodel and so on. This aided at arriving optimal plan and design, and testing of parameters of both systems to evaluate if flexibility is enough to introduce a new product.

Also, Flexibility Enablers such as a common assembly sequence, similar assembly interface and common parts are infused in CFM. Another approach adopted is design for assembly (DFA) which could be integral design that implies reduction in the number of parts or modular design that means every component is designed for a particular function and selection of cost effective and easy processes, used of standard parts, reduced number of operations, alignments, and symmetric products.

To facilitate development of compensative flexibility, the following assumptions are necessary:

(i) The assembly system is semi-automated; transportation systems are automated while assembly operations are with human assisted machine; flexibility is actually a meeting point between manual and automated.

(ii) Assembly system is a modular system: uncoupled and multi- directional transport system.

(iii) The assembly plant is already in existence and product architecture is already designed.

(iv) There is a room for reconfiguration, but expansion is not possible.

(v) Each workstation is to complete one stage or process of work.

(vi) The new product designed is treated as derivative or a variant which size and dimensions are within the allowable limit of the configurable assembly system.

Design of Compensative Flexibility

Product design and assembly planning are considered as macro variables. While other variables in which product design and assembly system flexibilities depend on are referred to as enablers, sub-variables, or micro variables. The micro variables include modular product design, parts commonality, parts standardisation, part- process interface standardisation, computer aided design (CAD), design for assembly (DFA), adaptable material supply, increased commonality, versatile workforce, standardise work content, common assembly sequence, similar assembly interface, integrated product properties and strategic planning.

A compensation suffered by either product design or assembly system is what brings about the effectiveness of CFM model in a manufacturing industry. One of these attributes or enablers of product design and assembly system such as modular design, if selected or varied will cause a positive effect on the flexibility of the system.

Enablers or micro variables aid macro variable (product design and assembly system) leading to product introduction. In this era of mass customization, to arrive at product introduction it requires integration and interaction with customers through personal contact cloud, internet and/or survey, technology development, company's differentiation and projected variances resulting from modularization as depicted above. The inputs to product design are standard parts, assembly sequence, common parts, interface, modularization, engineering design and design for assembly. These inputs contribute to produce a product that can be assembled in an already existed assembly system. For assembly system, data of assembly system are supplied to product designer while inputs such as modularization, sequencing, balancing, and schedule are to aid in the process of assimilability.

Compensative flexibility Model is generated from interaction with customers through personal contact, cloud, internet and/or survey, company differentiation, Technology development and/or projected variances resulting from modularization. Product function requirements and assembly process or data are converted into part geometry and technological specifications in the conceptual design stage. From the alternatives generated, most appropriate conceptual design will passed into the preliminary design and detailed design. When a detailed design is completed, parts and assembly models of the design will be used by production engineers to generate assembly plans. The contents of an assembly plan vary with the production environments. The basic information for the generation of plan includes part mating precedence, assembly sequence, assembly operation, part preparation process, human factors, and other consideration. The generated assembly plan should also be compatible with the activities in shop floor production, such as assembly system design and layout, scheduling, and production control.

Product Design in a Compensative System

Product design in a compensative system follows the following pattern:

(i) Standard engineering design processes are to be followed. Also, assembly requirement should be incorporated into the product design procedures.

(ii) Design with product function development, modularization and Design for assembly (DFA). In the process of designing a product using this model, industry 4.0 attributes and imposed specification will be applied to achieve the process of designing and simulation of product.

(iii) Creating parts geometry models of individual parts of an assembly using solid modeling in three Dimension (3D), wire frame, sweep representation, sectioning, auxiliary projections, isometric and orthographic design, knowledge base representation, feature base representation, constructive solid geometry, and boundary representation.

(iv) Conceptualization of product design with assembly sequence, workstation, assembly mode and capabilities. Also, customer's need and company's differential are provided for concept creation meeting the conditions set for compensative flexibility design concept.

(v) The product should have a modular design, standard components, few members of components (a little more or less) and the same operation with the assembly system. Also, the new product should have similar interface with the other derivatives, it should also have standard and standardized components, the weight, size and shape should be within the acceptable range and number of components should be within the acceptable range with the existing variant. It should be such that can be assembled by the already existing flexible assembly plant.

Asking technical questions such as:

(i) Must the part move relative to other parts already installed in the assembly? It is only unique if the movement is essential for product function.

(ii) Must the part be made of different material? It is only unique if the material type is essential for product fit, form or function.

(iii) Must the part be separated from other parts? It is only unique if there is a separation requirement for in-service adjustment or replacement.

