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Flexibility in Assembly Planning Through Product Design in Industries

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ABSTRACT: Manufacturing processes and equipment that can handle preconceived and emergency changes with low penalty in time, effort, cost and performance are required in the industries to accelerate introduction of new product, handle breakdown of systems and modification of already existing products. Though there are several attempts on this research, especially in development of equipment capable of handling industrial changes but the results are still not satisfactory. Contributing to achieving a Flexible assembly system. Compensative flexibility Model/Approach was carried out in this research to handle Flexible Assembly system through product design. The model developed performed: generation of assembly sequence, schedule and balancing for assembly planning at the product design stage, extracted product assembles requirements for product design at the conceptual stage to guide the designer; synchronized assembly system and product design and; modularized assembly system and product design. Transportation system of an Assembly system of an engine was simulated using ProModel Simulator and the result was remarkable. Also the design of IC engine using two variance; inline and V IC engines showed remarkable improvement in parts interchangeability and commonality with modularized design; 76% of the parts used in inline engine were also used in the V engine variance. Results from simulation runs with 8 automatic guided vehicle (AGV) in the system were observed, with the average time spent by parts in the system and the average time blocked were significant dropped as number of buffers and AGV were increased; the effect was more pronounced with 8 AGVs and 8 storage buffers in the system. The average (AVG) time blocked with 8 AGV and 1 storage buffer was 56.7 minutes and reduced to 0 minutes when the number of storage buffer increased to 8 with 8 AVGs, the percent reduction was 100 percent while AVG time in the system with one storage buffer was 59.34 minutes and reduced to 4.37 minutes with 8 storage buffers which is 96.9 percent reduction. The variation of number of vehicles and buffers reduced or increased the time component spent in the system. Thus, if correct workstation or assembly system resources are determined and designs are modularised, more articles will be introduced to the market, time to market will reduce, many variances will be produced and there will be reduction in the cost of production. The application of this technique is recommended for processing industry.

KEYWORDS: Assembly, Automatic guided vehicle, flexibility, planning, product design.

1.0 INTRODUCTION

The circumstances in which production system operates changes constantly due to external factors such as development of new and rapid technology, constantly changing customer demands for products, the short lifecycle of products and internal factors which are company's differentiation, and increased product functions. These make manufacturing system complex and very competitive. To meet up to these demands satisfactorily and effectively, many companies are adopting flexibility; flexible systems and flexible approach. This is captured in the work of Jain, which stated that a shift in focus has occurred towards flexibility as one of the most sought-after properties in modern manufacturing systems.Many researchers also recognized this paradigm shift towards flexibility to bring about optimal utilization of factory facilities and to explore more areas with the possibility to eliminate completely nonflexible operations. According to [1], Flexibility in manufacturing system has attracted attention among researchers in recent years with an increase of approximately 3.5folds number of publications between 2008 and 2013 compared to 1987 and 1995.

Research works on this subject has few definitions that are closely related to the objective of this paper , though there is no consensus definition yet, these are as follows: [2] described a flexible system as a system that is reversible adaptable to changing circumstances in the context of a principle preconceived scope of features. Upton, 1994, considered the effects of flexibility. He defined flexibility as the ability to change or react with low penalty in time, effort, cost or performance. Other scholars defined flexibility in terms of competition; Flexibility is a priority because it offers performance excellence to manufacturing companies [1] and supports the other competitive criteria: quality, delivery, and price. [3] Flexibility is a complementary property to productivity, meaning that companies must be both productive and flexible [4].

Emergence of flexibility was herald as the solution to manufacturing industries by many, the same way with robotics and artificial intelligence (AI) but the situations that vitiated those two still extended as capabilities, dimensions and enablers are still not completely understood. Also, there is no consensus definition of the topic and therefore the benefits are still not completely understood and utilized. This is proving that proposed solutions or inventions on this topic are not definite in their results or application. It is a call for more research.

The growing attention towards flexibility in manufacturing companies also highlights the significance of flexibility in assembly systems and product design as essential parts of the manufacturing system. An assembly system is a transformation system in which product parts/modules are gradually joined together into the final products through assembly operations performed by the operators [5**]** stated that an assembly system as collection of interrelated components such as people and machine organized to work together towards an end, with different parts and modules that can be factor into different sets, it is imperative for the system to be able to handle variant sets. This was identified by the duo of Elmaraghy that described an assembly system to be flexible to adapt quickly to product variety, changing demand volume with shorter product lifecycle, decreasing lot sizes and simultaneously achieving quality and productivity [7**].**

There is no agreement to whether an automation system, manual system or mix should be considered a flexible assembly system (FAS). Moreover, it is not agreed if flexibility in assembly system should be seen as an approach or automation machines. [8] defined flexible assembly system as a series of versatile workstations that are connected to an automated material system. Although several researchers have considered a flexible assembly system to be a system equipped with different automated machines or robots working in the line [9**]**, some researchers have associated manual assembly operations with the achievement of high flexibility and a high number of product variants in the assembly system [10**].**

Given the major investments in assembly systems, an appropriate product design supports handling product variety by effectively utilising the capabilities of assembly systems[11]. A superior product design saves time and costs for assembly systems with reduced components, easy assembly operations, and optimal part structures in an accessible working space of assembly tools[12].The growing product variety, on the one hand, and the capabilities of a flexible assembly system, on the other hand, highlights the pivotal role of product design in a flexible assembly system

The introduction of Robots, Artificial Intelligence (AI) Machines, Computer Numerical Control (CNC) Machines, Three Dimension (3D) printing, and other flexible Machines were aimed at achieving flexibility in manufacturing system. Sadly, these Machines did not achieve the desired results as flexible machines alone were not enough to cause a shift in the system.

Also, with extensive amount of research, hypothesis, models, framework and publications[13] reviews on flexible manufacturing highlight lack of complete understanding of the concept and underline the need for more studies [14] **.**Concurrently, enablers of flexible manufacturing system are unclear in theory and specific management issues regarding their implementations in practice still needs to be identified [13].

Aside, for assembly system, most of the research in this domain addressed the design, balancing or scheduling issues of flexible assembly system [15],[16]. In fact, definitions of flexible assembly system are not holistic and lopsided not detailing the characteristics of flexibility in assembly system. For instance, a flexible assembly system is considered as a system equipped with different automated machines or robots working together [9**]** and in other cases, manual operations are regarded as decisive factor in achieving high flexibility [17**]** Considering the insufficient and inconsistent research studies on flexible assembly systems and the ambiguity surrounding the concept of manufacturing flexibility in theory and practice, a flexible planning is required to harness and articulate proper procedure and method of operating an assembly system.

The lack of understanding of flexibility in manufacturing system is not limited to processing and assembly context but affects also the relationship between product design and assembly system. The link between flexible assembly systems and product design has remained unidentified despite its significance to theory and practice. The investigation of this link is particularly critical for flexible assembly systems since high product variety leads to increased complexity in assembly systems. Although product variety allows manufacturers to satisfy a wide range of customer requirements, it is regarded as a major contributing factor to increased complexity in assembly operations and assembly systems as a whole [18**].**

It is important to harness all the achievements in flexible assembly system through planning; a flexible planning system that will consider both automated and manual operations is necessary, that is what this research is set to achieve. Also a synergy between assembly system and product design will harvest success in both systems through determining the requirements of a flexible assembly system for product design and requirements of product design for a flexible assembly system.

Assembly system and flexibility as the foundation and veritable tool respectively for assembly planning is discussed alongside with Theoretical works, experiments, surveys and case studies carried out in this field in a quest to examine planning assembly system and product design as a concurrent engineering.

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 [19], assembly system is an open system where collection of elements to form a unit and their interactions form its functions. An assembly system requires resources to carry out it functions. These are broken down into sub-systems which include human system, material handling system, work-cell, computer and information system, technical system, building and premises, and management system. [20] stated that the elements of the assembly system are characterized by the organization of work and the choice and arrangement of the physical facilities and human resources. Expanding on observations from other authors, [21] defines 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[22]. An assembly operation is generally performed by completing three primitive actions (Edwards, 2002): 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)[23]. An assembly line typically consists of a number of 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[23]. 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 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 [1]. Flexibility is a competitive priority that offers performance excellence to manufacturing industries. It also supports competitive criteria such as quality, delivery and price [24]. It is seen as a complementary property to productivity; a company has to be productive and flexible [4]. Flexibility is essential to assembly systems[5]. 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 Flexible assembly systems are gaining significant value due to their practical importance and theoretical challenges in creating product variety[9].

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 [25].The automated assembly technology is a comprehensive technology which combines the mechanical design, robotics and sensors and detection techniques [26]. As an important part for industrial production, the automated assembly can decide the total cost of production and productivity. With the increasing functional demand for industrial products, more advanced automated assembly technology are accessed to meet the sophisticated demand [27]. The operation of FAS is similar to 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.

Flexibility dimension is a circumstance in which flexibility is required[27] .Each operation in an assembly system and also manufacturing is identified to suggest a certain dimension of flexibility that is needed to accommodate it[28],[29].Accordingly, various dimensions of assembly flexibility have been presented but different names have been employed to refer to the same dimension of flexibility[30], no consensus regarding the underlying dimensions of flexibility has been achieved [31]. The following dimensions were summarized by [32] : 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.

Manufacturing flexibility is not achieved through a single factor; rather, it is created through a combination of factors as sources of flexibility[33]. The factors or sources that contribute to achieving or creating flexibility in manufacturing or assembly systems are referred to as the enablers of flexibility in his work[34] regarded flexibility as a product of several important enablers: corporate culture, management structure, process technology, facility layout, and information systems. According to [35] four general areas; strategy, environmental factors, organisational attributes, and technology constitute the dominant forces that influence manufacturing flexibility.

Modularity, Modular development, Modularisation, or Modular Design are used interchangeably by many researchers [5]. 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 [35] **.**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 components 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.[36] argue 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 [37**]** Modular products may be defined as machines, assemblies or components that accomplish an overall function through combination of distinct building blocks or modules [38**]** 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 [39].

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.[40],[41] introduces methods to cut out a module from function structures using module heuristics. These methods identify modules from a functional model of a product, create rough geometric layouts and group products into families based on function.[42] presents Modular Function Deployment (MFD) which is also based on functional decomposition, but other modularity drivers than functionality are 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. Identification of modules; 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.

Modularity drivers include interfaces, functions, interchangeability 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 [43**].**

Modularity enables firms to achieve a number of strategically important advantages in competing in product markets.[43]identifies four such strategic advantages including greater product variety, faster technological upgrading of products, greater speed in developing new products, and cost reductions. 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, interchangeability, 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 have 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.

Design is the description of a product to be made in the language understood by designers and producers. According to [44]. Design generation is the ability to visualize something internally, in the mind's eyes and been able to make external visualization. Product design is the detailing of the material, shapes, and tolerance of the individual parts of a product [45**].**Design and development of a product comprises the transformation of conditions, needs, requirement into a concept or idea able to satisfy it [46**].**Therefore, from the above definition design 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 assemblability 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. [46] 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. [44**]** stated that there is no definitive formulation of the problem in the early stage; the problem is vogue, and criteria and conditions unknown. 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.[46] 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[47,[48]. 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 after concept generation. According to [44**]** drawing is used for communicating concept or idea created to the manufacturer. 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, 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 exacted and behaviours of various members can be tested before mass production. Figure 2.1 shows the stages of product design.

