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Towards Developing Real-Life Models: A Simulation Modelling of an Ideal Vehicle Assembly Line Using Arena Simulation

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Abstract

We present an ideal model of a typical vehicle assembly plant by generalizing selected case studies from the literature. The ideal model was extended to capture certain realities of material handling to obtain new scenarios. The Arena simulation platform was used to model both the base and scenario models. Data and probability distribution were obtained from specifications from the literature and random projections. Using the number of outputs from the vehicle assembly plant, the base model and the scenarios were analyzed. Results of the sensitivity analysis of the scenario models confirm that as real-world systems emanate from the ideal systems for example by capturing material handling realities, the production or service outputs are constrained either positively or negatively. Thus, showing the need for understanding different configuration settings of material handling equipment when scaling up production outputs is desired. The simulation modelling and analysis employed are useful both as classroom illustrations on material handling, aid for engineering education and other users in need of general understanding and applications of discrete event simulation modelling.

Keywords

Generic vehicle assembly, Material handling modelling, Scenario analysis and arena simulation

1. Introduction

The automotive industry is one of the several manufacturing industries that contributes positively to the industrial and economic base of countries. The automotive industry also largely impacts diverse sectors of a country's economy due to its end products that facilitate the distribution and movement of goods and persons. Developed countries such as Germany and Japan, are known to have several lines of vehicle assembly plants (Wirabhuana et al., 2008). On another hand, developing countries such as Kenya, South Africa and Nigeria have seen the need to scale up their low-capacity vehicle assembly plants due to the large volume of imported vehicles (Ikome et al., 2022, Gorham, 2022).

The vehicle assembly process could come with several variations depending on the type of vehicle being manufactured such as trucks, cars, bus. However, the importance of a generic assembly procedure for different types of vehicles was discussed by (Wang et al., 2011, Wy et al., 2011). According to Wang et al. (2011), Oumer et al. (2016) the generic assembly starts from the arrival of different vehicle parts into the assembly facility. The parts are then distributed into different sections of the assembly plants based on the manufacturing schedule. Typical sections/areas of the assembly plant include the body shop, paint shop, assembly section, buffer area, quality inspection and motor pool section. Important in the vehicle assembly process irrespective of the manufacturing plan is the need to ensure that the process is efficient and effective, delivering the expected number of vehicles while ensuring resources are adequately utilized. Therefore, productivity improvement through the optimization of several decisions and resources such as indicated by Oyewole and Adetunji, (2020) and Oyewole, (2020) become critical. The simulation modelling technique has been very useful as a productivity, analytical and improvement tool in a lot of manufacturing environments (Wy et al., 2011, Dengiz et al., 2016). In the vehicle assembly plants several studies have been conducted using the concepts of simulation modelling such as (Wang et al., 2011, Dewa and Chidzuu, 2013, Zhao and Li, 2015, Oumer et al., 2016, Moon et al., 2021, Thanou and Matopoulos, 2021).

In this paper, we present a discrete-event simulation model of an ideal vehicle assembly line. This is done by generalizing selected vehicle assembly models presented in the literature. We also extend the models by considering some material handling realities such as the modelling of a type of conveyor within the assembly plant and the use of resource-constrained material handling. Using the ideal or base model as a benchmark, initial parameters of the extended models were obtained. Furthermore, sensitivity analysis was performed on the extended models to obtain insights into the impact of selected variables on the type of material handling system introduced. We also indicate the assumptions we have introduced in obtaining the basic and extended models. We specifically use the Arena simulation modelling platform by Rockwell automation due to its convenience and vast use in the modelling of Discrete Event Simulation (DES) studies useful for our generic vehicle assembly (Guiguet and Pons, 2022).

This study hopes to be useful to the general interest readers in engineering towards teaching the development of complex models from basic models. In addition, this study could assist in understanding selected material handling design specifications and data to collect for real experimentation. For example, during the covid-19 pandemic, site visits to local plants were limited for real data collection. Therefore, understanding certain models were possible through sensitivity analysis of appropriate projected data.

Section 2 presents a related study on the use of arena simulation software in vehicle assembly. In Section 3, we discuss the model formulation and assumptions. The experimentation and analysis performed are presented in section 4. We present the results obtained and provide some insights on the findings in section 5. This study ends in section 6 with a conclusion and possible future directions.

