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Maven: A first step towards a digital twin for synchronous logistics in the automotive industry

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Abstract

This paper is concerned with the development of a simulation model designed as the basis for an operations-focused Digital Twin of a synchronous supply process in an automotive assembly line. The simulation model has been co-designed and developed by both simulation experts from the University of A Coruna and industrial engineering experts from the Maviva logistics company. The model has been developed in Flexsim, and it contains the entire set of assets, resources, and operations involved in the synchronized delivery of components to the assembly lines of the Stellantis Group Plant in Vigo (Spain). Since it is aimed at providing an actual and updated digital operational asset for the Maviva logistics firm, a significant effort has been put in the model's parameterization so that enabling its adaption to new production circumstances and its interoperability and integration with current data systems in real time. The first application cases and results are presented in this paper.

Keywords: M&S, Discrete events simulation, Synchronous supply, Digital twin

1. Introduction

Established in Vigo (Spain) in 1994, Maviva S.A. is a leading logistics firm for the automobile manufacturing sector, and part of the industrial division of the Ferrovial Servicios company since 2017. Amongst other services, Maviva is a recognized industry specialist in providing synchronous supply of components for Just in Time automobile assembly lines. A Maviva's key client is the Vigo Production Centre of the Stellantis Groupe, with production capacity in excess of 2,250 vehicles/day of different models of the Citroën, Opel, Peugeot, Vauxhall and Toyota brands. The plant exports 87% of the production to 85 different countries, and it employs more than 6,500 people. In effectively serving such an important client, failing is not an option. To this end, Maviva's logistic centre in Vigo has to deal with and synchronize different sources of variability. First, coordinating and absorbing the different parts manufacturers supply chains variability -with providers from Morocco, Tunisia, Turkey, Iran, and Americas-, and then, connecting -by storing, collecting, arranging, and delivering- tens of references from those different supply chains with the vehicles assembly lines under a just in time (JIT) scheme. Last, Maviva must adapt and respond to the intrinsic variability arising from the cars manufacturing plant, from changes in mid-term manufacturing plans that determine the types of vehicles and quantities -and thus, the needed re-arrangements for new components in Maviva's plant and operations- to more tactical adaptions to working conditions (changes in predefined sequences, emerging downtimes, etc.). But Maviva must also keep the pace of the demanding technological evolution of the automotive sector and support client's commitment to Industry 4.0.

MAVEN (Maviva's Emulation Environment) is a development project between Ferrovial Servicios and the University of A Coruna aimed at providing Maviva with a first version for the Maviva's Vigo logistic plant Digital Twin (DT). The first step is to develop a complete simulation model as a decision support system focused on enhancing Maviva's capacities to cope with variability, increasing their flexibility and resiliency by dramatically widening and deepening the space of solutions to explore and analyze. Also, MAVEN targets the necessary cultural, organizational, and infrastructural requirements to allow the scaling-up towards the establishment of a real operations-focused DT.

This paper is concerned with the development of a simulation model designed as the basis for a DT of a synchronous supply process in an automotive assembly line. The paper describes the methodology followed, the main features of the simulation model, the experimentation carried out to validate and obtain preliminary results and the approach adopted to build a model that can be synchronized with production data systems in real time and therefore serve as a DT of the logistic process.

2. Bibliographic Review and Scope

The automotive sector is widely acknowledged for being one of the most innovative and demanding supply chains .Concepts such as Lean or Just In Time have been pioneered by companies in this sector and have led to tightly synchronized supply chains in which vehicle manufacturers can maximize the responsiveness of their supply chain while by minimizing the lead times, the inventories and the errors and quality defects (Miemczyk & Holweg, 2004).

Synchronous supply requires that manufacturers deliver components to assembly lines in the exact quantities required and in the sequence in which different stock-keeping units (SKUs) will be consumed in the line (Bennett & O'Kane, 2006). In practice, it requires implementing a highly efficient logistic system that can deliver the ordered SKUs without errors and very tight turn-around times between a few minutes and a few hours. In the case study presented in this paper, these logistic operations are performed by a third party logistic provider that operates a proximity warehouse located next to a car assembly line in the city of Vigo (Spain).

Synchronous flow is generally achieved adopting two approaches (Farouk et al., 2020). First, if the manufacturer is located close to the assembly plant, they may serve the orders already sequenced according to the sequence of vehicles that enter the assembly line. However, if the manufacturer is located overseas or at a long distance from the plant, then a proximity warehouse with a stock of various SKUs is built and the picking and sorting process is performed in a synchronous mode as the orders arrive from the assembly line. An alternative approach is using Just in Sequence deliveries in which the manufacturer ships pre-sequenced Unit Load Devices (ULDs) which are later re-sequenced if needed as the assembly issued the orders (Taube & Minner, 2018).

