Customized Mixed Model Stochastic Assembly Line Modelling Using Simulink

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Abstract **- Assembly lines have been critical to the successful operation of manufacturing plants over the years. This is mainly attributed to the ability of assembly lines to adjust to the needs of the industry at any given time. Therefore, it is imperative that assembly lines adjust to the era of smart manufacturing commonly termed as Industry 4.0. This latest trend in industrial revolution has many facets, changing the way products are designed, manufactured and delivered. One such standout feature of Industry 4.0, is how it has changed the way products are ordered. Industries are moving from a conventional make-to-stock approach to a make-to-order approach. This paper looks at how a customized ordering system can be modelled for a mixed model assembly line. The research is based on a case study using a water bottling plant which can bottle 500 ml and 750 ml bottles. The economic viability and a preliminary model for the project was done and documented previously. This paper is structured such that it initially provides an introduction to the research. Secondly, it provides an overview of the previous model and its limitations. Thirdly, the paper shows how the current model has been developed in Simulink to introduce customized ordering. Finally, the results obtained from the simulation are shown. The primary aim of this research is to develop a Simulink model for customizing the input of a water bottling plant. This model can then be used to optimize the time to manufacture water bottles and contribute to the broader research area of Mixed Model Stochastic Assembly Line Balancing.**

Keywords - component; Industry 4.0;Assembly Line Balancing; Modelling; Simulation; Customization.

I. INTRODUCTION

The manufacturing industry is undergoing significant changes with the advent of Industry 4.0. These changes are as a direct result of the penetration of Information and Communication Technologies (ICT) [1]. Industry 4.0, a term coined in Germany, [2] has since been widely acknowledged by governments around the globe [3] as the future of the manufacturing industry.

The key components of Industry 4.0 [4], which were established by extensive research in academic and business publications, are identified as Cyber Physical Systems (CPS), Internet of Things (IoT), Internet of Systems (IoS) and SMART factories.

Cyber Physical Systems [5] integrate the physical and virtual world, while Internet of Things [6] enables communication between sensors and actuators connected to the manufacturing systems. Internet of Services [7] allows clients and vendors the ability to place orders or offer their services via the internet. SMART factories [8] ensure that the different processes which run in the background are in communication with each other therefore are aware of the position of a device or the stock of a component necessary for manufacture.

The use of these key components portray a shift in the manufacturing scene. In the past, the focus was on mass production [9] or on a make-to-stock approach. The more recent trend is to allow the customer to decide the products they desire to purchase. This approach to give the customer more purchase freedom is termed as mass customization [10] or make-to-order approach.

The most important component of any make-to-order manufacturing system should be its ability to provide product variety [11]. Product variety can be introduced to a manufacturing plant by using Mixed Model assembly lines. Mixed Model assembly lines are those [12]–[14] which produce many different models of a product on the same assembly line. The time to manufacture the different models cannot be pre-determined, hence they have stochastic operation time. These type of assembly lines are classified as Mixed Model Stochastic (MMS) assembly lines.

Studies related to the work discussed in this paper have focused on various other industrial sectors like the manufacture of vehicle components [15], garment industry [16], ship building [17] and automotive cables [18]. However, all these studies have focused on the assembly lines manufacturing a fixed variety fixed of products, thereby limiting the choice of the consumer.

This paper deviates from this path by focusing on modelling a customized mixed model assembly line using the case study of a water bottling plant which can produce 500ml and 750ml bottles. A preliminary model was developed which could simulate the desired outputs. The limitation of this model was that outputs could not be customized to a specific order placed by a customer.

This paper initially gives an overview of the case study and the previous model. This will shed further light on the limitations of the previous model. Secondly, the paper proceeds to develop a new model which aims to improve the previous model by introducing customized ordering. Thirdly, the simulated outputs of the new model are shared in the results and finally a discussion is conducted on the way forward.

II. PLANT OVERVIEW AND MODELLING

This section looks at the initial study [19] that was done to establish the economic viability of the water bottling plant, hence forward referred to as the plant, and the Simulink model that was developed to support [20] this study. Simulink was chosen as the modelling platform because several research models, [21], [22], [5] similar to the work discussed in this paper, was developed using this software tool.