2. Related Study

In this section, we present a selected review of studies that have considered a generic vehicle assembly plant, including considerations for material handling and have used the Arena simulation platform in modelling. The importance of using a generic model due to the time-consuming and error-prone nature of building a real manufacturing simulation model was emphasized by Wy et al. (2011). The arena simulation software is built and updated with specific material handling constructs or logic that enables the incorporation of material handling such as conveyances, and transporters into the modelling operations of a typical manufacturing plant (Kelton et al., 2015, Wilson et al., 2022).

Wirabhuana et al. (2008) performed a scenario analysis of a general truck assembly problem using Arena and considered performance measures such as outputs, cycle time, and line efficiency. Their focus was on improving material handling through line balancing and facility re-layout. Using a case study of an automobile company, Dewa and Chidzuu (2013) demonstrated optimizing a typical manual automobile assembly line using Arena. Their interest was in improving production outputs through bottleneck management. Analysis was also presented to show the effects of variables such as vehicle sequencing, batch sizes, and individual vehicle models. Wy et al. (2011) in their study on material handling for cellular and conveyor assembly considered material handling logistics in assembly lines such as parts feeding, cart circulation, and kitting of parts. They acknowledged the use of simulation tools such as Arena but they used the Auto mod software as the simulation language. Wang et al. (2011) studied a general automotive assembly system and developed a data-driven simulation methodology to model and conduct a what-if analysis of the system using real-time online data. Arena simulation was used to model the material handling and assembly line developed. However, they suggested optimization using certain material handling requirements such as driver capacity as a future improvement to their work. A discrete event simulation of a door production line in an automotive assembly plant making two types of doors using Arena simulation was studied by Zhao and Li (2015). Though material handling was not discussed in their model, their interest was in investigating the key performance of production systems and proposing a control policy for high throughput Soroush et al., (2014) used the Arena software for modelling and analyzing the product's assembly process to minimize cycle time. They considered only forklifts as material handling equipment and showed sensitivity analysis with different capacities of the forklifts to investigate operation, material and waiting time.

Thanou and Matopoulos (2021) used the arena simulation to analyze the material flow and specifically the returns in an automotive plant and to suggest areas of the plant that could result in efficiency gains. Furthermore, they noted several studies that have considered material handling flow in the literature.

This study specifically contributes to the literature on material handling requirements of automobile plants by highlighting possible relationships between selected material handling variables such as conveyor speed, length, transfer resources and outputs from a generic vehicle assembly perspective. Therefore, a general contribution is made to productivity improvement through the understanding of the impact of resource settings.

3. Model Formulation

3.1 System Description

We present below a basic description of the typical vehicle assembly plant from which the complex configurations in existence could be obtained. In a typical vehicle assembly plant, different parts are shipped from different sources or distribution warehouses and are either temporarily stored in an in-plant warehouse or moved into the plant on a just-in-time basis. Following this is the separation of different parts based on the assembly schedule. Parts scheduled for bodywork are assembled and enter the body shop. In the body shop, operations such as spot welding and assembly of parts such as sheet metals are performed (Moon et al., 2021). After the bodywork, checks are conducted to ensure the right in-process subassemblies from the body shop get into the next process called the paint shop. At the paint shop, it is ensured that operations such as priming, cementing, sandpapering, chassis priming, and final painting are conducted on the parts. Quality checks are then conducted on finished work from the paint shop including other parts needed for final assembly. The finished or final assembled vehicles are sent to the motor pool having passed through proper interior and exterior inspection.

3.1.1 Assumptions to obtain the ideal vehicle assembly model

To obtain the ideal or basic modelling configuration, the following assumptions were made. These assumptions are often altered when real-life cases are modelled.

- Defective parts are disposed of immediately and need no rework.
- Buffer sections are not included.
- Material handling is not considered for the moving of parts within the system.
- A termination simulation model with a defined start and stop for a day (one shift) is modelled. (Usually manufacturing environments run with a continuous shift and on a steady state basis).

Figure 1 below illustrates how parts move from the point of entering the assembly plant to exiting as an assembled product.