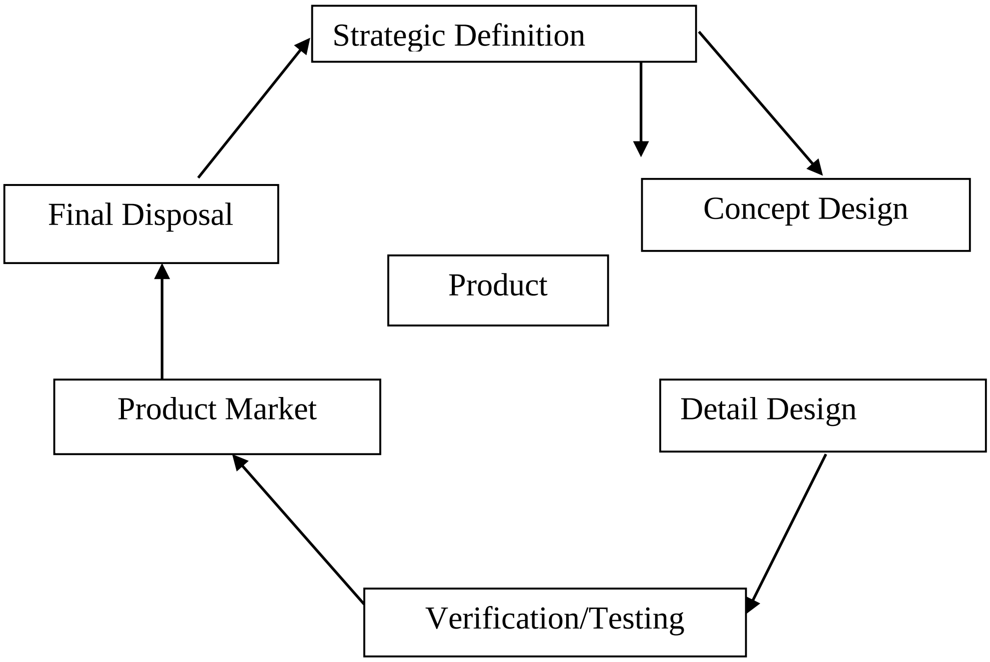


Figure 1: Product life cycle [44]

Decomposition, allocation and execution of tasks sum up to be what assembly planning is all about[49]. A taxonomy of assemble and task planning by IEEE enlisted three methodologies of planning to include planning and integration of design and manufacturing, offline planning under uncertainty and online planning execution and reaction. According to [50] 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 operation 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 [51**]. 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.

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.[52]. 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, [53**]** formulates 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 [54]. 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. [54] proposed 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 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 make contact with 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 of the “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. **[**55] 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. Bourjault 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. [56**]** improved on liaison graph by introducing a Diamond Graph. His input was the introduction of non-history dependent non-restrictive assumptions.[57] proposed AND-OR graph, a very compact representation for both assembling and sequences. (Huang and Lee 1989) 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 [58**]**to overcome some limitations of planners based on disassembly since some assemble sequences cannot be derived from the reverse of a disassembly sequence.

[59**]** 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. [59**]** 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.

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[6] The very reason for this lack of success is that assembly is dependent on expert knowledge and experience which is difficult to formalize [61**].** 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 [62]**.**

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 [63]. 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[64] . 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 assemblability at the design stage in order 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 [65].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.

A large number of methods for solving the path planning problem based on an environment map for mobile robots are known [66] **.**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 [67**].**

Cell Decomposition; Cell decomposition methods divide the robot's free space into several regions, so 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 mid points 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 take into account the geometric and kinematic constrains of the robot. Different approaches have been developed using a random planner or nonholonomic graphs.

[5**]**in her research defined 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, the research study described 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 researches 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 researches before [5] were limited towards replacing the inflexible system but she 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 her research, as a requirement that must be fulfilled by the product designer, she 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, she was particular towards assembly system; hence the inability to reconfigure most assembly system is a great limitation to the success of her work. This is what this research is intended for as planning of assembly system and product design in industry. Flexibility will explored and utilized- compensative and utilization flexibility to bring about flexibility of the system.

The objective of the research is to examine flexibility-in assembly planning and product design in industries: Develop a model/frame work for product assembly and product design, incorporate flexibility in product assembly and design, with emphasis on compensative and utilization flexibility. Different products design will be carried out and a computer model used to assemble to evaluate its usefulness in a virtual assembly system.

2.0 METHODOLOGY

The research method adopted include;

(i) Development of a Compensative Flexibility Model (CFM) for assembly planning and product design; the model developed performed; (i) generation of assembly sequence, schedule and balancing for assembly planning at the product design stage, (ii) extracted product assembles requirements for product design at the conceptual stage to guide the designer, (iii) synchronized assembly system and product design and (iv) modularized assembly system and product design.

(ii) Experiment process; the developed framework was tested using promodel simulation and evaluation application.

(iii) Verification of the model; the model generation process was compared with other models that perform the same functions. Also, the processes for problem generation and the approaches for solving same through arithmetic, empirical formula and experimental verification was done. .

(iv) Validation or comparison with other models.

2.2 Development of Compensative Flexibility

Compensative according to[68] **(America Heritage Dictionary of English Language Fifth Edition, 2016), i**s to offset, counterbalance. As applied in this work the three 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 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.

2.2.1 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 have to 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 aid at arriving optimal plan and design, and test 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.

[69]**](Kern *et al*., 2016)** work on planning of workstation in modular automotive assembly system which identified modularisation as a solution to assembly system planning is considered.

The model is for evaluation of the flexibility of product design and assembly planning. Moreover, contact and translation matrix was used for generation of sequence, AutoCAD software was adopted for solid models, orthographic, isometric and sectioning drawings, and also for assembly of the sample product.

2.2.2 Assumption

To facilitate development of compensative flexibility, the following assumptions were made;

(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 work station 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

2.2.3 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.

A schematic of the Macro variables with their detailed relationships are as shown in Figure 2.

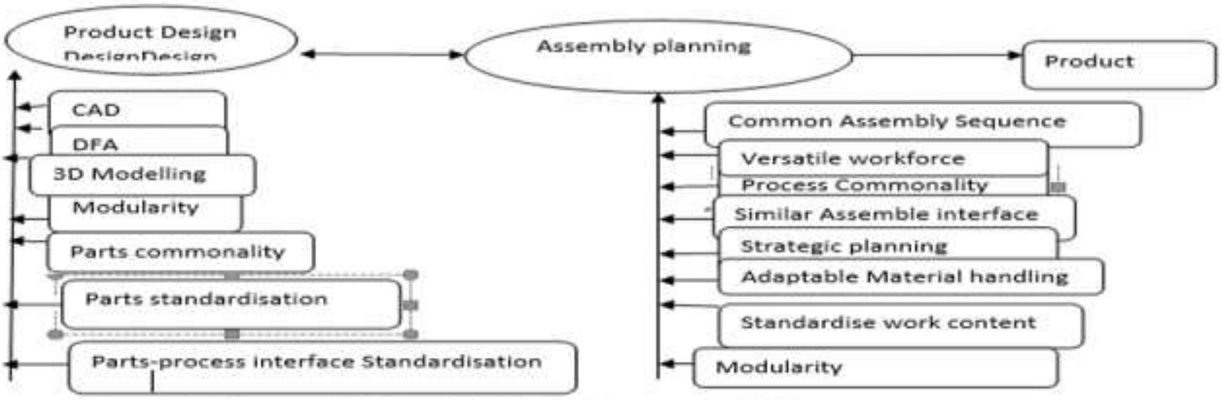


Figure 2: Macro and Micro Variable (Researcher 2022)

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 design that can be assembled in an 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 assemblability. An architectural framework for compensative flexibility is as depicted in Figure 3.

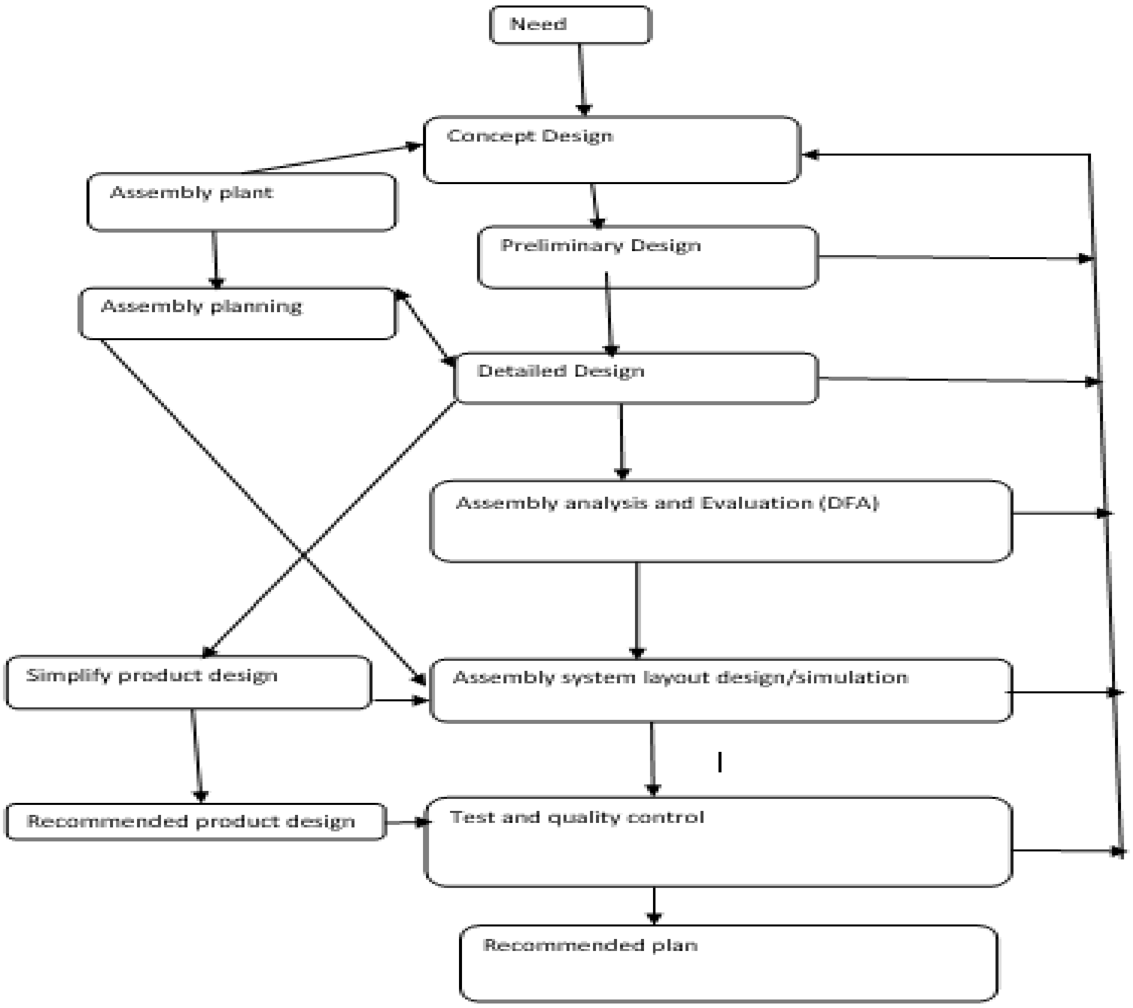


Figure 3: Flexibility Model (Researcher, 2022)

Compensative flexibility Model is as depicted in Figure 3 above; need 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.

2.3 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. The only exemption which is the interest of this dissertation is the assembly requirement that must be incorporated into the product design standard 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.

2.4 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 work station, 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.

2.5 Analysis of parameters of Compensative analysis

Table 1. Assembly System performance Measurement

Performance Measurement	Description	Objective
Measuring lead 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	

2.6 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.

2.6.1: COMPONENTS IN ENGINE

The basic parts are modeled and they are; sump, crankshaft, engine block, connecting rod, piston and rings, camshaft, cylinder head and rocker arm. ancillary, standard and other auxiliaries such as bearings, gears, chains, bolts and nuts, pumps, injectors, governors, racks, control mechanisms, exhaust, turbo chargers, radiators, etc were not designed; this was to reduce the complexity of the system. The rocker arm in this research refers to rocker arm, push rod, valves and springs. Figure 4 presents an overview of internal combustion engine.