The aim of the plant, as mentioned in the previous section, is to produce bottled water in 500 ml and 750 ml bottles. A 3 dimensional CAD model of the plant was developed to demonstrate how the plant would look once completed. This is depicted in Figure 1.

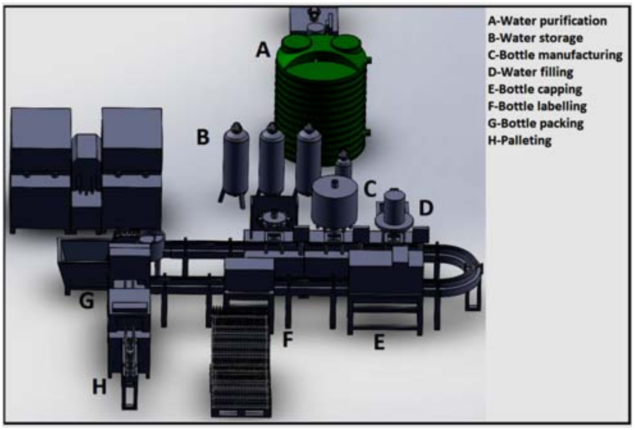

Figure 1. A 3dimensional CAD model of the plant

The CAD model depicted in Figure 1 was split into three main sections for the purposes of creating a Simulink model. These are the water storage unit, the bottle manufacturing and storage unit and the water filling unit. The water storage unit of the plant comprises of sections A and B from Figure 1, while the bottle manufacturing unit is made up of section C and the water filling unit has section D.

For the purposes of design simplicity, section E to H have been omitted in the preliminary model. The Simulink model for the plant with the three units are shown in Figure 2.

As seen from the Simulink model shown in Figure 2, the three units are created using five subsystems. The water storage unit consists of a source and storage tank subsystem. The source subsystem provides a constant source of water with a lower and upper limit to the Storage tank subsystem.

The storage tank subsystem is the input to the water filling subsystem. The fact that it acts as an intermediary block between the Source and Water filling subsystem means that it has a continuous state, therefore the net flow of water is equal to the difference between the water coming from the source and the water flowing out of the tank.

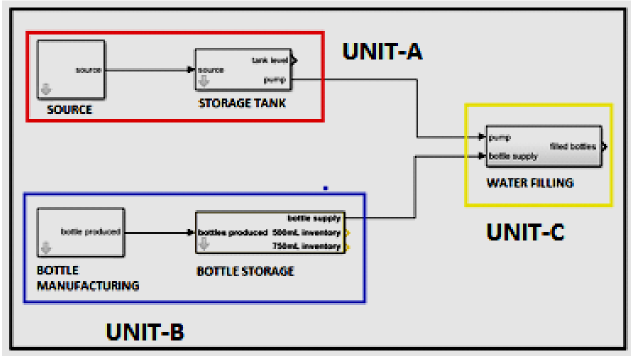

Figure 2. Simulink model for the plant showing three main units

The second unit in the model is the bottle manufacturing and storage unit. This unit is independent of the water storage unit and comprises of two subsystems, namely the bottle manufacturing subsystem and the bottle storage subsystem.

The flow rate of water from the source subsystem, the pump flow rate from the Storage tank and the time taken to manufacture bottles is defined under a mask in Simulink. These parameters can be varied to suit a specific manufacturing need. Table 1 lists all subsystem parameter and their respective mask values used in this model.

TABLE I. SUBSYSTEM PARAMETERS AND THEIR MASK VALUES

Subsystem	*Quantity*	*Mask Value*
Source	Source flow rate	6kg/sec
Source	Source upper limit	8kg/sec
Storage Tank	Pump flow rate	4kg/sec
Storage Tank	Pump upper limit	10kg/sec
Storage Tank	Maximum Tank capacity	1000m^3
Storage Tank	Initial tank capacity	0m^3
Bottle manufacturing	Time taken to produce bottle	2sec
Bottle storage	Initial number of 500ml bottles	0
Bottle storage	Initial number of 750ml bottles	0
Bottle storage	Output rate of bottles	2sec

The design criteria of the plant stipulate that bottles be manufactured in batches of six. This is achieved by passing a sine wave through a compare with zero block with an output HIGH Boolean. The positive half cycle of the sine waves yields 500 ml inventory and the negative half cycle produces 750 ml bottles.