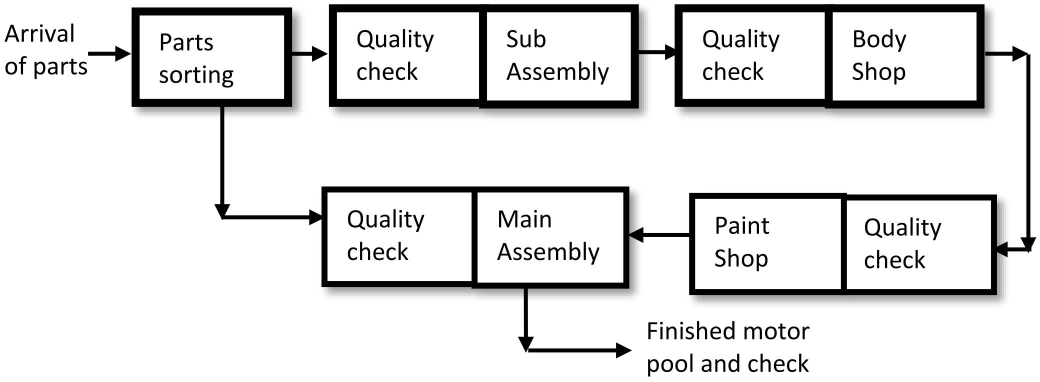

Figure 1. Flow chart showing an ideal vehicle assembly process

3.3 Simulation model building

3.3.1 Simulation modelling for the base model

The logic and assumptions used in building the simulation model for the base problem are discussed.

Assumptions during model translation

- There could be several numbers of parts (n-parts) referred to as entities required to be assembled and with several processes and different quality checks. However, a 3-part assembly are utilized for illustration purposes to be assembled without loss of generality.
- Instantaneous movement of parts in the system with no material handling.
- There are resources such as machines used to process the parts.
- Entities (parts) seize the resource for a time and releases the resource after the time duration.
- No scheduled breaks and failures for resources and resources operate on a fixed capacity.
- Queues are First in First out.

Figure 2 below presents a pictorial representation of the modelling logic used. For the general n parts, the first quality check sort the parts into the first (1 to k) parts, which are scheduled for other quality checks, bodywork and painting while the other (k+1 to n) parts go to the final assembly operation to produce the finished product (vehicle product) r often less than the starting number of n parts.

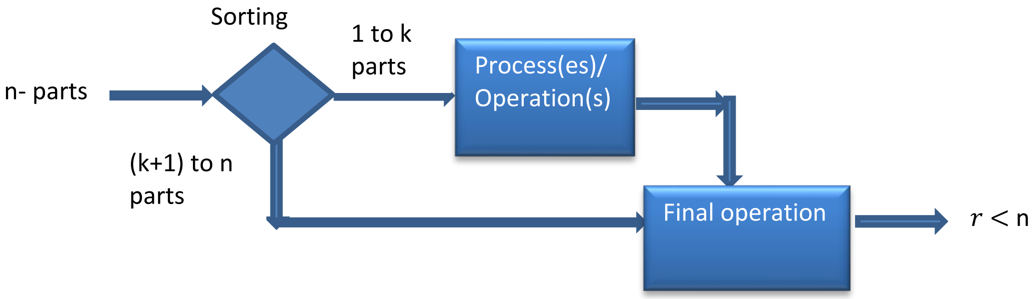

Figure 2. The basic logic used in building the model

We further present the actual arena logic modules used and reasons for choice in Table 1 below, while Figure 3 below presents the model logic flow chart in arena symbols.

Table 1. Arena modules selected to develop base simulation logic

Arena Module	Reason(s) for selection
Create	Arrival of parts into the system
Assign	Assign the different part types to be assembled
Decision	Sort the parts into the respective section of operations
Process	For Quality checks, subassembly operations, and other operations such as body shop, painting etc.
Batch	Group parts based on part types
Dispose	To end the simulation by disposing of the parts