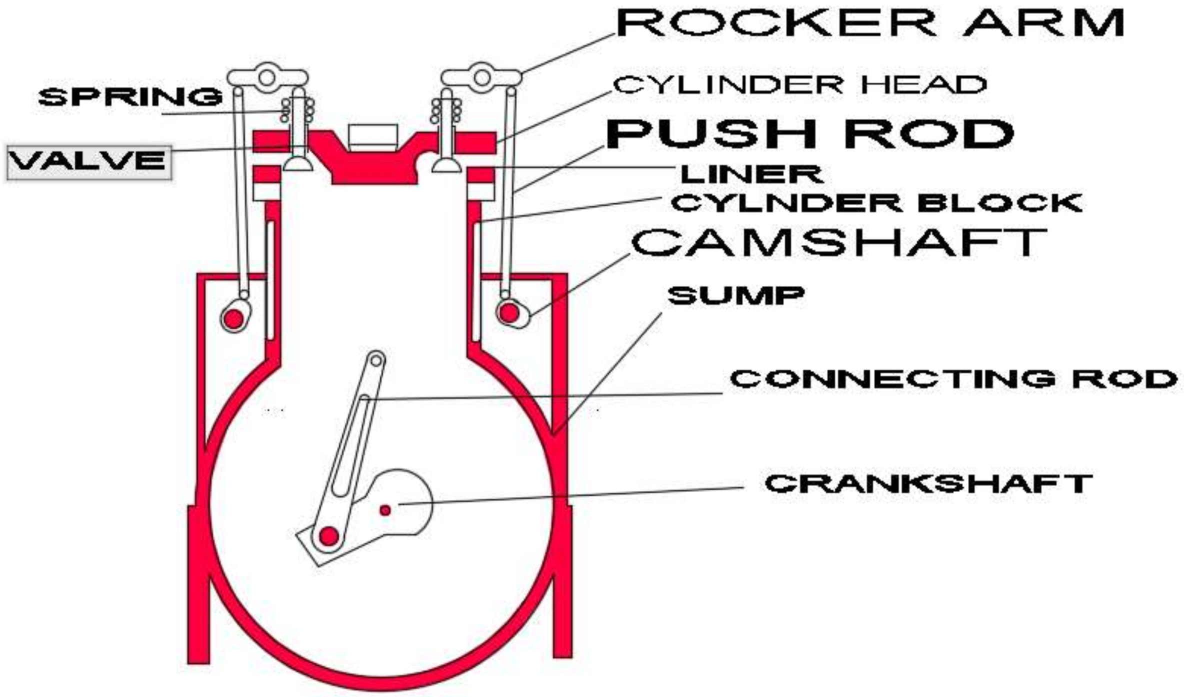


Figure 4: Overview of Internal Combustion (IC) Engine Parts for Inline Engine

Figures 5, 6 and 7 show relevant parts, engine orientation for V engine.

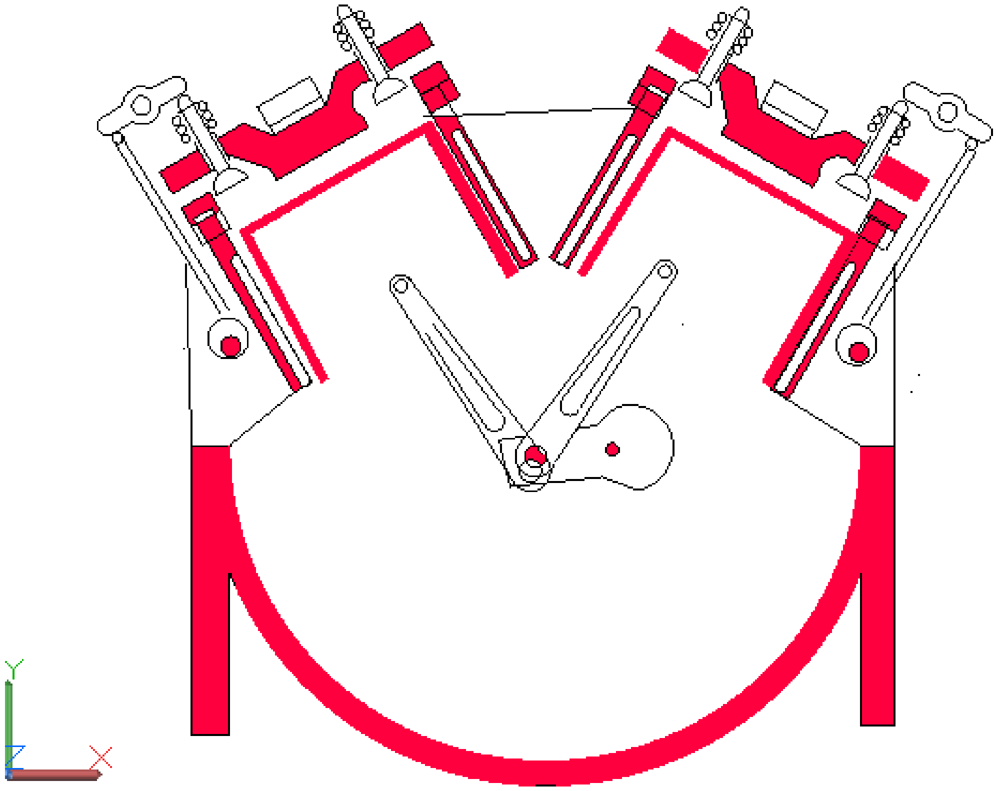


Figure 5: Overview of Internal Combustion (IC) Engine Parts for V Engine

Figure 6: V Engine block

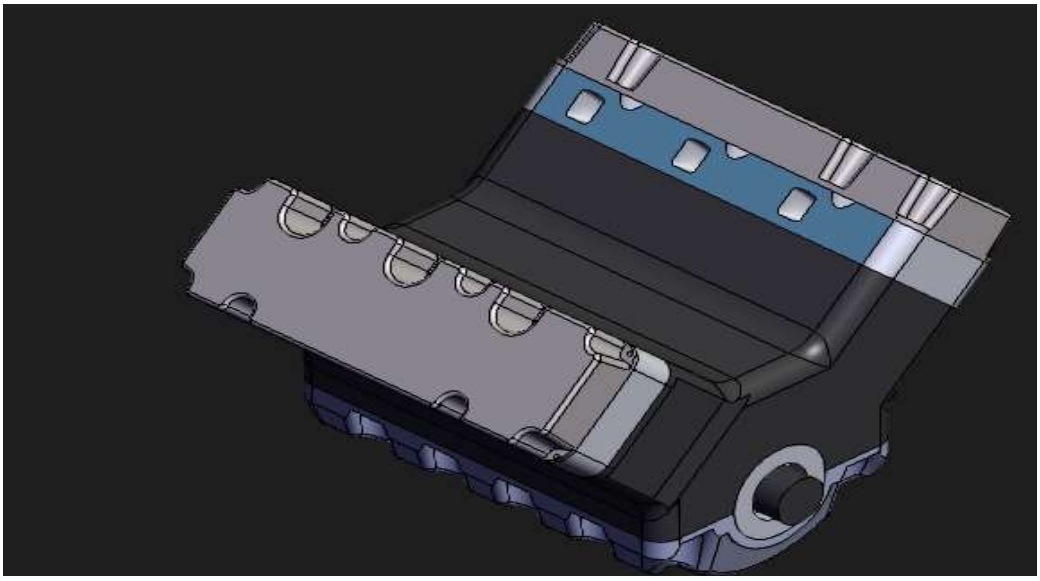


Figure 7: Assembly system planning in an automotive industry

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 this planning include; 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:

2.6.2 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 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	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 work station

(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.

Assemble plant layout is as shown in Figure 8.

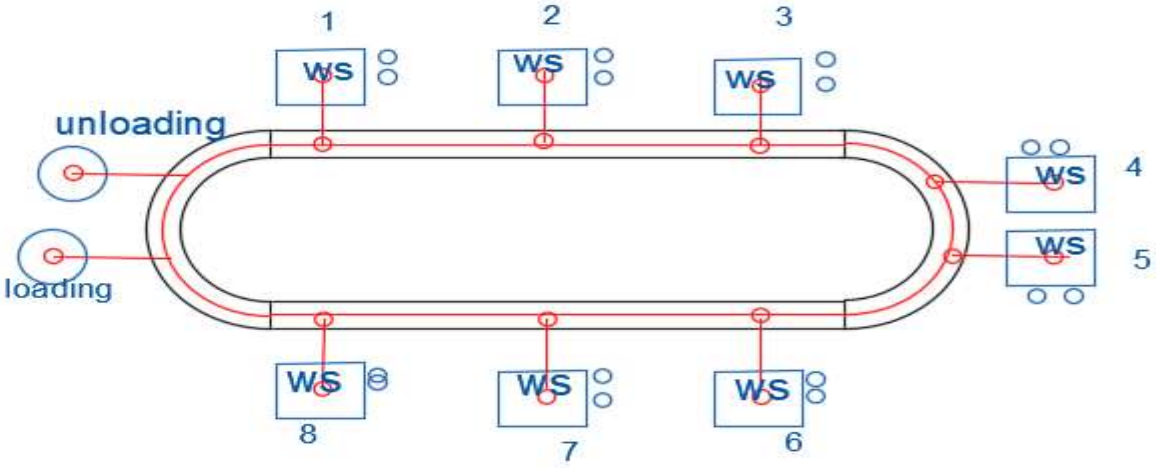


Figure 8: Assembly plant loop layout for Engine Assembly

The information above was simulated and the results of assembly plant planning are as presented.

2.6.3 Product Assembly planning

Scheduling, sequence, balancing, manpower, transport system and actual processing. Gantt chart was used for Scheduling of Engine parts planning assembly and is as show in Figure 9.

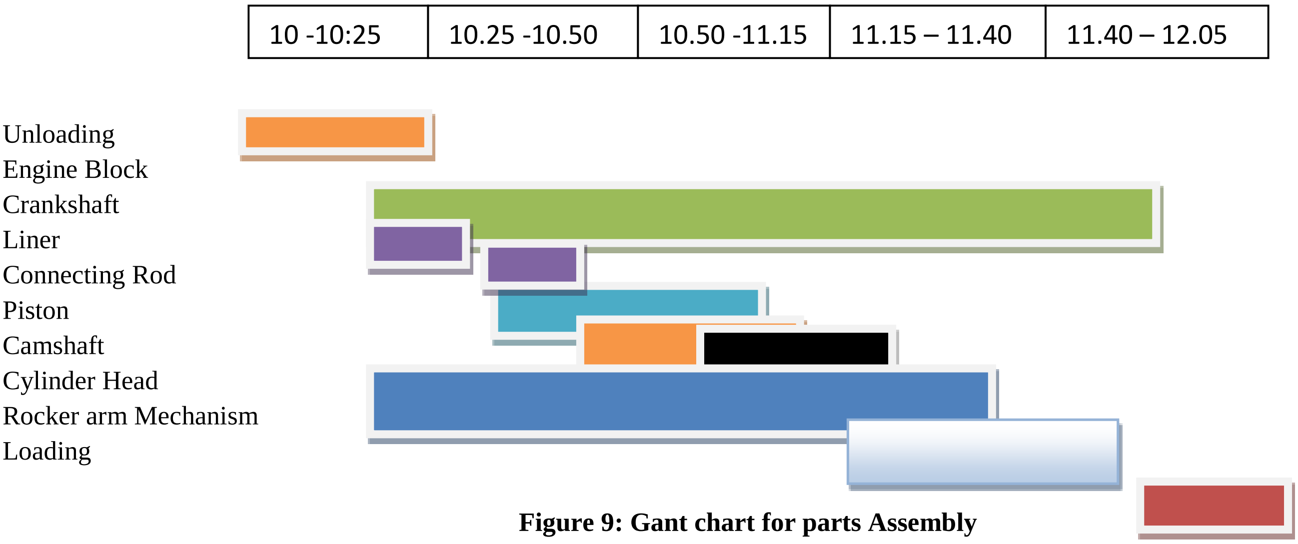


Figure 9: Gant chart for parts Assembly

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 component 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 3.1 below represents the 1 x 6 matrix of contact and translation.