The output of the bottle manufacturing subsystem is fed to one of the inputs of the bottle storage subsystem. The other two inputs are firstly the initial count of the bottles which is defined under a mask in the subsystem and

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secondly, the count of the number of bottles filled with water.

The number of bottles filled with water is obtained from a GoTo block defined in the water filling unit. The output from the GoTo block is fed to a triggered subsystem, which removes a bottle every time it is pulsed. An image depicting the model for the 500 ml and 750ml bottle storage is shown in Figure 3.

The water filling unit is connected to the water storage unit. Therefore, the input of the water filling unit is the output of the storage tank. The successful operation of the water filling unit is depended on how the unit can distinguish between 500 ml and 750 ml bottles.

In order to achieve this, a modulo 12 counter is used, which will count the first six (0-5) and be triggered for the next six (6-11). The first six bottles will be 500 ml and the next six will be 750 ml bottles. There will also be a GoTo block which is triggered as each bottle is filled. This GoTo block is connected to the bottle storage subsystem as mentioned previously. The simulated output of bottles being filled is shown in Figure 4.

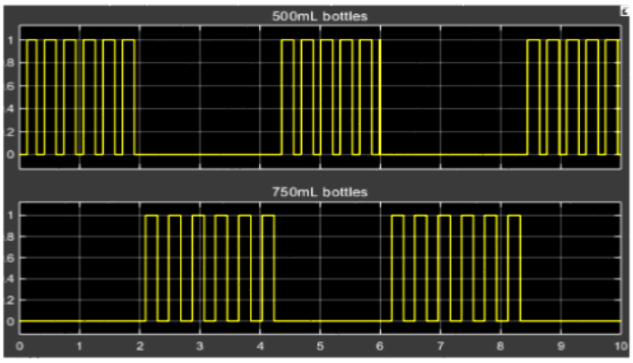

Figure 4. Simulated output of water filling subsystem showing the 500 ml and 750 ml bottles.

III. MODEL CUSTOMIZATION

As mentioned in section 2, the previous model used a modulo 12 counter to switch between 500 ml and 750 ml bottles. To overcome this limitation, firstly the customer requirements must be fed into a table from which it can be accessed by the Simulink model. This can be done by setting up a table in MATLAB script with the requirements of the customer. The script can be called from the model to execute the required action. A sample of the customer requirements is shown in Table 2.

TABLE II. CUSTOMER REQUIREMENTS

Customer Name	*#500ml bottles required*	*#750ml bottles required*
A	90	90
B	125	60
C	60	150

The modulo 12 counter needs to be replaced with a subsystem that can read the values in customer requirements table to the new model. This can be achieved by using a one dimensional lookup table. The data from the customer requirement table can be transposed and flattened to appear as a row of information to the table. A relational table with a memory block can be used to check if the number of bottles in each row has been reached.

As soon as the number of bottles in the first row has been achieved, a trigger element can be set up to first index the data and the move to the next row in the look up table. This can be continued till the last row in the lookup table has been read into the model and defined in the index. The distinction between 500 ml and 750 ml bottles can be made by calling a function in the model which checks the index where the data has been read from. By default, the 500 ml bottles will be indexed in the odd rows while the 750 ml will be indexed in the even rows. The water filling unit with the customer requirements subsystem is shown in Figure 5 and the customer requirements subsystem with the lookup table and memory block is shown in Figure 6.

IV. RESULTS AND ANALYSIS

This section looks at the results of the modification to the model discussed in section 3 and discusses the results with respect to previous model. As expected, with the addition to the model, customer requirements should be read in from the input table that was depicted in Table 1. A scope output connected to the water filling subsystem is shown in Figure 7.