(iv) In designing a product using modularity, mapping of component to function and its rearrangement in forming variance model, combinatorial and rearrangement, standardization, changeability, combination and substitution are enshrined in the process. Another driver of modularity is interface especially spatial interface; this is concerned with meshing of parts, related movement, size, and shape. This is important since it is concern with assembly or joining together of parts; method of insertion or joining should also be standardized with the assembly processes.

(vi) Another aspect that can aid in product design in compensative flexibility is knowledge-based modeling where human expertise and experience in products, process or factory environments is stored for future use or when is required. One important feature of knowledge -integrated model is the ability to build abstract taxonomies of product or process as objects and to store the knowledge of former designs, possible alternative parts in an assembly, or the abilities and validity of processes used for a specific class of products. The use of knowledge-based models enhances the capability of information support during the product modeling process, although the automated processing of knowledge in a variety of application systems remains a topic for further research. Also feature based modeling; high level information, such as forms, functions, designer intent, material properties, technological parameters and manufacturing precision (tolerance and accuracy), is stored within a product model. Such high – level information is essential for downstream reasoning processes. Feature recognition and conversion will play a very prominent role in the context of concurrent product process design.

(vii) Redesign parts after critical analysis by grouping, redesigned for more than one functions, use standard parts and module from other variant compatible with the assembly system. This adjustment should lead to a better design with minimum parts to cost trade-off. After following the necessary procedures, the product design should pass the criteria set for conceptual design.

Assembly Planning in a Compensation System

The major steps in assembly planning are decomposition of task, allocation of task and execution of task. This is achieved through relationship graphs such as AND OR graph and diamond graph or computer aided design (CAD) model and detailed description of various parts. Planning assembly system entails workstation, assembly line layout, tools and equipment, personnel and resources and method or types of planning includes scheduling, sequencing and balancing. In application of compensative approach or model, Gantt chart is used for scheduling, contact and translation graph or virtual prototyping for sequence while balancing is arrived at by simulation.

Gantt chart is used in deciding the start and end time and date of an activity. Sequencing is the base for assembly planning as it gives order of assembly and equipment layout. Assembly sequence planning (ASP) is a concept that brings about generation of possible order of assembles and the best in terms of cost, time, ease to assemble and resources is selected. The one selected is known as optimal sequence. Scheduling is resources allocation including human, materials and tools, business and cycle time and shifts. Balancing is considered as determining time that a component spent in a workstation, feed rate and through put.

In a compensation system planning, prototyping and simulation are used; both product and assembly system including components, system layout, equipment and tools, etc are modelled in 3D (three dimensions) and simulated using different patterns. Thus, a pattern that returns minimal consumption of resources, time, and cost is the best method or procedure for arriving at the production of a new product.

Analysis of Parameters of Compensative Analysis

Basic expressions for compensative analysis and performance measurement are presented in Table 1.

Table 1: Assembly system performance measurement

Performance Measurement	**Description**	**Objective**
Measuringlead Time(MLK)/make span/total flow	The total time required assembly a product through a FAS, including any lost time due to delays, time spent in buffers, reliability problems, and parts transfer	Min(MLK) = ∑MLK
Throughput (production quantity)	Daily and weekly quantities of different parts assembled by FAS. Comparison of actual quantity to schedule	Max(P) = ∑P
Availability	Uptime proportion (reliability) of Assembly Station	Max(A) = (MTBF-MTTF)/MTBF

Utilization	Utilization of each assembly station as well as average utilization of the FAS specified period	Max (U) = Q/PC
Tooling	Information on various aspects of tool control	

For adoption of new models to the assembly line operation, there are many ways of synchronizing them. One of the ways is degree of freedom as represented in Figure 2.

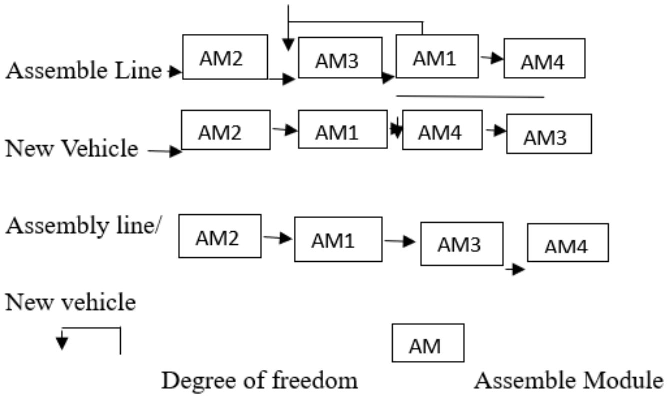

Figure 2: Using degree of freedom to enable planning of product flexible assembly line [44]

The formula for assembly freedom according to[44] is given in Equation 1.

$$y = \frac{x^2 - x}{2} \qquad \text{Equation 1}$$

where y is the number of cells for which the degree of freedom has to be determined, x is the number of modules.
For cost estimation, the best sequence for assembly a product, heuristic search algorithm A^* by [45] is utilized. This is given in Equation 2.