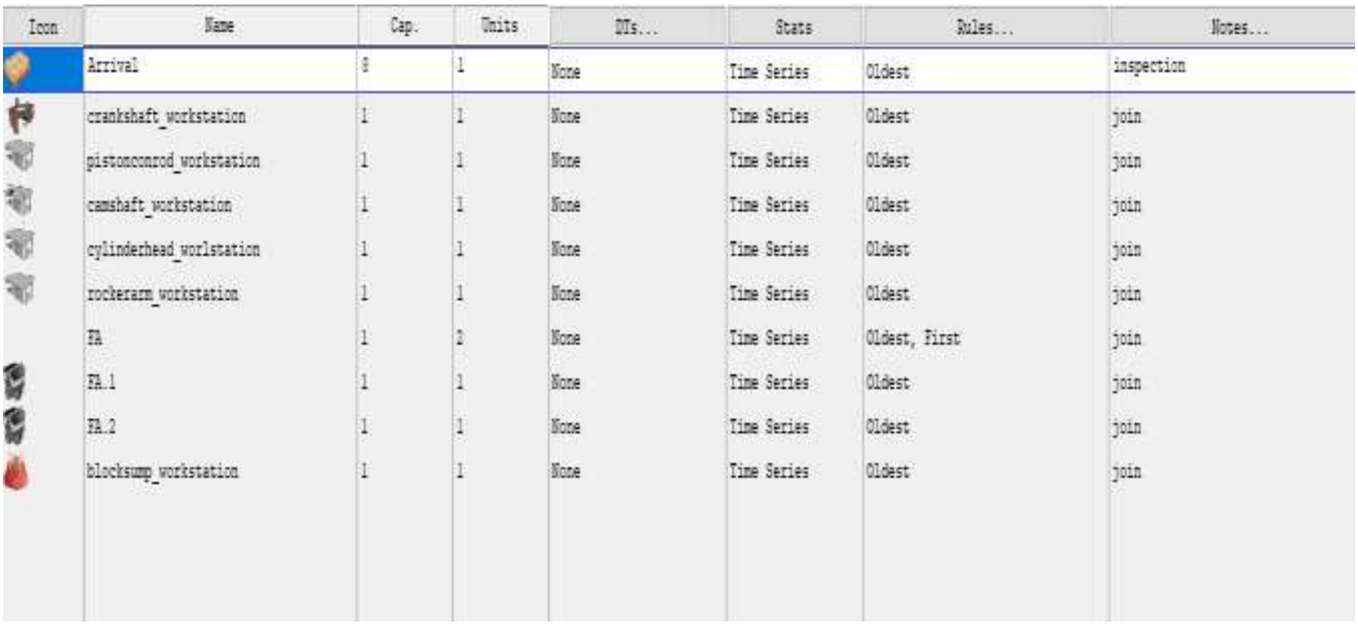
For determination of sequence of engine using contact and translational matrix, four parts; part 1; engine block (P1), part 2; liners (P2), part 3; piston (p3) and part 4; Cylinder head (P4) were considered. This is because the standard assembly sequence of an engine is from sump to cylinder head.

Table 3. Contact and Translation matrix

Pair	C_{+x}	C_{+y}	C_{+z}	C_{-x}	C_{-y}	C_{-z}	T_{+x}	T_{+y}	T_{+z}	T_{-x}	T_{-y}	T_{-z}
P_1p_2	1	1	1	1	1	1	0	0	0	0	0	0
P_1p_3	0	0	0	0	0	0	1	1	1	1	1	1
.P_1p_4	1	1	1	1	1	1	0	0	0	0	0	0
P_2p_1	1	1	1	1	1	1	0	0	0	0	0	0
P_2p_3	1	1	1	1	1	1	0	0	0	0	0	0
P_2p_4	0	0	0	0	0	1	1	1	1	1	1	0
P_3p_1	0	0	0	0	0	0	0	1	1	1	1	1
P_3p_2	1	1	1	1	1	1	0	0	0	0	0	0
P_3p_4	0	0	0	0	0	0	1	1	1	1	1	1
P_4p_1	1	1	1	1	1	1	0	0	0	0	0	0
P_4p_2	0	0	0	0	0	0	1	1	1	1	1	1
P_4p_3	0	0	0	0	0	0	0	0	0	0	0	0

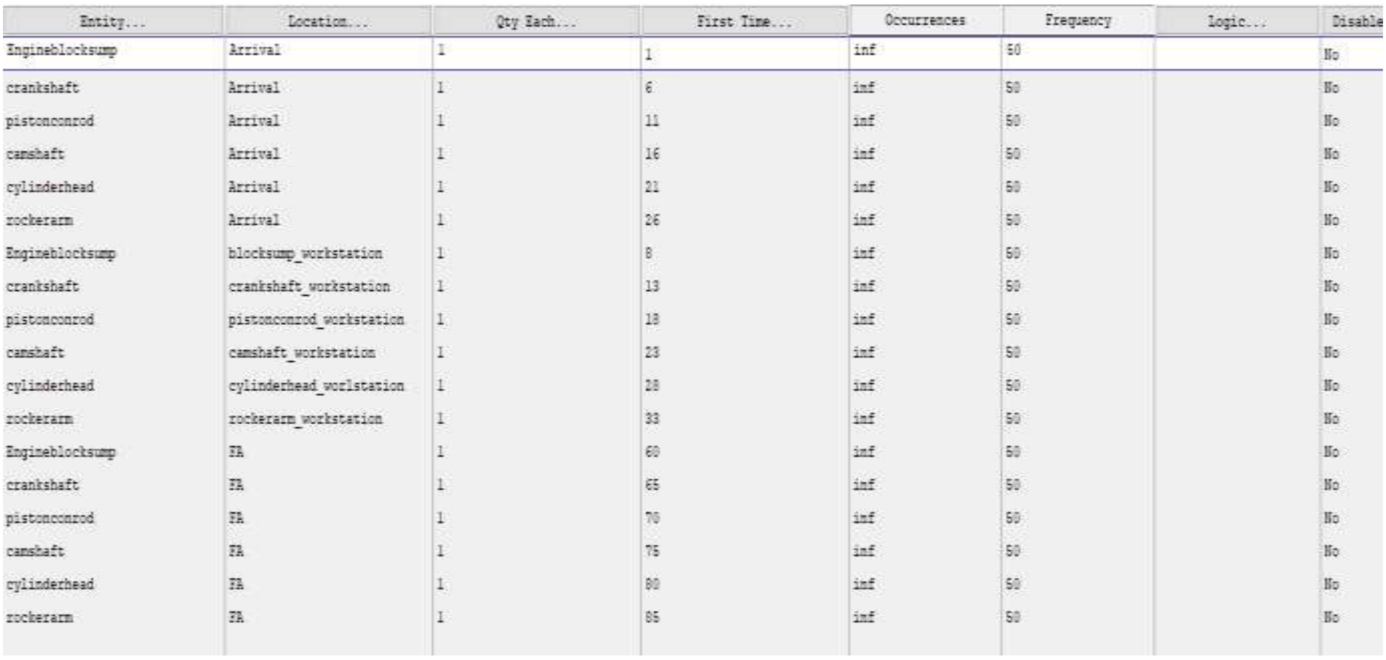
From the matrix shown above, the components that have contacts are P1P2, P2P1, P1P4, P4, P1, P2P3 and P3P2. If further analysis such as deciding the base part or frame was made, it will lead to determination of optimal sequence. For IC Engines there is a standard assembly sequence from sump to Cylinder head so that was applied, thus the determination of sequence was not required. The matrix represented above is just to explain the usefulness of the contact and transitional matrix in sequence generation. Assembly from Bottom to Top Cylinder is the required standard though some activities can be done concurrently and pre assemble possible.

After determining the schedule and sequence, the process was simulated in the promodel app. Figures 10, 11, 12 , and 13 are the simulation logic snipped from the app.



Icon	Name	Cap.	Units	DTs...	Stats	Rules...	Notes...
	Arrival	8	1	None	Time Series	Oldest	inspection
	crankshaft_workstation	1	1	None	Time Series	Oldest	join
	pistonconrod_workstation	1	1	None	Time Series	Oldest	join
	camshaft_workstation	1	1	None	Time Series	Oldest	join
	cylinderhead_worlstation	1	1	None	Time Series	Oldest	join
	rockerarm_workstation	1	1	None	Time Series	Oldest	join
	FA	1	2	None	Time Series	Oldest, First	join
	FA.1	1	1	None	Time Series	Oldest	join
	FA.2	1	1	None	Time Series	Oldest	join
	blocksump_workstation	1	1	None	Time Series	Oldest	join

Figure 10: workstation location Logic



Entity...	Location...	Qty Each...	First Time...	Occurrences	Frequency	Logic...	Disable
Engineblocksump	Arrival	1	1	inf	50		No
crankshaft	Arrival	1	6	inf	50		No
pistonconrod	Arrival	1	11	inf	50		No
camshaft	Arrival	1	16	inf	50		No
cylinderhead	Arrival	1	21	inf	50		No
rockerarm	Arrival	1	26	inf	50		No
Engineblocksump	blocksump_workstation	1	8	inf	50		No
crankshaft	crankshaft_workstation	1	13	inf	50		No
pistonconrod	pistonconrod_workstation	1	18	inf	50		No
camshaft	camshaft_workstation	1	23	inf	50		No
cylinderhead	cylinderhead_worlstation	1	28	inf	50		No
rockerarm	rockerarm_workstation	1	33	inf	50		No
Engineblocksump	FA	1	60	inf	50		No
crankshaft	FA	1	65	inf	50		No
pistonconrod	FA	1	70	inf	50		No
camshaft	FA	1	75	inf	50		No
cylinderhead	FA	1	80	inf	50		No
rockerarm	FA	1	85	inf	50		No

Figure 11: Arrival Logic

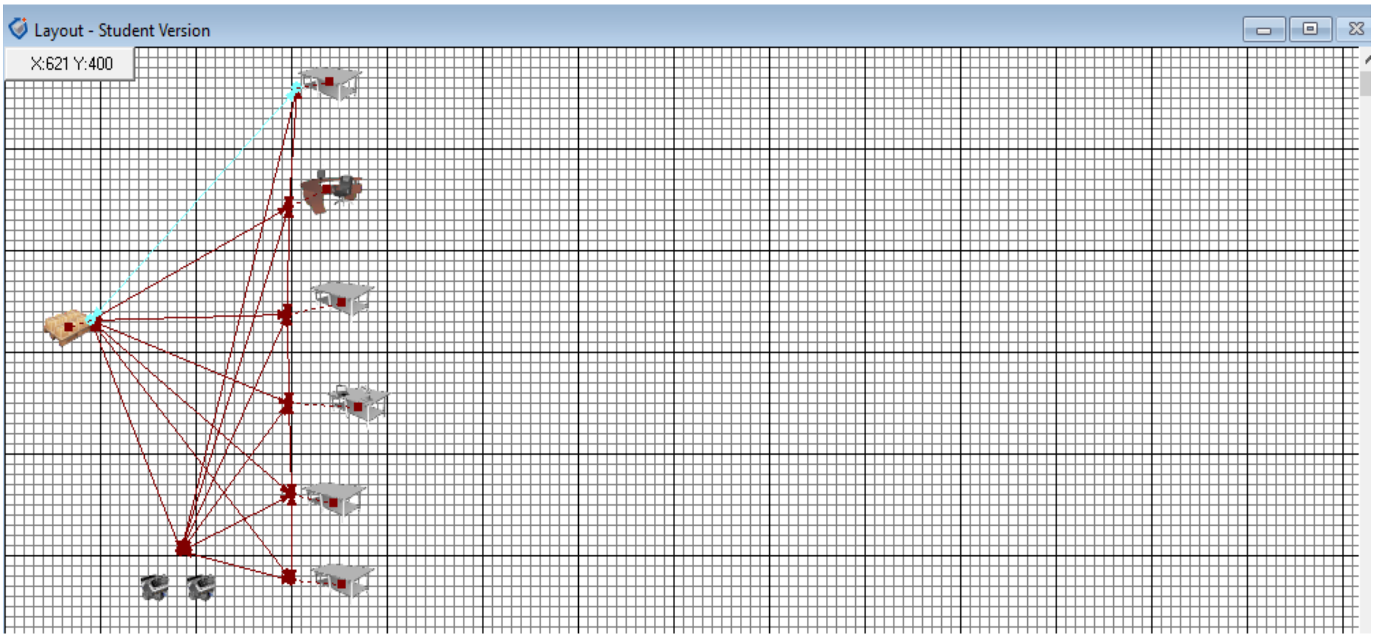
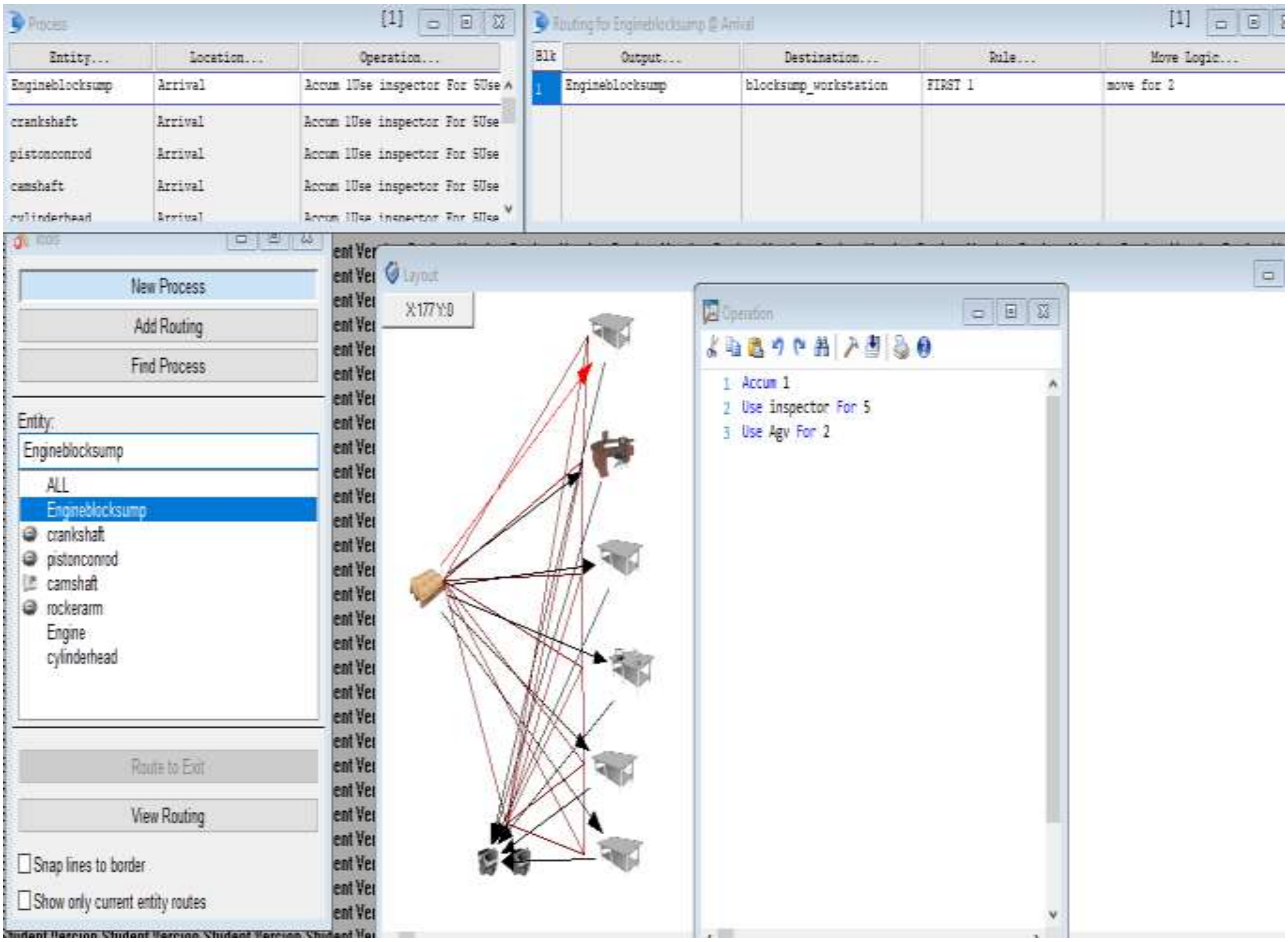