All these supply systems require operational excellence because, if a stockout is caused in the assembly line, the economic cost of an interruption is very high. They are systems subject to high levels of variability in the sequence of orders received and (depending on the plant) in the turn-around time required to deliver the parts. Thus, M&S offers an ideal tool to analyze the complexity of these systems (Edward J. Williams, 2012).

M&S has particularly become one of the key enabling technologies in Industry 4.0 (de Paula Ferreira et al., 2020). On the one hand, M&S allows to analyze the implementation and integration of multiple I4.0 technologies. On the other hand, a simulation model can be viewed as a digital asset than can contribute to the digitalization of a production process. In this regard, several authors have analyzed and discussed the role that simulation plays in the development of a digital twin (DT) (dos Santos et al., 2021).

In order to develop the digital twin of a process, dos Santos et al. define the DT as the integration between a simulation model and process data in such a way that the information can be synchronized in real time and, thus, the model results used for decision making. Other authors as Flores-Garcia et al. point out the importance of a simulation model to develop a DT, but conclude that the features of a simulation model are insufficient to build a DT (Flores-García et al., 2020).

Regardless of the academic discussion about the definition of a DT and its relationship with M&S, these technologies serve the ultimate purpose of supporting decision making and thus, the appropriate level of detail required and the nature of the models developed will be dependent on the type of relevant decisions that need to be made and the characteristics of the real system. For instance, the case study considered in this paper is a logistic plant. In this facility, the major decision problems that determine performance are operational. For example, in this case there is not complex equipment whose physics need to be modelled to predict failures that may affect production quality or performance. Most tasks are manual or require standard forklifts or towing tractors that do not have critical maintenance requirements. Thus, most of the relevant aspects of the system can be accurately represented in a classical discrete events simulation model.

3. Process Description

The processes studied in this paper are concerned with the synchronous supply of parts to a car assembly line. The activities carried out in the logistic facility are:

1. Truck unload and storage of car parts. Maviva supplies SKUs of different parts manufactured by various manufacturers. The stock covers different time lengths between a few days and up to several weeks. The parts are stored in pallets or customized containers.
2. Feeding the picking stations. Forklifts retrieve the containers or pallets from the storage and place them in the picking area. Two main types of picking systems are used: carton live storage for boxed items and forward picking areas with the pallets or containers laid out on the floor, under the racks or on mezzanine floors.
3. Picking and sequencing for synchronous delivery. Assembly orders are issued by the car assembly line specifying the SKU required and the sequence of delivery. The picked parts are loaded in customized wagons or boxes (named BACs) that will be carried to the assembly line
4. Transportation to the assembly line. The wagons with the sequenced parts or BACs are carried to the assembly line by towing tractors.

One of the key variables that determine the operations is the turn-around time, which is the time available from the receipt of the supply order from the assembly line to the time in which the part will be assembled in the vehicle. The whole picking, sequencing and transportation process needs to be completed with enough margin to ensure that the assembly line doesn't suffer a stockout of parts. Thus, the total turn-around time is the sum of:

- Waiting time since the order is received until the worker reads and picks the part. This time mainly depends on the availability of the worker assigned to the operation. If it has been assigned more tasks, it may increase the waiting time.
- Picking time (it requires grabbing the part, walking, registering the action in the system plus placing it in the wagon or BAC). This time mainly depends on the picking technology used (voice picking or bar code scanning), the distance from the picking station to the BAC or wagon and the manual handling times.
- Waiting time until the wagon or BAC is full plus some additional time required to register the shipment or dispatching the wagon or BAC. It depends on the wagon / carton capacity and the decision rules used to determine the departure time. If one of the parts is urgent, the towing truck may depart with a partial load.
- Transportation time. It includes the time required to load the wagon or BAC, travel to the assembly line and unload it there.