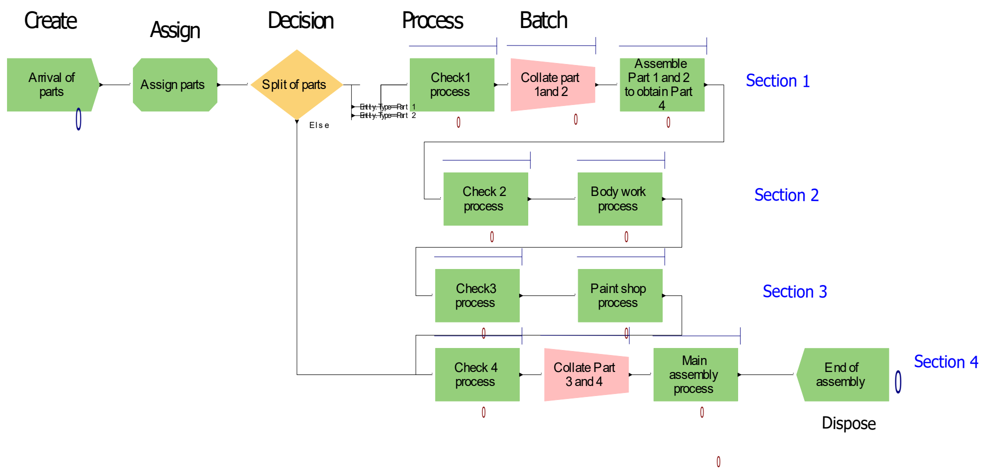

Figure 3. Flow chart showing the model logic units for the basic/ideal model

3.3.2 Extensions to the ideal vehicle assembly process

Two model extensions were derived from the ideal model and termed Scenarios 1 and 2. These scenarios are discussed below:

Scenario 1: Extension with transfer resource constraints. This incorporates a transfer resource which could be a forklift for transferring in-process inventory between one major section and the other. A resource is stationed between one section and another and moves forward and backwards between the sections.

Scenario 2: Extension with Conveyor modelling. A non-accumulating conveyor (Kelton et al., 2015), which stops momentarily at the location of the entity is used as the material handling device for the movement of parts between sections.

The two scenarios are illustrated in Figure 4 below. In this Figure, scenario 1 is captured with double arrow lines (forward and backward movement of resource) in blue, while scenario 2 is captured with dashed thick red lines. It is assumed that there are x sections of the assembly plant consisting of different processes grouped.

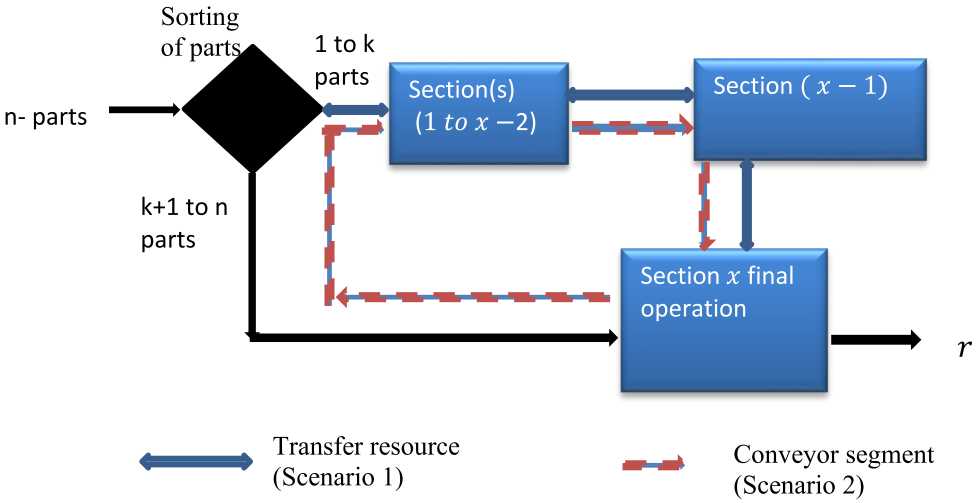

Figure 4. The basic logic used in building the model scenario 1 and 2

The logic modules useful for modelling scenarios 1 and 2 and the reason for selection are further presented in Table 2. below. An illustration of the flowchart showing the extended simulation model for scenario 2 using the logic models of Table 2. is presented in the Appendix.

Table 2. Arena modules for extended simulation logic

Arena Module	Reason(s) for selection
Create	Arrival of parts into the system
Assign	Assign the different part types to be assembled
Decision	Split the parts into the operations
Station	Location of parts
Enter	Access to material handling resource, present station of parts and routing to the next station
Leave	release of material handling resource, present station of parts and routing to the next station
Process	For quality checks, subassembly, operations, other operations such as body shop, painting etc.
Batch	Group split parts based on part types
Dispose	To end the simulation by disposing of the parts

3.4 Performance measures for analysis

We utilized the number of outputs (final product or vehicle produced) to analyze the ideal and extended scenarios. Other measures such as the number of parts waiting to be processed at the body shop and paint shop, and utilization of resources at the Body shop, are also usable but due to the quick opportunity the number of outputs provides in measuring the performance of the system, the number of outputs was focused on.