Figure 12: Layout



Entity...	Location...	Operation...
Engineblocksump	Arrival	Accum 1Use inspector For 5Use
crankshaft	Arrival	Accum 1Use inspector For 5Use
pistonconrod	Arrival	Accum 1Use inspector For 5Use
camshaft	Arrival	Accum 1Use inspector For 5Use
cylinderhead	Arrival	Accum 1Use inspector For 5Use

Blk	Output...	Destination...	Rule...	Move Logic...
1	Engineblocksump	blocksump_workstation	FIRST 1	move for 2

```
Accum 1
Use inspector For 5
Use Agv For 2
```

Figure 13: Processing Logic

3.0 RESULTS AND DISCUSSION

Results 3.1

Table 4 shows the simulated results of plant layout with no buffer

Table 4. Simulation results of Plant layout with no Buffers

Resource; AGV	Simulation Run (min)	AVG time in move Logic (min)	AVG time in operation (min)	AVG time Blocked (min)	AVG time in system (min)	Total Assemble
1	887	2.08	1.584	85.00	88.7	10
2	432	1.17	1.587	40.40	43.20	10
3	328	1.24	1.585	30.00	32.8	10
4	296	1.03	1.583	27.00	29.6	10
5	266	1.03	1.578	24.01	26.6	10
6	246	1.02	1.567	22.02	24.6	10
7	240	1.15	1.620	21.30	24.07	10
8	258	1.00	1.600	20.65	25.80	10
9	250	1.06	1.600	20.62	25.0	10

Table 5 shows the simulated results of plant layout with eight buffers.

Table 5. Simulation results of Plant layout with eight Buffers

Resource; AGV	Simulation Run (min)	AVG time in move Logic (min)	AVG time in operation (min)	AVG time Blocked (min)	AVG time in system (min)	Total Assemble
1	783	3.31	1.37	72.6	78.3	10
2	563	3.01	1.32	50.53	56.3	10

3	495	3.02	1.30	40.2	49.1	10
4	310	2.52	1.33	20	30.3	10
5	185	2.03	1.30	7.14	18.5	10
6	143	2.05	1.35	2.3	14.3	10
7	60.3	1.50	1.40	1.00	6.32	10
8	45.2	1.42	1.33	0	4.05	10
9	45.0	1.40	1.40	0	4.3	10

Table 6 shows results of plant layout with one AGV.

Table 6. Results of Plant layout with one AGV

Storage Buffers	Simulation Run (min)	AVG time in move Logic (min)	AVG time in operation (min)	AVG time Blocked (min)	AVG time in system (min)	Total Assemble
0	558	3.31	2.30	86.39	93.2	6
1	528	3.5	2.41	80.17	88.1	6
2	500	4.30	2.51	79.00	85.3	6
3	450	3.03	2.32	79.30	85.2	6
4	480	3.02	2.40	77.30	84.5	6
5	500	4.04	2.31	72.45	80.3	6
6	530	3.6	2.25	72.50	80.1	6
[1]7	498	3.1	2.31	70.30	79.5	6
8	520	3.0	2.35	50.40	80.4	6
9	498	3.2	2.45	50.20	80.00	6

Table 7 shows results of plant layout with eight AGVs.

Table 7. Assembly plant layout with eight AGVs

Storage Buffers	Simulation Run (Min)	AVG time in Move Logic(min)	AGV time in Operation (min)	AVG time Blocked (min)	AVG time in system (min)	Total Exits
1	593.4	1.01	1.37	56.7	59.34	10
2	420.9	1.02	1.37	40.47	42.09	10
3	201	1.21	1.38	17.23	20.07	10
4	160	1.24	1.36	14.0	15.52	10
5	132	2,25	1.35	11.18	13.20	10
6	67.2	1.17	1.38	4.17	6.72	10
7	30	1.15	1.35	0.50	3	10
8	27	1.12	1.37	0.10	2.59	10
9	24.9	1.10	1.39	0	2.49	10
10	26.6	1.09	1.37	0.2	2.66	10

Table 8. Simulation Results of Inline Assembly by varying workstations and AGV

Resources; AGV	Work Stations	Simulation Run (Min)	Average time in logic move (min)	Average time in operation (min)	Average time Blocked (min)	Average time in system (min)	Total Assembled
1	9	1800	4.3	162	39.2	204	34
1	18	1824	4.00	162	20.4	188.5	66
1	27	1810	4.20	162	8.01	177	110
1	36	1800	4.0	162	3.02	166	138
1	45	1834	4.1	162	0.2	163	139

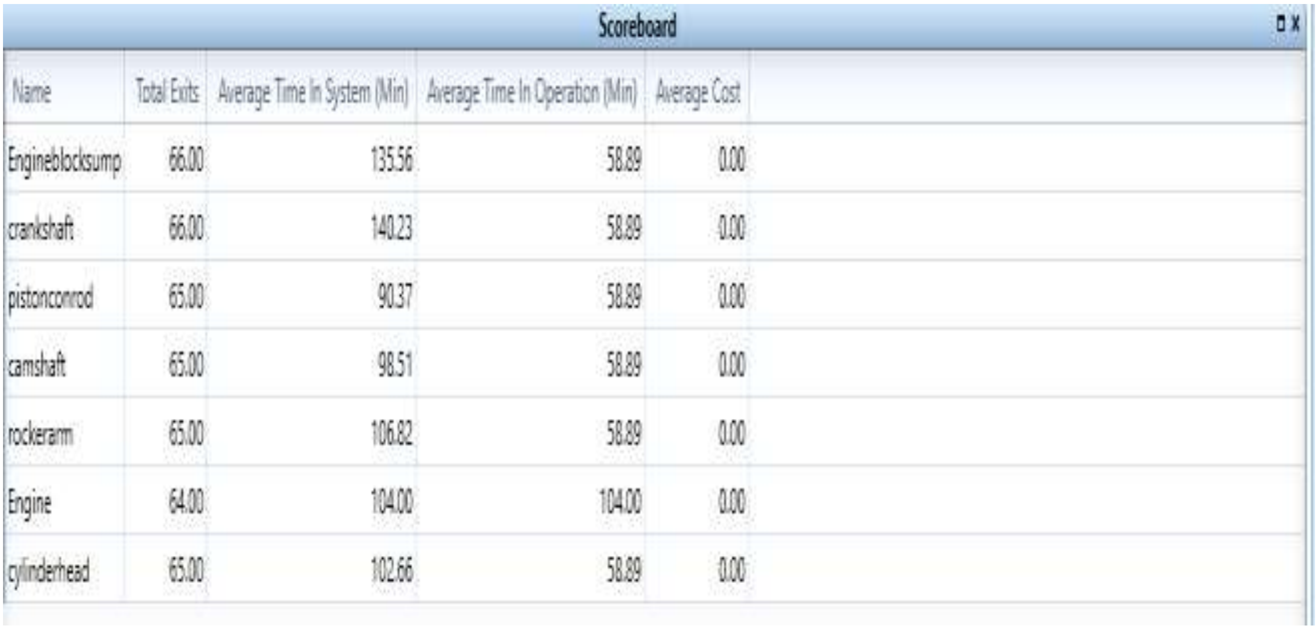
---

[1] Time in Move logic: the move logic window allows you to define the method of movement as well as any other logic to be executed prior to or after the move actually takes place. It is the time it takes to define the move logic and its execution

Table 9. Simulation Results of Inline Assembly by varying workstation capacity and AGV

Resources; AGV	Work Stations capacity	Simulation Run (Min)	Average time in logic move (min)	Average time in operation (min)	Average time Blocked (min)	Average time in system (min)	Total Assembled
1	1	1800	4.3	162	39.2	204	34
1	2	1824	4.00	162	20.4	188.5	66
1	3	1810	4.20	162	8.01	177	110
1	4	1800	4.0	162	3.02	166	138
1	5	1834	4.1	162	0.2	163	140

Table 10. Snipped Sample Result (scoreboard) From the Promodel Simulation of an Inline Engine



Scoreboard

Name	Total Exits	Average Time In System (Min)	Average Time In Operation (Min)	Average Cost
Engineblocksump	66.00	135.56	58.89	0.00
crankshaft	66.00	140.23	58.89	0.00
pistonconrod	65.00	90.37	58.89	0.00
camshaft	65.00	98.51	58.89	0.00
rockerarm	65.00	106.82	58.89	0.00
Engine	64.00	104.00	104.00	0.00
cylinderhead	65.00	102.66	58.89	0.00

Table 11. Simulation Result for V Engine

Resources: AGV	Workstations	Simulation run time (min)	Average time in Logic move (min)	Average time in operation (min)	Average time Blocked (min)	Average time Tool changed (min)	Average time in system (min)	Total assemble
1	9	1862	3.8	162	49.8	15	286	32
1	18	1860	4.2	162	13.62	15	194	68
1	27	1853	4.0	162	3.46	15	182	92
1	36	1863	3.9	162	0.56	15	168	130
1	45	1861	4.0	162	0.2	15	140	131