Minimal cost $f(n) = g(n) + h(n)$ Equation 2

where n is the nodes, g(n) is the cost from initial node, h(n) is the cost from current node and f(n) is the estimated cost.
Therefore, cost for current node is given in Equation 3.

$$h(n) = g(n) - f(n) \qquad \text{Equation 3}$$

Assembly Time Calculation: assembly time is the addition of setup time and actual assembly time. To calculate setup time is given in Equation 4.

$$Ti = Qio + \sum_{j=1}^{n} QijXij \qquad \text{Equation 4}$$

where Tiis the setup time, Qi0 is the initial set up time, Qij is contribution of part j when entering i , x_{ij}= {1, if component *j* has already assembled, for $i = 1, \ldots, n$; 0, otherwise, for $i = 1, \ldots, n$ }.
Total assembly time is calculated as given Equation 5

$$T_{ass} = \sum_{i=1}^{n} (T_i + A_i) \qquad \text{Equation 5}$$

where T_i is the setup time, T_{ass} is total assembly time and A_i is assembly time for a component.
The objective function is to reduce the total assembly time (T_{ass}) which will be the effect of flexibility as the result of developed model. To calculate the objective function is given in Equation 6.

$$Z_1 = \min \ T_{ass} \qquad \text{Equation 6}$$

where Z_1 is the objective function for total assembly time and minT_{ass} is the smallest assemble time
Mathematically, sequence is defined as given in Equation 7.

$$S = \sum_{I-1}^{n} O_i$$ Equation 7

where S is assembly sequence, Oi is assembly operations,

If there are operations with the process order Pn $P_1, P_2 - - - P_n$

And $P_1 \leq P_2 \leq P_n$

Therefore, the sequence is as given Equation 8.

$$O_1 \rightarrow O_2 \rightarrow O_n$$ Equation 8

Optimal sequence of the assembly is given in Equation 9.

$$Z_2 = \min \ S$$ Equation 9

where p is process order, O is operations, Z2 is optimal sequence and minS is the sequence with minimum processing time.

Completion time

If c_j is completion time, d_i is due date and L is lateness, therefore lateness is calculated as given in Equation 10.

$$L = c_i - d_j$$ Equation 10

The geometric relationship between parts will affect part assemble as some parts will require reorientation before assembling. It is important to reduce reorientation to have effective. The total number of reorientations necessary during the assembly of a part is a function of the geometry of the part and the subassembly. Reorientation is defined as given in Equation 11.

$$R = \sum_{j=1}^{n} R_j$$ Equation 11

R_i is 1, reorientation is needed when entering component i, for (i = 1, ..., n), otherwise o,

Optimal reorientation is given in Equation 12.

$$Z_3 = \min \ R$$ Equation 12

Balancing is concerned with deciding the feed rate of components to be assembled. This is the ratio of arrival time to processing time and is as given in Equation 13.

$$F = \sum_{i=1}^{n} Ai / ui$$ Equation 13

where F is the feed rate, Ai is the assemble time, µi is the components arrival time.

Optimal feed rate is given in Equation14.

$$Z4 = \min \ F$$ Equation 14

where Z4 is the optimal feed rate and minF is the smallest feed rate required

To calculate the ultimate scheduling is as given in Equation 15.

$$Sc = Z_1 + Z_2 + Z_3 + Z_4$$ Equation 15

where Sc is the schedule, Z1, Z2, Z3 and Z4 are the optimal assembly time, sequence, reorientation and feed rate respectively.

Application or Experimentation of CFM in Automotive Industry

There are over 30,000 parts in an automobile; the basic parts are engine, transmission, body and chassis. The engine combust fuel internally; internal combustion Engine (IC), move the piston up and down creating a chain of motion or momentum that is transferred to the crankshaft which in turns convert into a rotational motion. Other parts are cylinders, valves, and lifters (camshafts).

For experimentation of CFM in this dissertation, an IC is considered. There are different layout of IC engine such as Single cylinder engines, In-Line engines, V engines, W engines, X engines, U engines, H engines, radial engines and delta engine. These are narrow down again to In-line and V engine. As proposed by the CFM parts of engines were modeled, assembled, and simulated in autoCAD and promedel.