3.5 Model Verification and Validation

Verification ensures the simulation model work without errors and functions to the users' intention. All the models developed were checked for errors using the check model function, debug bar and animation. Using animation, we stepped through the model in small spaces to visualize the movement of parts through various logic for the appropriateness of our intentions.

One of the aims of validation is to check the performance of the developed system when compared to the real system. Due to the goals of this study which give us the flexibility of either using, not entirely or not using real-life data at all, validation to compare scenario outputs with real output was not done. However, we ensured the ideal models were generated from the established operations in the literature, the effect of random data used in the model was taken into consideration by replicating the experiment a few times and sensitivity analysis spanned across possible real values of variables for material handling.

4. Data and Experimentation

4.1 Data generation

In this section, we present the type and values of data input for the base and extended problems used for the module logic within Arena software. To obtain real data for the different sections, observations using time study, reasoning from similar established processes in the literature, and expert opinions comprise some of the sources of data used. However due to our objective of this paper and more emphasis on the simulation model formulation, some random data values were utilized, and some basic assumptions were used to model the scenarios.

For the resources used in every process, we assume the "seize, delay and release" of all parts and have assumed the triangular distribution as it is often used to model task activities. The actual probability distribution could follow any of the known distributions such as gamma, uniform, Weibull, and exponential and could be determined with the Arena input analyzer. The data input used is shown in Tables 3 and 4 below.

4.2 Parameter Fixing for the extended scenarios

Our interest was first to ensure a fair comparison between the base and extended scenarios. Since the extended scenarios were modelled with material handling assumptions, our goal was to search out the parameters that could still give the same number of outputs as the base model. We essentially wanted to determine the configuration settings of the material handling of the extended scenarios that can still obtain the same number of outputs as the base scenario. This guided us in decreasing or increasing resources of only the material handling as we ensured process/activity times were kept constant for the base model and extended scenarios to achieve a fair comparison of the outputs.

Table 3. Data input type and value for the base model

Arena Module	**Key input type or Probability distribution**	**Input value(s)**	**Other Assumptions**
Create: Inter arrival Parts per arrival	Random (Expo)	2 hours 10 parts/batch	Parts arrive in batches and slowly into the assembly process
Assign	Discrete (DISC)	DISC (0.2, 1, 0.3, 2,1.0,3)	Three main parts for assembly
Decide	n- way by condition	3- Parts index	Parts are split based on the type
Process (Check 1 to 4)	Triangular (TRIA)	1-3: (5,6,7) mins 4: (8,9,10) mins	Final inspection more detailed other inspections
Batch + Process (subassembly)	Parts to group	Parts 1 and 2	Parts grouped by attribute
Process: subassembly Body shop Paint shop Main assembly	All triangular (TRIA)	A: (10,12,15) secs B: (10,12,15) mins C: (8,9,10) mins D: (10,12,15) mins	all operational activities within this section
Resource (Check 1 to 4)	Fixed capacity Units to seize =1	1 to 4: (2 resources)	No failures and Schedules
Resource: subassembly Body shop Paint shop Main assembly	Fixed capacity Units to seize =1	A: (2 resources) (B to D) (4 resources)	No failures and schedules

For the extended scenarios, the data inputs comprised additional modules including those listed in Table 3 above were utilized. In Table 4 below, we present the additional modules utilized. Type 1 and 2 refer to the material handling Arena modules for transfer resources and conveyors respectively. The set of letters and numbers coded in Table 4 is defined, for example, A11 is coded as (first letter first digit second digit). The first letter represents the sections of the process (Part release), the first digit represents the type of material handling (transfer resource, and the second digit represents the logic module used (leave).

Table 4. Data input type and value for the extended model

New Arena Module Introduced	**Key input type or probability distribution**	**Input Value(s)**	**Other Assumptions**
Stations	Parts	Name of location	-
Leave (type 1): A12 parts release	A12, B12 to E12: Constant delay time Connect type: route	Move time= 10mins Load time=5mins	loading and routing the parts to the next station