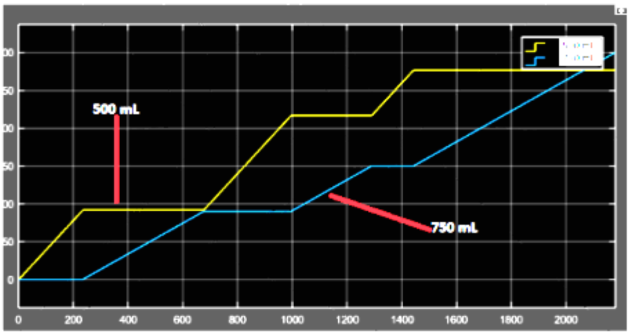

Figure 7. Scope output of water filling subsystem with reference to Table 2.

As can be seen from Figure 7 the water filling subsystem starts filling the 500 ml bottles according to the order shown in Table 1. After it has reached ninety 500 ml bottles it goes to the 750 ml bottles which are also ninety. This completes the order of Customer A. The subsystem then moves to Customers B and C. On analysing Figure 7 with Figure 4, which was of the previous model, it can be established that the addition to the new model has the ability to read in customer inputs and fill the bottles in that order.

V. CONCLUSION

The aim of this paper was to model a customized mixed model assembly line. A case study using a water bottling plant which can fill 500 ml and 750 ml bottles was used to propel the study. Prior to undertaking this study, a preliminary model was developed as part of an economic feasibility study. The limitation of that model was that it was only able to produce batches of six 500 ml and 750 ml bottles.

The paper initially described the overview of the plant and the previous model with depictions in Figure 1 and 2 respectively. The paper then shifted focus to the water filling subsystem in the previous model as this is where the change needs to be made to enable customization. The output waveform of the previous model, which showcases the limitation described previously is shown in Figure 4.

The next section of the paper shows how the model was modified to include a customized input. This done by creating a MATLAB script to input customer requirements. The MATLAB script can then be called from the model. A table representing customer requirements is shown in Table 1. It was designed to take 500 ml and 750 ml orders for three customers. This section of the paper also shows the changes made to the model to bring about the change. This is shown in Figure 5 and 6.

The next section of the paper shows the results of the changes made to the model. This is depicted in Figure 6 and is with reference to the input in Table 1. On comparing the output of the new model with that of the previous model shown in Figure 4, it can be clearly seen that there is a marked improvement in the system. The plant model has gone from one which was randomly outputting 500 ml and 750 ml bottles in batches of six to one which can take inputs from customers and output them accordingly.

The results in Figure 7 show that the model has been improved to accept the inputs of the customers. Therefore, as part of the future work, a study needs to be done to see how the customer requirements can be read out of a cloud environment into the MATLAB model. This would bring in key components of Industry 4.0 such as Internet of Things (IoT) and Internet of Services (IoS), defined in the introduction, into the model.

Another possible direction that the study can take is to see if real time optimization for several customer requirements is possible for this model with constraints like the level of water in the storage tank and the number of bottles in storage. These results can contribute to the research in mixed model assembly line balancing.

SMART manufacturing, as stated in the introduction, is the future of industry as it stands. This paradigm shift brings with it challenges that were different from those encountered previously. This paper aims to find solutions to these challenges by building the model for a water bottling plant and incorporating components to it so that it can function as a smart manufacturing plant once completed.