Assembly System Planning in an Automotive Industry

Automotive industry has four stages, Stamping, Body in White (BIW), Painting and Final Assemble (FA) in its production process. FA of an Engine is considered for planning, and these are planned; scheduling, sequencing and balancing planning are necessary for an assembly plant. In the assembly line of an Assembly plant for engines depicted by the overview of the engine parts, eight workstations are necessary as follows:

loading and unloading Station, Engine Block, Crankshaft, Camshaft, Liner, Piston, Cylinder Head, Connecting Rod and Rocker Arm Mechanism workstation. Assembly plant planning is as follows:

Assembly Plant Planning

In designing an assembly system, many configuration parameters are possible for work in progress storage capacity, layout configuration- transport path, workstation processing time; assembly and transition time, loading and unloading station and tool handling and preparation station. These design alternatives for assembly system is as shown below in Table 2.

Table 2 Design attributes and configuration parameters

Design Attributes	FAS Components	Configuration Parameters	Number of Alternatives
A	Work-in-progress (WIP) – Storage Capacity	1 – No storage, 2. Buffer Storage, 3. Storage Rack, 4 Storage Rack with Aisle	4
B	Layout Configuration –Transport Path	Linear, 2. Loop, 3. Ladder, 4. Open, 5. U shape	5
C	Workstation processing time; Assembly and transition time	Assembly only, 2. Assembly + washing, 3. Assembly + Measurement, 3. Assembly + Washing +Measurements	4
D	Loading/Unloading Station	1, No station, 2. Common, 3 separate	3
E	Tool handling and preparation	1. Offline, 2. Online	2

Assumptions below are to aid in the simulation process of the system in determination of the assembly plant planning and product assembly planning.

(i) Eight workstations; each operation is carried out in a particular workstation.

(ii) Loop layout: loop layout was considered for the implementation for the new FAS. The key rationales are Loop layout is suitable for mid variety and mid volume range, Loop layout consists of secondary handling system which is required to provide desirable flexibility of routing, it has reduced material transfer time and traffic control is easy to implement in loop layout.

(iii) An AGV material handling system; an Automated Guided Vehicle (AGV) system is a common material handling system that uses independently operated, self-propelled vehicles with the ability to transfer loads to locations and through complex paths.

(iv) 8-station pallet pool (e.g. 1-8 buffers); buffers provided to store parts that are awaiting assembly to avoid obstruction.

(v) AGV speed – low, medium and high; to regulate the speed of AGV.

(vi) Set up times and tooling change times are independent of the job sequence and can be included in assembly times.

The information above is simulated and the results of assembly plant planning are as presented in chapter Four.

Product Assembly Planning

Scheduling, sequence, balancing, manpower, transport system and actual processing. Gantt chart is used for scheduling of engine parts planning assembly.

In sequence determination, Contact and Translation matrix is used. In this model, if two components do not have contact in +X, +Y, +Z, -Y, and/or -Z Cartesian coordinates then a sequence with a sequential order with those components is not feasible. The contacts between two components, a and b, are represented by the 1 x 6 binary function C_{ab} = (C 1, C2, C3, 4CC5, C6). A matrix called the contact function matrix is then defined as follows: Ci = 1, signifies contact in the direction i; C = 0 signifies no contact between a and b where (I = 1, 2, 3, ………n). The translational translation, which is defined by T_{ab} = (T1, T 2, T 3, T 4, T 5, T 6). In this function, Ti = 1 signifies that part b can move freely in the direction of i without collision with part to prevents part b from moving freely. The Table 3.3 represents the 1 x 6 matrix of contact and translation.

For determination of sequence of engine using contact and translational matrix, four parts; part 1; engine block (P1), Part 2; liners (p2), Parts3; piston (p3) and Parts 4; Cylinder head (P4) are considered. This is because the assembly sequence of an engine is standard from sump to cylinder head.

II. Ddiscussion

Research, collaboration, or concurrent engineering is one the approach this model suggests. To define and/or introduce new product correctly, and to continuously improve manufacturing operations, manufacturing and assembly department must effectively collaborate with product design department, procurement and plant operation. Task and process planning can no longer be completed serially and independently of other functions. There are so many dependencies among them that they must work in parallel to shorten the overall distance.

Furthermore, visibility of design department; Product development typically has little or no visibility into the manufacturing planning process. This makes it difficult to consider the impact their design decision has on the cost of product manufactured. Since the manufacturing engineers have little visibility into the department, they have trouble keeping track of changes that may have significant cost implication. Often these costs aren't discovered until the change has been approved and implemented, and manufacturing must address the problem. The cost of designing and assemble is reduced by 80 percent as most of the parts in a compensative design and assembly system rearranged only a few is replaced or added.