B12: subassembly section C12: Body shop section D12: Paint shop section E12: Assembly section	Station type: Station Transfer resource per section (Fixed capacity)	Transfer resource Capacity = per section	through a capacitated transportation resource unloading time same as loading time
Enter (type 1): B11: subassembly section C11: Body-shop section D11: Paint-shop section E11: Assembly section	B11 to E11: Unload time Transfer resource per section	Move time= 10mins unload time=5mins	Different transfer resource used between sections Unloading time same as loading time
Leave (type 2): A22 parts release B22: subassembly section C22: Body-shop section D22: Paint-shop section	A22, B22 to E22: Access to conveyor Constant delay time Connect type: Conveyor Station type: Station	load time=5secs	For loading and moving the parts to the next station using a conveyor. load time estimated during parameter tunning
Enter (type 2): B21: subassembly section C21: Body shop section D21: Paint shop section E21: Assembly section	B21 to E21: Constant delay time Exit from Conveyor	unload time=5secs	For unloading of parts to discharge the conveyor. Unload time estimated during parameter tunning
Conveyor	One loop conveyor	Velocity = 20ft/minute Cell size=7ft Maximum cell occupied = 2	Non accumulating Assuming average length of vehicle = 14 ft
Segment	Part release to entering of Assembly section	Conveyor segment= 28ft per section	Segments connect each section containing the processes

4.3 Experimentation and Sensitivity Analysis

For this experimentation, we limit the number of replications to five (5). The simulation was conducted based on the assumption of 1 shift (8 hours per day) for a week (5 days per week). Arena Version 16.1 student edition was used to perform the simulation.

Sensitivity analyses were based on the extended scenarios to understand the effect of some changes in the material handling model configuration and parameters used. We specifically were interested in observing how changes in the parameters of the material handling variables of the extended scenarios can affect the performance of an ideal vehicle assembly model. For example, how an increase in the speed of the conveyor in scenario 2 affects the outputs produced. In addition, for scenario 1, it will be interesting to quantitatively experiment with the effect of capacity decrease or increase of the transfer resource.

5. Results and discussions

5.1 Parameter fixing

The results of the parameter tunning discussed in section 4.2 are presented in table 5 below. The table shows the material handling transfer resource and conveyor parameters obtained by ensuring the number of outputs is the same.

Table 5. Parameter fixing results for fair model comparison

Performance measure	**Base model**	**Scenario 1**	**Scenario 2**
Number of outputs in units (final parts)	15	15	15
Material handling resource parameters After tunning	No material handling. Flow depends on the instantaneous flow between connecting logic modules	Four different transfer resources per section With a fixed capacity	Conveyor segment= 28ft per station Velocity = 20ft/minute Cell size=7ft Maximum cell occupied = 2 Assuming average length of vehicle = 14 feet

5.2 Sensitivity Analysis result

Figure 5 below shows the number of outputs obtained as the segment of the conveyor is increased based on three different levels of velocity for the conveyor. The centroid was obtained using the popular k-means clustering algorithm (Awad and Hamad, 2022).

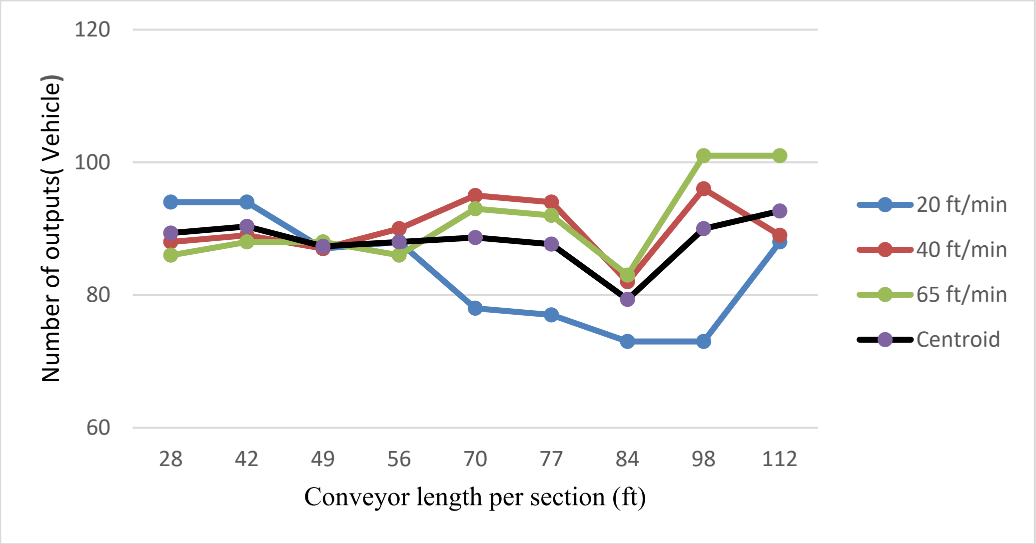

Figure 5. increasing conveyor segment at three levels of velocity

The results of Figure 5 suggest a downward and upward trend as the conveyor segments increased in length. However, the centroid shows more of a downward trend before outputs finally increased with the long conveyor segment. Looking at these results could initially indicate that the longer the conveyor, the longer the time it takes for parts to travel through the system. However, an increased number of outputs with longer conveyor segments subject to increasing velocity could indicate more space on a fast-moving conveyor.