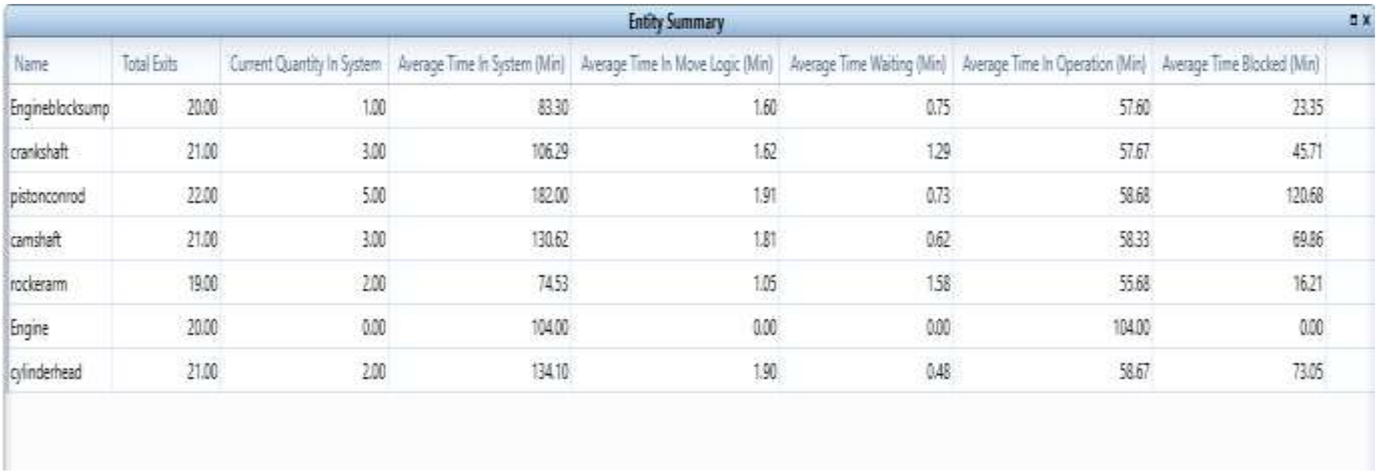
Tables 12 to 15 show : Snipped location summary of the V engine simulation result, Snipped Entity Summary of the V Engine Simulation Result, Snipped Resource Summary of the V Engine Simulation Result and Snipped Scoreboard of the V Engine Simulation Resul

Table 12. Snipped location summary of the V engine simulation result

Location Summary

Name	Scheduled Time (Hr)	Capacity	Total Entries	Average Time Per Entry (Min)	Average Contents	Maximum Contents	Current Contents	% Utilization
Arrival	20.21	8.00	116.00	79.62	7.61	8.00	8.00	95.19
crankshaft workstation	20.21	1.00	22.00	50.81	0.92	1.00	1.00	92.17
pistonconrod workstation	20.21	1.00	23.00	50.04	0.95	1.00	1.00	94.89
camshaft workstation	20.21	1.00	22.00	51.63	0.94	1.00	1.00	93.65
cylinderhead worlstation	20.21	1.00	22.00	51.95	0.94	1.00	1.00	94.23
rockerarm workstation	20.21	1.00	20.00	50.84	0.84	1.00	1.00	83.84
FA.1	20.21	1.00	11.00	103.90	0.94	1.00	1.00	94.23
FA.2	20.21	1.00	11.00	103.44	0.94	1.00	1.00	93.82
FA	40.43	2.00	22.00	103.67	0.94	2.00	2.00	94.02
blocksump workstation	20.21	1.00	21.00	49.99	0.87	1.00	1.00	86.56

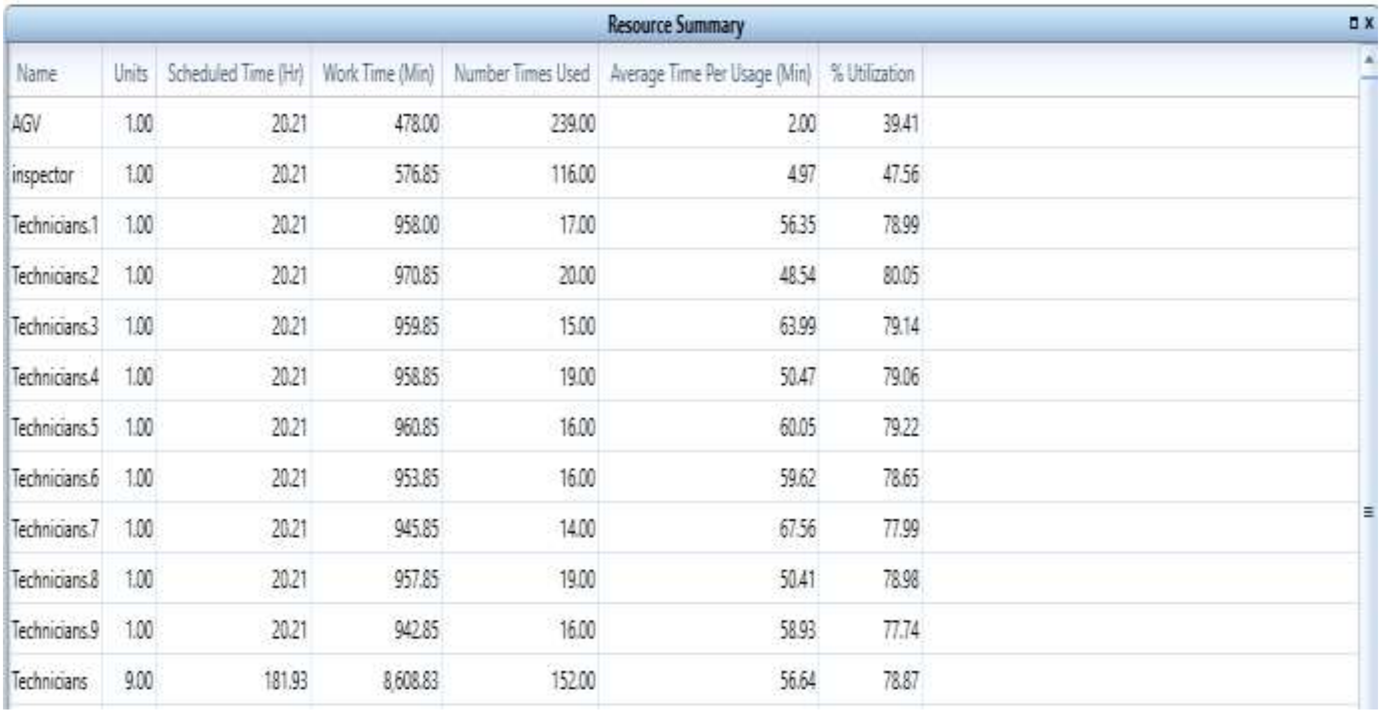
Table 13. Snipped Entity Summary of the V Engine Simulation Result



Entity Summary

Name	Total Exits	Current Quantity In System	Average Time In System (Min)	Average Time In Move Logic (Min)	Average Time Waiting (Min)	Average Time In Operation (Min)	Average Time Blocked (Min)
Engineblocksump	20.00	1.00	83.30	1.60	0.75	57.60	23.35
crankshaft	21.00	3.00	106.29	1.62	1.29	57.67	45.71
pistonconrod	22.00	5.00	182.00	1.91	0.73	58.68	120.68
camshaft	21.00	3.00	130.62	1.81	0.62	58.33	69.86
rockerarm	19.00	2.00	74.53	1.05	1.58	55.68	16.21
Engine	20.00	0.00	104.00	0.00	0.00	104.00	0.00
cylinderhead	21.00	2.00	134.10	1.90	0.48	58.67	73.05

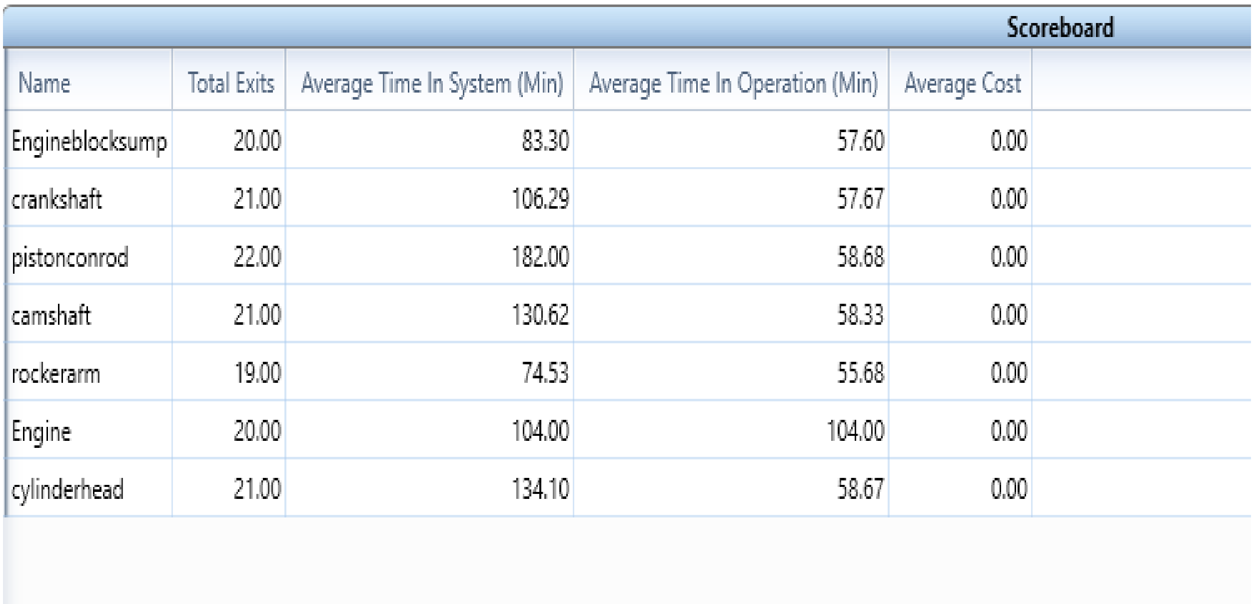
Table 14. Snipped Resource Summary of the V Engine Simulation Result



Resource Summary

Name	Units	Scheduled Time (Hr)	Work Time (Min)	Number Times Used	Average Time Per Usage (Min)	% Utilization
AGV	1.00	20.21	478.00	239.00	2.00	39.41
inspector	1.00	20.21	576.85	116.00	4.97	47.56
Technicians.1	1.00	20.21	958.00	17.00	56.35	78.99
Technicians.2	1.00	20.21	970.85	20.00	48.54	80.05
Technicians.3	1.00	20.21	959.85	15.00	63.99	79.14
Technicians.4	1.00	20.21	958.85	19.00	50.47	79.06
Technicians.5	1.00	20.21	960.85	16.00	60.05	79.22
Technicians.6	1.00	20.21	953.85	16.00	59.62	78.65
Technicians.7	1.00	20.21	945.85	14.00	67.56	77.99
Technicians.8	1.00	20.21	957.85	19.00	50.41	78.98
Technicians.9	1.00	20.21	942.85	16.00	58.93	77.74
Technicians	9.00	181.93	8,608.83	152.00	56.64	78.87

Table 15. Snipped Scoreboard of the V Engine Simulation Result



Scoreboard

Name	Total Exits	Average Time In System (Min)	Average Time In Operation (Min)	Average Cost
Engineblocksump	20.00	83.30	57.60	0.00
crankshaft	21.00	106.29	57.67	0.00
pistonconrod	22.00	182.00	58.68	0.00
camshaft	21.00	130.62	58.33	0.00
rockerarm	19.00	74.53	55.68	0.00
Engine	20.00	104.00	104.00	0.00
cylinderhead	21.00	134.10	58.67	0.00

3.2: DISCUSSION

Performance measures in term of total flow time, average time in system, average time blocked, and throughput were collected from ProModel's output program manager.

3.2.1 Plant Layout Results

From the simulation results of Tables 4, 5, 6 and .7 above of plant assembly layout with different arrangements, the Measuring Lead Time (MLK) for these layouts are; plant layout with no buffers (25 min), plant layout with 8 buffers (4.05), plant layout with 1 AGV (80 min) and plant layout with 8 AGVs (2.49). In determining optimal assembly time, the arrangement that return minimum assembly time [min (MLk) = ∑MLK], Table 7; plant layout with 8AGV and 8 buffers is the best arrangement for assembly plant design and arrangement. For general purpose assembly plant with small operation time, this is the best arrangement.
[2]

Also, Throughput is a measurement parameter in production industry; the quantity of product assembled for a day, week or month depending on the span of measurement for different arrangement. The arrangement that returned the highest quantity is the best layout and design that should be adopted [Max (P) = ∑p]. Table 4 with simulation time 24.9 minutes produce 10 articles is the smallest possible time in all the arrangements of plant layout to assemble a product (2.49minutes) per product. Therefore, the throughput is 2.49 minutes, thus the best arrangement is 9 buffers, 8AGV.

For more detailed explanation, graphs of Average (AVG) time in system against AGV and Average (AVG) time blocked in the system against AGV for the different arrangements are plotted. From Table 4 results; Simulation results of plant layout with no buffers is shown in bar graphs Figures 14 and 15 respectively.