4. Data collection and analysis

To develop a simulation model, all the relevant data needs to be identified, collected and analyzed to setup the model. The ambition in this project was to develop a simulation model that can serve as the basis for a DT, so an initial effort was made to identify the data needed to synchronize the model with the state of the system in real time. The following list of data sources were considered as inputs for model development:

- Assembly orders.
- Records from the assembly line. Each time that a car enters the preassembly buffer and the assembly line, an event is generated in the system. This information gives the initial estimate of the assembly time for a specific part. Along with the assembly start time for each vehicle, it allows to monitor the state of the preassembly buffer in real time.
- Short- and long-term production plans. They give the expected number of units of each SKU that will be demanded by the assembly plant in the following days and in the following months. Obviously, the short-term production plan is more accurate, but still may suffer slight variations when the real assembly orders are issued.
- Current stock availability of each SKU in the picking and storage areas. Location of each unit load in the warehouse and picking areas.
- Expected truck arrivals.
- Time measurements of picking times as well as picking area feeding.
- Transportation times (from the picking areas to the assembly line and return).
- Wagons and BAC's capacities. Palletization and containers capacity.
- Container, pallet and BAC sizes.

5. Simulation

The simulation model was developed in the software Flexsim.

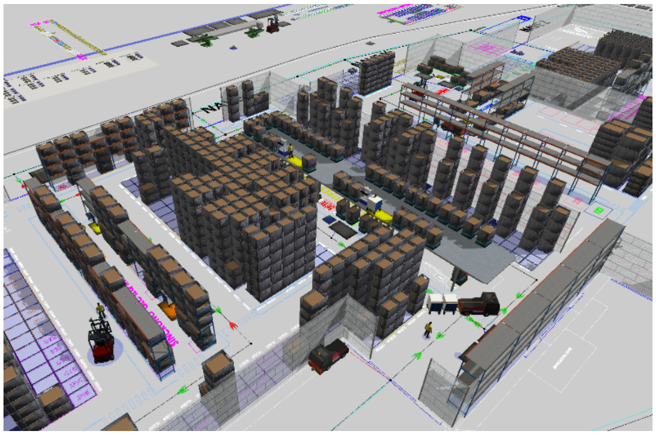

Figure 1. General view of the simulated plant with 14 different types of synchronous supplies.

To simulate the demand and the turn-around time in a realistic fashion, the pre-assembly buffer of vehicles is simulated as well as the variability in arrivals to this process and the interruptions in the production line. The time between arrivals to that buffer can be generated in two ways. First, a set of real arrival records can be simulated to either emulate the process in real time or to simulate a past period. Second, if the goal is to simulate future conditions, a sample with more than 17,000 observations is resampled using a bootstrap method to simulate TBA values following the real statistical distribution.

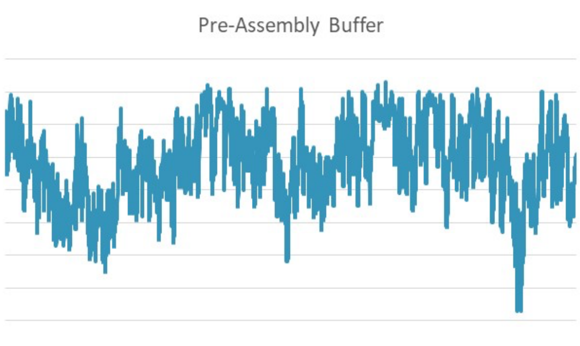

Figure 2. Example of a 2-week pre-assembly buffer simulation.

Since the type of activities are very similar for different types of parts, the first step was to develop a custom set of reusable and parameterized objects and logics that could be applied to different synchronous supply processes. The following types of objects were developed as customized Fixed Resource process flows:

- Picking stations. A picking station is defined as a location (usually on the floor or on a carton live storage system) in which a unit load device (ULD, i.e., a container, pallet or box) that contains several units of one reference is laid out waiting until the items are retrieved by the picker. To reduce the number of items in the model, containers are represented in the storage area as a single Flowitem with a label that stores the number of parts. Then, the picking station creates an individual Flowitem for each part picked. The empty container or box is then sent to the empty ULD area. This station also sends requests to feed new ULDs from the storage area when the parts are consumed.
- Sequencing stations. This is the central object of the model. It is the location where a wagon or BAC is loaded with parts according to the sequence received from the assembly line. The object has a complex parameterized logic that allows to simulate different loading sequences and logics to determine when to dispatch the items. It basically collects orders from the assembly line and requests an operator to perform the task of retrieving the parts and placing them in the wagon. The number of orders that will be read and sequenced together is a customizable parameter. Also, a specific operator can be set as the default task executer but, if it is busy when needed, a second support operator can be called. When the order is received, the SKU required is randomized according to the % of demand that corresponds to each SKU and the number of items is determined. In some cases, only one part is needed but for other synchronous systems more than one may be required. The dispatching logic checks the remaining time for delivery of the most urgent part in one shipment and, if the wagon is not full but the time left reaches a certain margin (given by the transport time plus some allowance) then the wagon is dispatched to prevent a stockout.