Our second interest was to observe the effect of increasing the conveyor velocity at different conveyor segments. It is assumed that the conveyor segments do not change per section. Figure 6 below illustrates the results obtained.

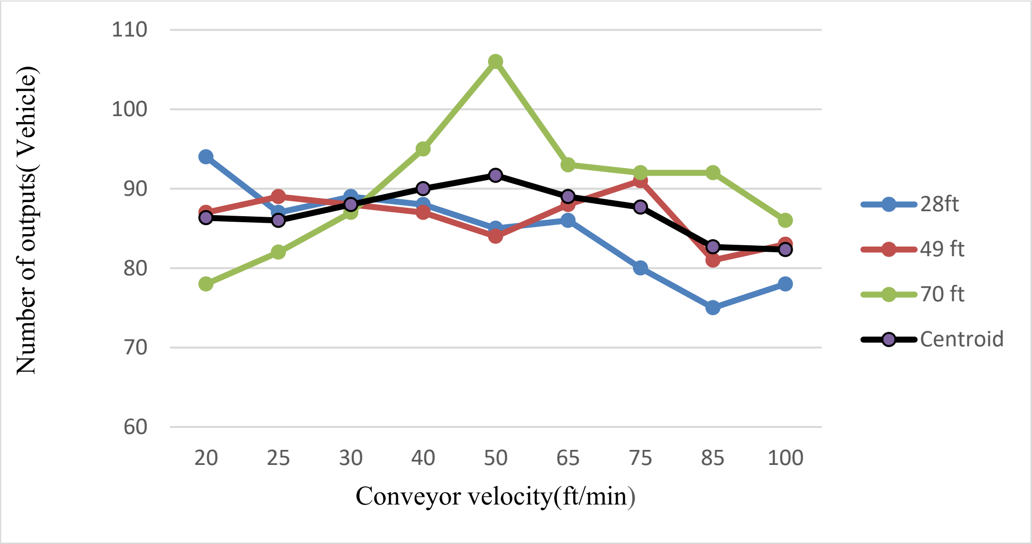

Figure 6. Increasing conveyor velocity at three different lengths of the conveyor segment

Similarly, increasing the conveyor velocity at a constant conveyor length could either result in increased or reduced outputs. Looking at the centroid line, a gradually increasing number of outputs followed by a gradually decreasing number of outputs even with increased conveyor velocity is shown. The results follow the logic that the increased length of the conveyor increases more parts on it and increasing speed also increases the flow of the parts. However, a high very high-speed conveyor might be very unstable for parts on it thus counteracting the gains of increased output.

Thirdly, our interest is to observe the impact of resource-constrained material handling on the number of outputs. This was done under a constant move time and assuming a fixed capacity for the resource. Figure 7 below shows the effect of increasing the transfer resource capacity under constant move time.