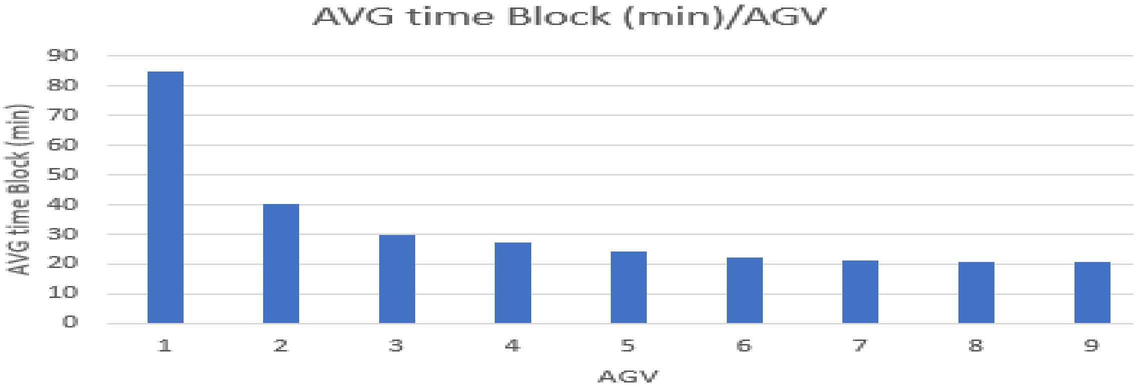


Figure 14: Graph of AVG time Blocked against AGV

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[2]). Average (AVG) time in operation: the time AGV takes to transport parts from unloading to assembly station and back to unloading station. Average (AVG) time Blocked (min): the time a component has to wait for it to be picked up. Average (AVG) time in the system: this is the combined time a component spent in waiting, on transit and the time for move logic to initiate a command.

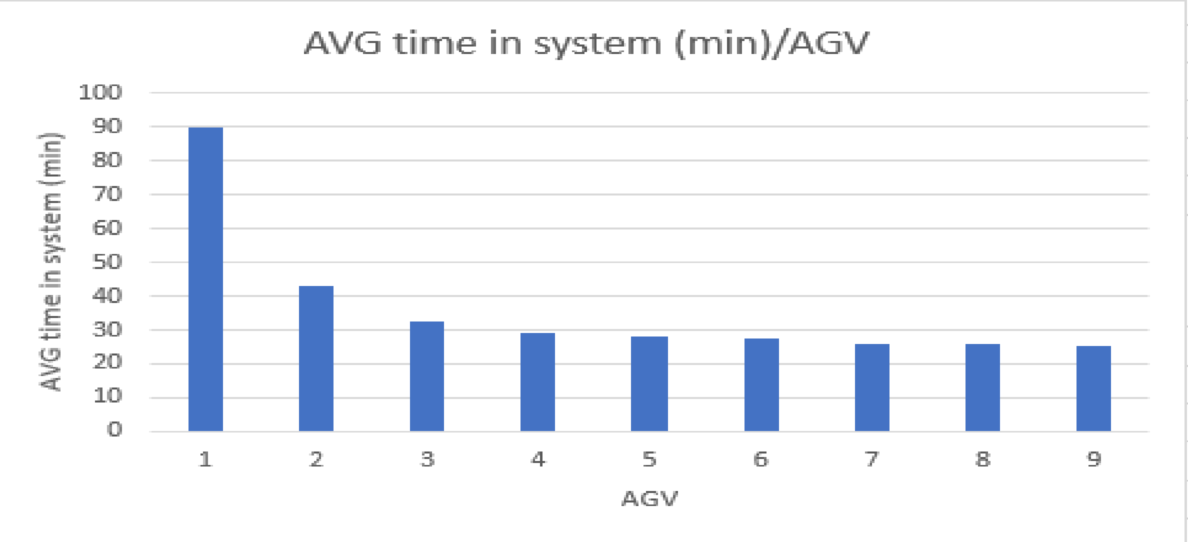


Figure 15: A Plot of AVG time in system against AGV

In the case problem mentioned above, the following observations were made from the ProModel output viewer; the average time spent by parts in the system decreased with an increased number of AGVs (from 1 to 10). It was observed that in the first setup, as shown in Table 4, the average time spent by parts and average blocked time was reduced significantly when the number of the AGVs were increased; an increment in number of AGV from 1AGV to 8AGV showed reduction in average time blocked and the average time in the system from 85 minutes and 90minutes to 20.6minutes and 25minutes respectively. This implied that variation in AGV has a significant effect on time spent in the system.

Also from Table 5 results: Simulation results layout with eight buffers are plotted in Figure 16 and 17. Results from simulation runs with 8 Buffers in the system show that the average time spent by parts in the system and the average blocked time have a significant drop. The effect was more pronounced as it was the combined effect of variation in AGV and storage buffers

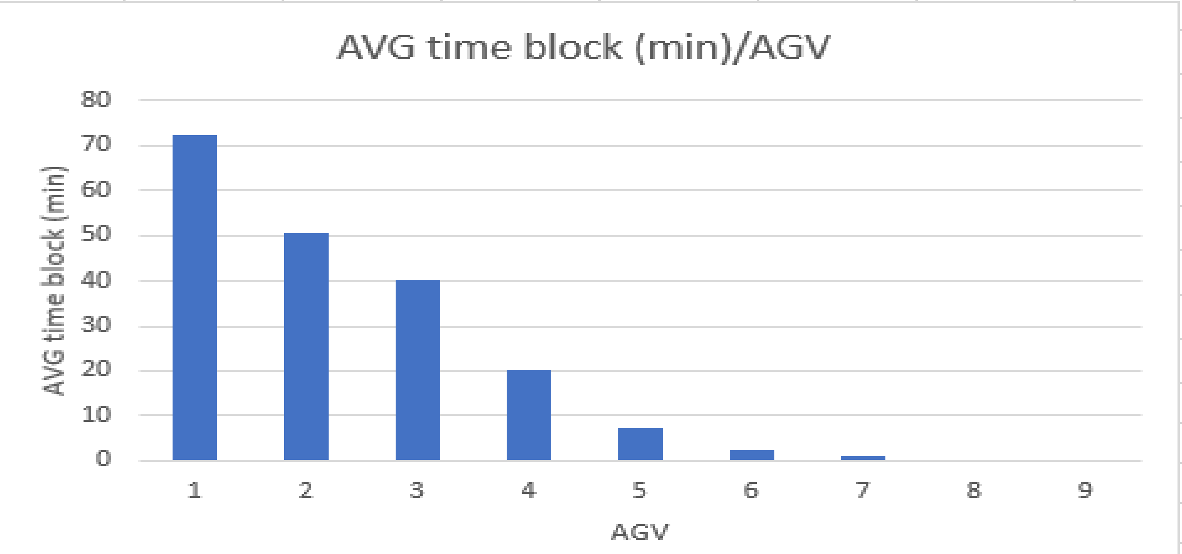


Figure 16: Graph of AVG time blocked (min) against AGV

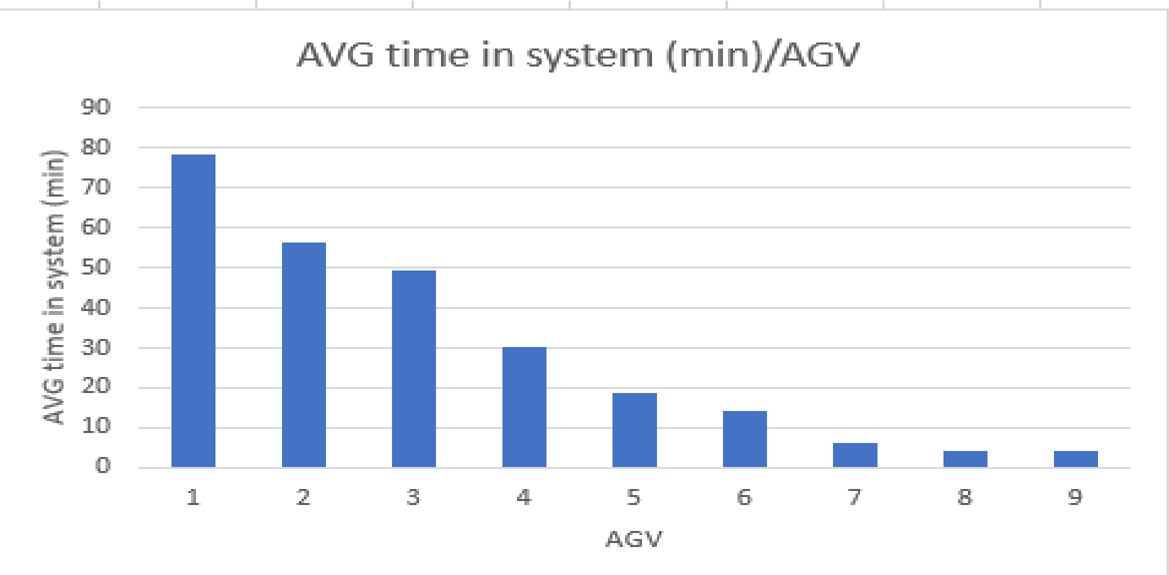


Figure 17: Graph of AVG time in system (min) against AGV

The graphs plotted indicated a reduction in AVG time blocked in the system from 72.6 to 0 minutes- Figure 16, with increase in AGV from 1 to 8 and AVG time in the system from 78.3 to 4.00 minutes, Figure 17**.** The combind effect of increasing AGV and storage buffers to eight reduced the blocked time to zero.

The research also considered the effect of a change in the numbers of storage buffers within the workstations. Subsequently, the storage buffers were varied while AGVs were kept constant and the outcome shown in Figures 18, 19, 20 and 21. The number of buffers in the workstation becomes a significant factor when the numbers of AGVs increased to eight. Detailed simulation runs were conducted for different numbers of buffers in FAS pallet pool.