Information sharing: it is difficult to share information about what's been done before, and this remain with those who did it. People either must figure it out again or locate the person who did it the last time. This leads to significant amount of wasted time and effort. Compensative system developed help a company store information of the assembly process including sequence, workstations, balancing, scheduling bill of materials (BOM), bill of process and product design history including parts, modules and variants.

Although the introduction of flexibility and modularisation provides the ability to assemble models in the same assembly line, there is still a lot of room for improvement with reference to mass customization. Compensative flexibility provides a common base for assembling of a great number of product variations, involving completely different models.

A better way to manage assembly process planning is to enable product design engineers to gain early access to assembly information and to collaborate with assembly department through compensation, so that manufacturing consideration can influence design decision. Leading companies are implementing a digital manufacturing environment that is tied to product Bill of Material (BOM) configurations, assembly information, modules, standard parts and the associated CAD data early in the design process and as the design progress. This manufacturing environment allows companies to automatically synchronize their bill of process to related product information so that accurate manufacturing process can be defined. In addition, automotive companies are achieving greater engineering synchronization through collaboration within the context of the manufacturing environment. All parties can conduct their design work in a digital representation of the plant floor. This makes it much easier for everyone to understand how their design affects the others. Now, design team don't have to meet in a single location or go to a physical plant to work in context. They can simply collaborate around a digital version from wherever they are in the world. Synchronizing product and manufacturing engineering leverage the strengths of the entire team to arrive at decisions that represent the best course of action for the business.

Throughout assembly process planning, manufacturing engineering develops the method, tooling and sequences required to assemble a product, along with the plant design and material distribution. Manufacturing engineering uses the BOM created by product engineering to generate that of manufacturing. As the assembly process is designed, manufacturing engineering usually validates and optimizes the tooling and processes in a physical prototype environment before releasing it to the plant. Numerous people representing the many functions involved in planning the assembly process need to work together to create the best possible process. Complete collaboration does not occur unless all of these people are physically present in one location for a design review. Only then do they fully understand how design of one part of process affects the others. However, when that collaboration session ends, people go back to their individual jobs and collaboration becomes difficult again. As things evolve throughout the development and planning process, the lack of continued collaboration leads to assembly process that don't match the latest part revision or process changes and/or tooling that impedes the overall assembly process.

The behaviour of a manufacturing system to the introduction of a new product testing on but not limited to time, cost and resources showed a remarkable improvement with compensative flexibility. Moreover, this is applied to test for optimal product design and assembly planning, aid on how to arrive at optimal product design and assembly system and validation with computer model.

Compensative flexibility is applied in an automotive industry, although the introduction of vehicle platforms provides the ability to assemble more models in the same assembly line, it brought about improvement with reference to mass customization. A platform provides a common base for the assembling of a great number of vehicle variations, involving completely different models and each version can be further customized with the addition or removal of optional components. However, it must be noted that of the four aspects name stamping, body shop, painting and final assembly, the greatest number of variants and thus, the extent of personalization, is carried out in the fourth level, namely the final assembly stage, where human workforce is mainly utilized. If these changes are handled in design stage and give appropriate modularity it wouldn't need addition department to handle the variation.

In addition, the cost, induced when changes in physical flows occur with the current systems, may be quite high and therefore, more flexible automation is required. Dedicated fixture has been effectively used for high production volumes, but it seems unable to cope with the large product variety. Moreover, the fixtures should be designed in such a way to assure repeatability and stability. This, in conjunction with the fact that the fixtures constitute a significant portion of the production cost pie, renders the need for fixture optimization imperative. Fixtureless assembly on the other hand, is not considered as a viable solution nowadays, due to the increased cost requirements for vision systems, sensing techniques and controller capabilities. Furthermore, limitations on the cooperation, between vision systems and robots during tool positioning (identification time), make the alternative of having systems able to be self-programmed, and with as little data as possible, preferable.

III. Conclusion

Set up time of workstation and transportation system traffic by varying automated guided vehicles and temporal storage buffers can be done by simulation traffic by varying automated guided vehicles and temporal storage buffers. It has the potential in reduction of AVG block time.Application of this model can be extended to processing, synergy will increase effectiveness. Furthermore, extent to the utilization of this approach in assemble system and product design is not limited to sequence, scheduling, balancing and layout but many other aspects**.** An application can be developed using this approach in determination of sequence, schedule, design, simulation of prototype or new variants and so many other aspects.

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