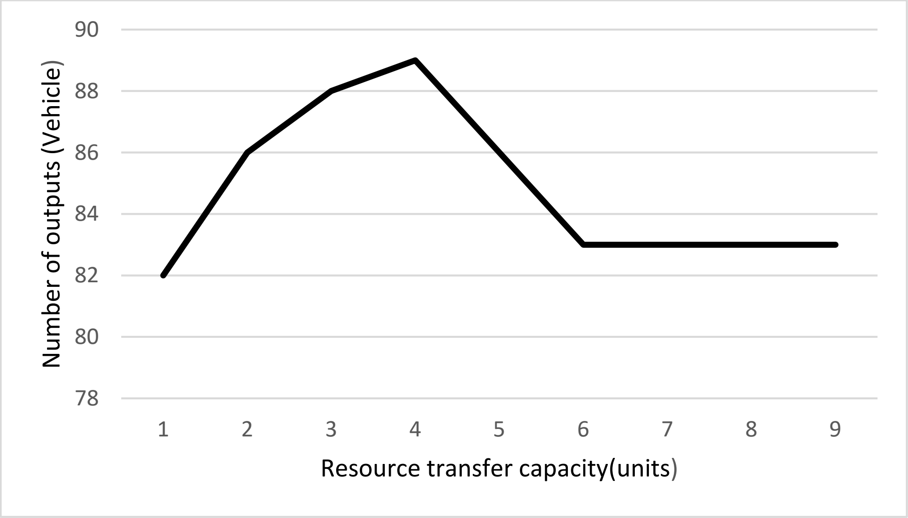

Figure 7. Resource transfer capacity effect on outputs

Figure 7 above suggests that an increase in transfer resources initially increases outputs which agrees with the reasoning of speeding operations or increasing flow through capacity increase. Furthermore, results from the table also show the likelihood of outputs becoming insensitive to resource increase. This will be most likely when the number of parts flowing through the system is much smaller than the transfer resource capacity.

6. Conclusion

In this study, a simulation model of a generic vehicle assembly plant was presented to illustrate the transitions of real models from ideal models using material handling assumptions. The conveyor and resource-constrained capacity scenarios were modelled into an ideal vehicle assembly model.

Sensitivity analysis showed that in the short run material handling devices have the likelihood of either increasing, decreasing, or keeping constant the outputs of a typical operation or process such as vehicle assembly. Therefore, showing the importance of different configuration settings and trading of variables to yield intended results for production outputs.

Findings from this study are useful during material handling and design specification to observe the possible relationships among certain variables of the system being designed. In addition, the discrete event simulation and modelling logic employed in this study could be a useful aid in engineering education research to study the flow of students under possible semester and assessment constraints.

This study could be improved with the use of more real-life data. In addition, several assumptions considered could be removed to see how this will impact the results. For example, some plants operate continuously, and steady-state modelling might be appropriate. Furthermore, resource schedules and failures could provide more practicality when considering resource utilization. More performance objectives such as the throughput, utilization of resources, cycle time, and average number in the queue for each process could also provide more insight into the material handling process. Lastly, complex robotic features, automated conveyors, automatic storage, and retrieval systems are realities to consider as the world moves in the fourth industrial revolution direction.

Appendix

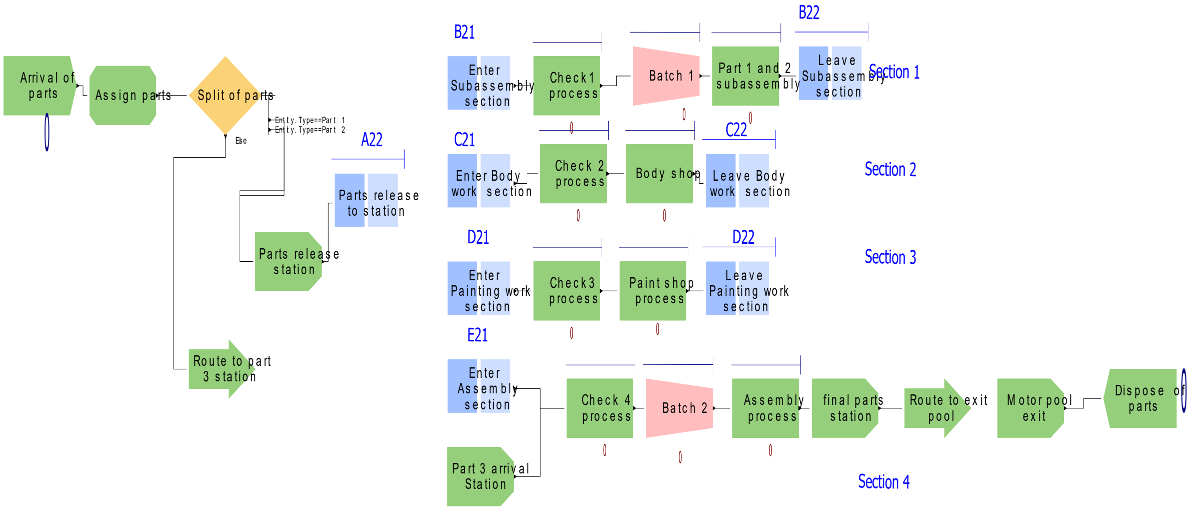

Figure A1 Flow chart showing the model logic units for Conveyor modelling (Scenario 2)

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