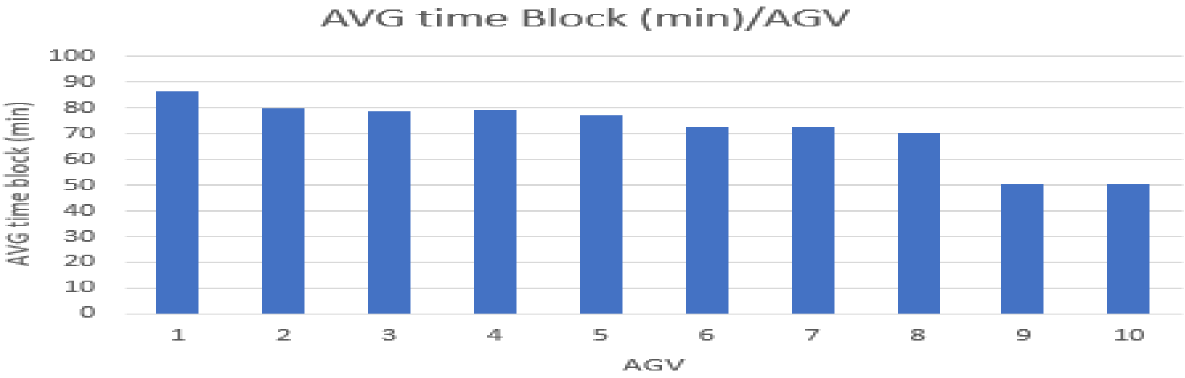


Figure 18:Graph of AVG time blocked (min) against storge buffers

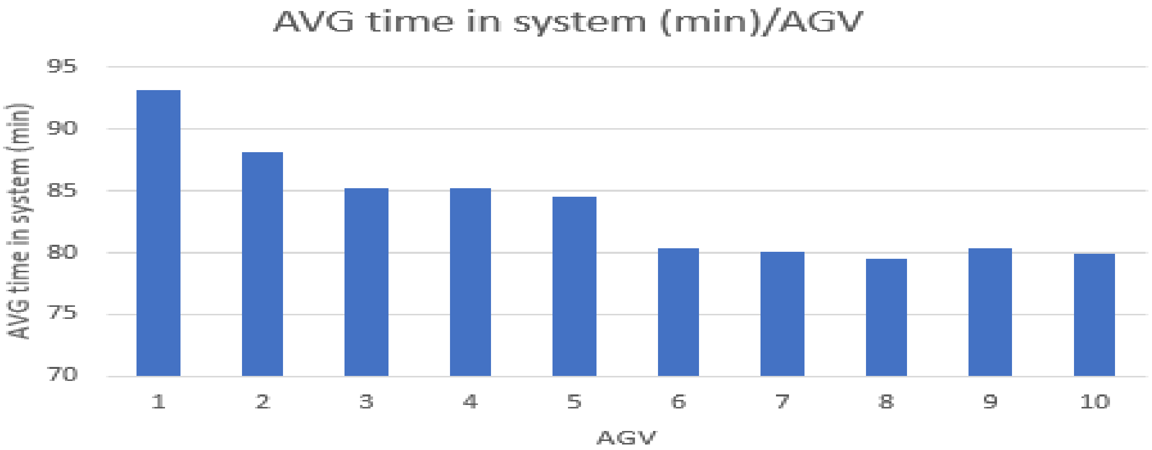


Figure 19: Graph of AVG time in System (min) against storage buffer

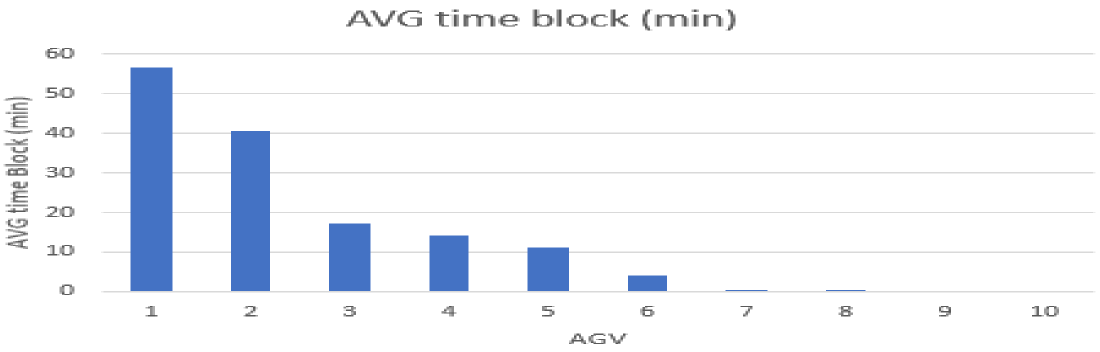


Figure 20: Graph of AVG time block (min) against storage buffers

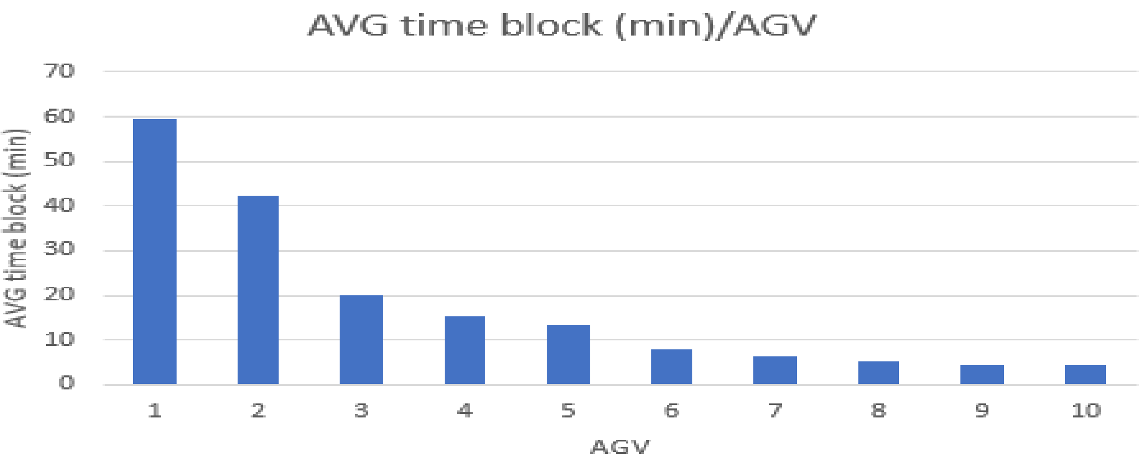


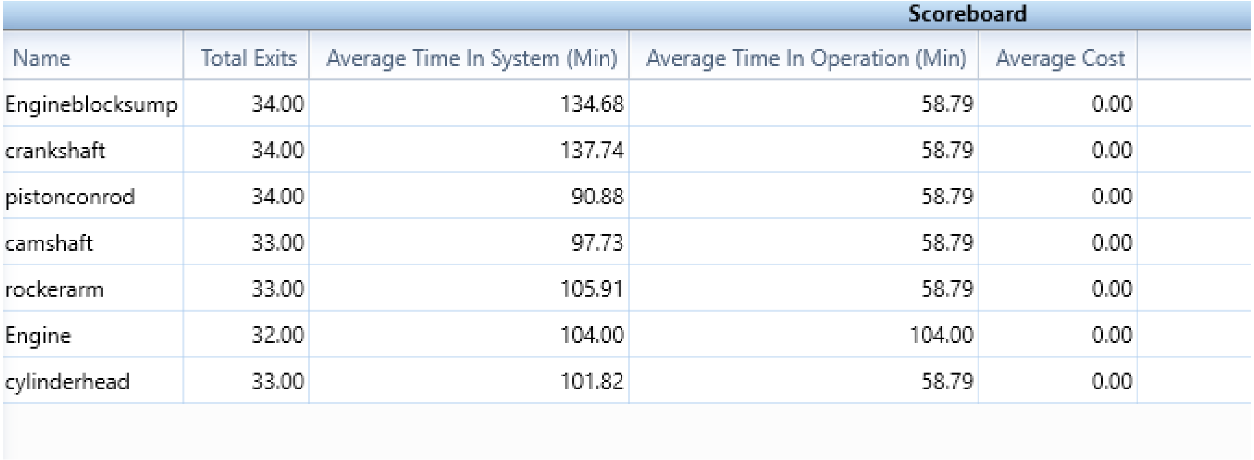
Figure 21: Graph of AVG time blocked (min) against Storage buffers

The observations made from the ProModel output viewer indicated the average time spent by parts in the system decreased with increased number of storage buffers (from 1 to 8). Also the waiting time by the components reduced with increased in storage system. As shown in Table 4.5; Result of workstation layout one AGV, an increment in number of Buffers from 1AGV to 8 AGV with 1 AGV showed reduction in average time blocked and the average time in the system from 86.39 minutes and 93.2minutes to 50.40 minutes and 80.4minutes respectively. The effect of variation in buffers on the average time blocked in the system was very minimal as only 41. 65 percent was achieved by adding 8 storage buffers to the system and for average time in the system 13.7 percent. Also from Table 5: Simulation results layout with 8 AGV plotted in Figure 19 and Figure 21. It can be observed that, the average time spent by parts in the system and the average blocked time have a significant drop. The effect was more pronounced as it was the combined effect of 8AGV and variation in storage buffers. The AVG time blocked with one storage buffer was 56.7 minutes and reduced to 0 minutes. When the number of storage buffer increased to eight the percent reduction was 100 percent while AVG time in the system with a storage buffer was 59.34 minutes and reduced 4.37 minutes with eight storage buffers, which is 96.9 percent reduction.

3.2.2: Inline Engine Result Discussion

From the simulation results of Table 8 and Table 9, it is evident that, the variation of workstations capacity or number of workstations that have effect on the number of products assembled. AGV variation is not effective because the time of travel is small compared to time in operation. Variation of workstations or capacity entails a corresponding variation in numbers of technicians, cranes and all the necessary tools. Tables 16 to 20 show; Scoreboard, location utilization, entity state baseline I, entity state baseline II and resource utilization.

Table 16. Scoreboard



Scoreboard

Name	Total Exits	Average Time In System (Min)	Average Time In Operation (Min)	Average Cost
Engineblocksump	34.00	134.68	58.79	0.00
crankshaft	34.00	137.74	58.79	0.00
pistonconrod	34.00	90.88	58.79	0.00
camshaft	33.00	97.73	58.79	0.00
rockerarm	33.00	105.91	58.79	0.00
Engine	32.00	104.00	104.00	0.00
cylinderhead	33.00	101.82	58.79	0.00

Table 17. Location Utilization

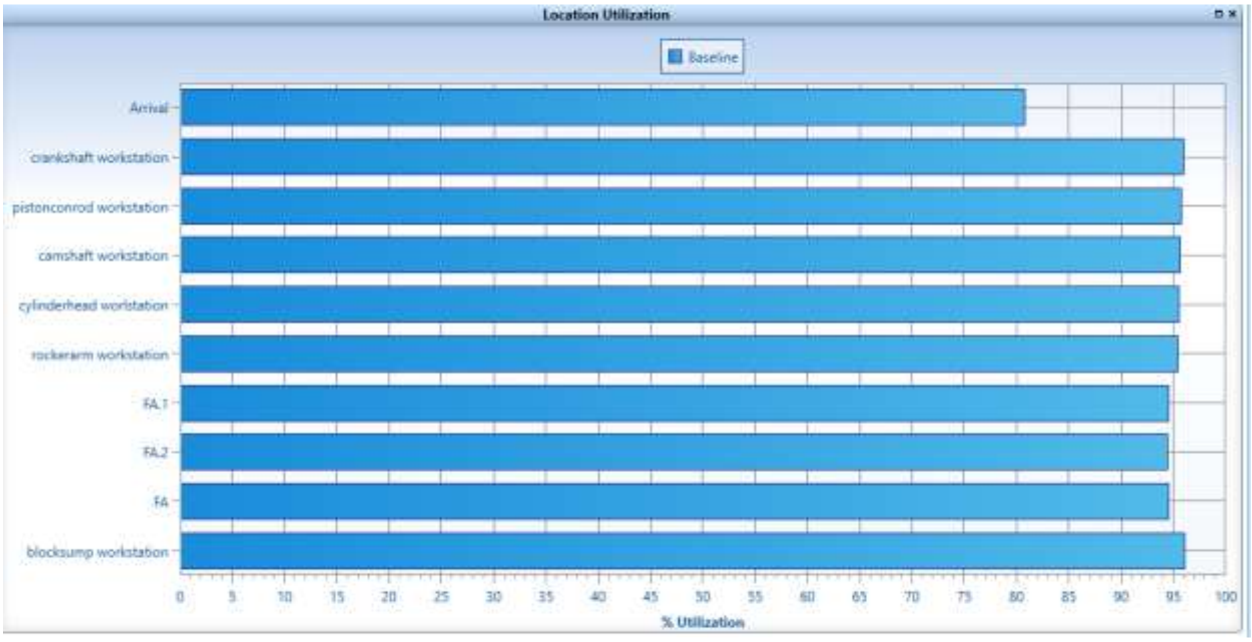


Table 18. Entity State Baseline I

Table 19. Entity State Baseline II

Table 20. Resource Utilization

3.3: Validation of Results

Two designs were made: for an inline engine and V engine, in that design major parts were considered. Five parts; cylinder head, liners, piston and rings, rocker arm mechanism, connecting rods and sump were all made interchangeable in both systems which represent 66.7 percent of the major components. Having 66.7 percent common parts reduced the cost of designing, fixtures and assemble reconfiguration by 66.7 percent which is a very great achievement.

Also, from simulation of the assembly process with eight storage buffers and eight AGV the AVG blocked time in the system reduced by 100% which proved that with this design, delay due to traffic can be completely eliminated. In terms of wastage too, it showed that the required numbers of Storage buffers and AGV are eight equal the number of workstations. So in transportation system the number of resources and temporal storage is defined.

4.0 CONCLUSION

Results from simulation using promodel simulator showed remarkable improvement on set up time of work station and transportation system traffic by varying automated guided vehicles and temporal storage buffers. Results from Table 4: Simulation results of workstation layout with no buffers; recorded decreased AVG time blocked in minutes from 85 to 20.65, a reduction of 64.35 minutes (75.7%) of the transportation time, AVG time in the system also reduced from 90 minutes to 25.8 minutes, 64.2 minutes reduction (71.3%). Table 5 simulation results of work station layout with 8 buffers; showed AVG time blocked reduced 72.6 minutes; 100% reduction in traffic time delay, AVG time in the system also recorded 75.25 minutes; 94% reduction in set up time. Variation of numbers of vehicles reduced or increased the time the component spent in the system. So with the simulation of the layout using automated guided vehicle and temporal storage buffers as variables, correct workstation resources are determine. Reduction in time spent in production will increase the number of articles output or sent to the market. Further application of this model is suggested for processing industries.

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