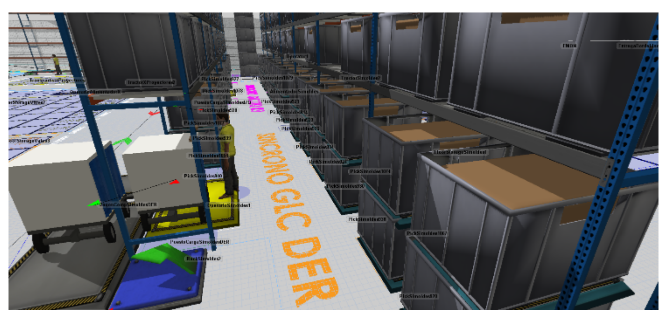

Figure 3. Example of a sequencing station (left) where the picker is loading some item in a wagon and floor picking stations (right).

- Assembly stations. They are the workstations in the car assembly line where the parts are assembled in the vehicles. This object checks whether the car model requires assembling one SKU and, if so, checks the number of units required and executes the process. The vehicle stays there during the duration of a cycle of the assembly line. If the part is not available, then it causes a line interruption.

- Transportation logic. Transport operations are performed by towing tractors. A set of default transportation tasks were modelled using Subflows (within a general Process Flow) that can be combined to generate different transport logics. One subflow orders a given tractor to collect a wagon or BAC of a part type. Another subflow performs the transport and unloading in the assembly line task. After unloading a full wagon or BAC, it loads an empty one in the line. The last sublow implements the process of returning to the logistic center and unloading the empty wagons or BACs. These subflows can be combined to generate complex transport logics. For example, one of the tractors is responsible for transporting 5 types of parts. A general operation logic calls the subflows to load several BACs until the most urgent one needs to depart to arrive in time. It then unloads the BACS in the required location, retrieves all the empty ones and returns. The designed subflows simplify the development of new transport logics that can exploit synergies from multiple synchronous supplies.

All the relevant model variables are parameterized through labels and object labels. Thus, it is possible to adjust the following parameters:

- Task times.
- SKUs list and % of consumption for each type.
- Available stock of each SKU.
- Assembly line cycle time.
- Travel speed and loading and unloading times.
- Number of orders grouped to be processed together.
- Time Margin before departure.
- Transport capacity.
- Worker assignments (default assignment and support).
- ULD capacities.

The main model results and KPIs are stored in tables and displayed in a dashboard as charts. These include:

- Pie charts of workers, workstations and transport systems utilization (forklifts, tractors).
- Assembly line stock of parts.
- Pre-assembly buffer content.
- Number of transport departures per hour.
- Throughput rate of vehicles assembled.

6. Model validation

The model was validated using two approaches:

- Comparing the utilization rate for each worker to the one measured by the "Methods" department of the company.
- Comparing the assembly line buffers real contents to the simulation results. In this case, the model results were presented to the company experts who checked if the variability shown in the model was an accurate representation of the reality.
- Comparing the number of transports/hour with the records in the company databases. The simulated transport departures depend on the simulated orders as well as the simulated turn-around times and the decision of when to depart. Thus, comparing the real and simulated number of transports/hour allowed us to check if the model was accurately representing the transport logics as well as the decisions of when to stop filling a wagon.

Multiple experiments were run, and the model results were shown and discussed with the company managers until a valid version of the model was accepted for the experimentation stage.

7. Results and Discussion

The simulation model, once validated, was applied to address several decision problems that the company faced during the period of the project. The ambition of this project was to provide the basis for building a DT of the process that can be useful in the daily operations in the long term, so the experimentation itself was designed as a means for testing the capabilities of the model for providing better answers to operational problems.

The following experiments were conducted during the duration of the project. They intend to exemplify some of main utilities of the model.

1. Picking area layout redesign.
2. Impact of an increase in the assembly line throughput.
3. Assignment of workers to workstations.
4. Addition of a new component synchronous supply.