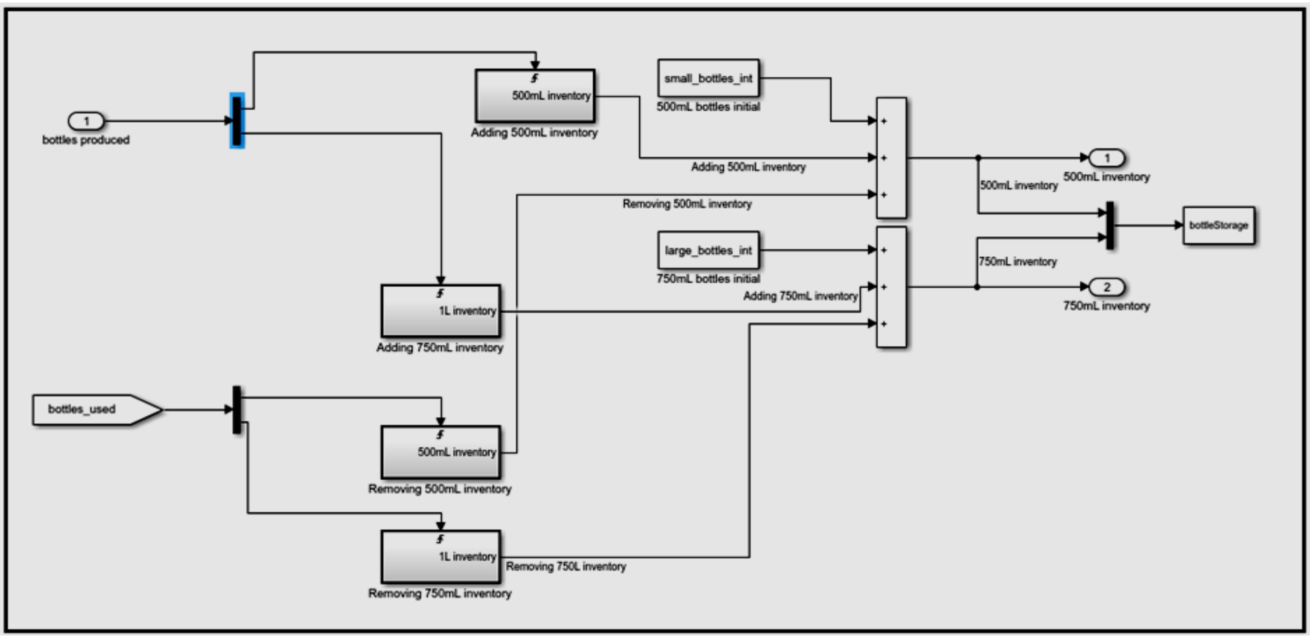

Figure 3. Bottle storage subsystem

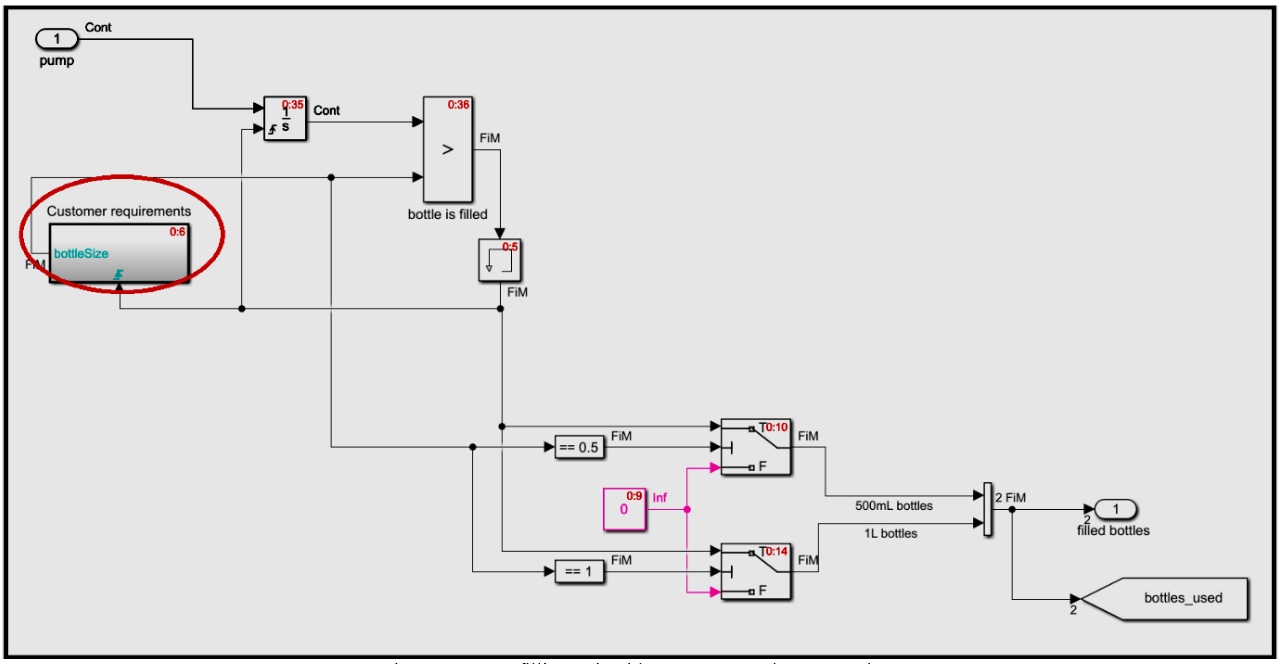

Figure 5. Water filling unit with customer requirements subsystem

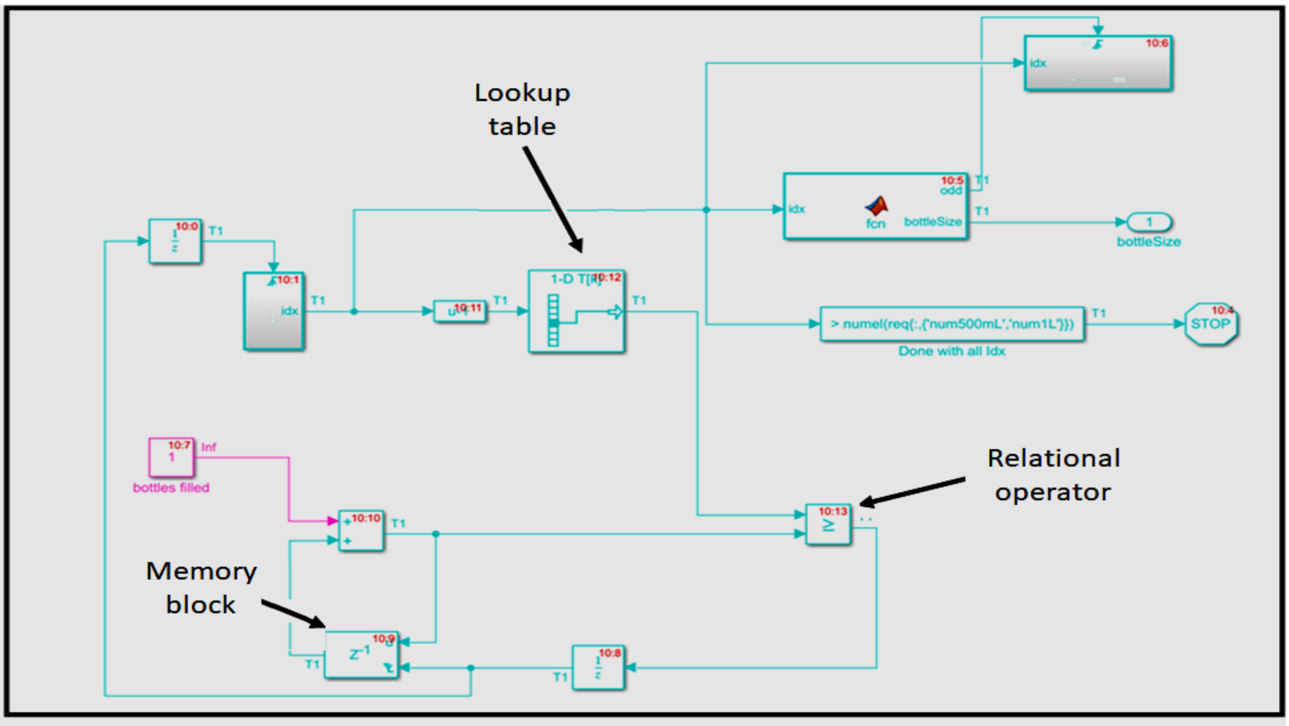

Figure 6. Customer requirements subsystem

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