7.1. Picking area layout.

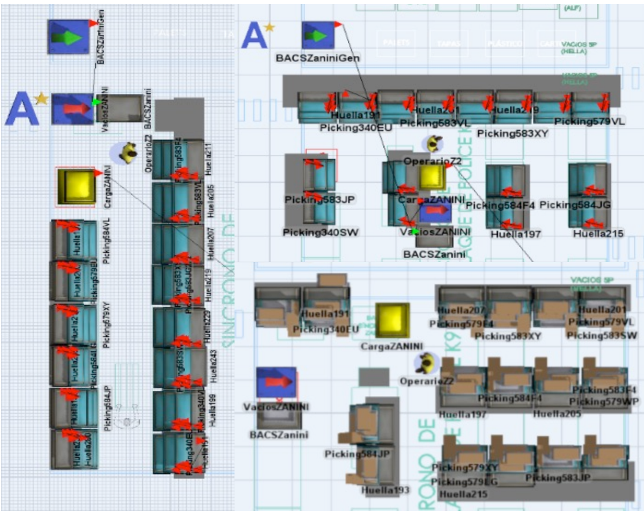

Figure 4. Different picking are layouts simulated (picking locations are in blue and the sequencing station in yellow). The bottom right one was the one that minimized the worker utilization rate.

The first problem analyzed using simulation was the redesign of the picking area for one type of components. The number of SKU's had been reduced and Maviva was interested in freeing up space for other processes. The layout has an impact of the travel times of the workers since different SKU's have different rates of consumption and distances to their picking locations. The picker must travel continuously between the sequencing station and the picking stations, so a good layout should minimize the total travel distance and place the SKU's with the highest demand closest to the sequencing location. Different layout configurations were simulated and the one that led to the lowest utilization rate of the worker was selected.

7.2. Impact of an increase in the assembly line throughput.

At one point during the project, the company was notified that the TAKT time of the manufacturing line was going to be reduced by 5%. That means the demand would increase by the same rate. Such a change would have an impact in utilization rates (more items picked per minute), but it would also affect the turn-around time, since the vehicles would reach the assembly stations faster.

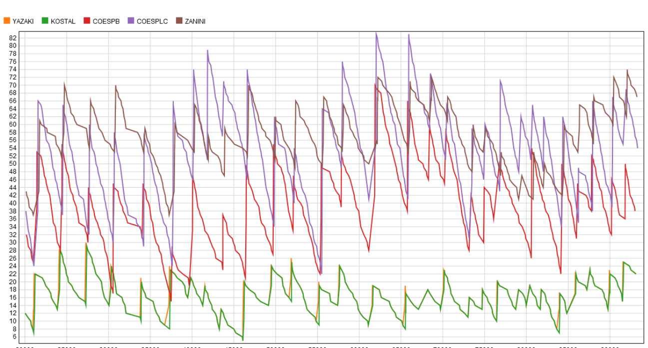

Figure 3. Assembly line stock of 5 types of parts simulated after the TAKT time reduction.

Model results showed that the current workers assignments and resources could absorb the increase in demand without adding additional resources and, thus, prevented incurring in over costs in additional resources that would not be needed.

7.3. Assignment of workers to workstations

The synergies among workers for various processes were evaluated using the model. One key feature of the model was the parameterization of the worker assignments. Each activity has a label, or a record in a table were the default operator in the model is established along with a backup worker that may assist if the worker is busy.

Assigning several tasks to a worker has the advantage of minimizing the labor costs, but at the cost of increasing the time wasted in switching between tasks (so the total utilization of several tasks is higher than the sum of each activity's utilization) and at the expense of increasing the risks of causing a stockout in the assembly line because of the additional waiting times. Determining if an assignment is valid is difficult using a spreadsheet due the non-linearities in utilization rates and the dynamic decisions of when to switch from one task to another to ensure that the parts will be delivered in time.

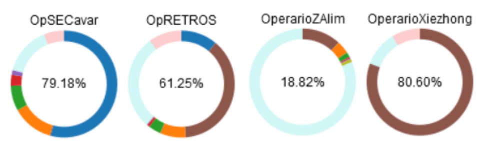

Figure 5. Utilization rate for the pickers of three type of parts and the forklift driver in one of the scenarios tested. The Forklift driver had a low utilization rate for these tasks, so it was assigned additional tasks in other processes.

Different assignments were simulated along the project to test different proposals for redistribution of the workload. The two KPIs analyzed for each scenario were the workers utilization rate and the risk of causing a stockout in the line.

7.4. Addition of a new component synchronous supply

The last type of scenario analyzed during the project was the addition of a new type of vehicle component to the ones supplied by Maviva. This scenario involved a layout redesign, adding new truck unload activities, the storage area, the picking area, and the transport activity to the assembly line. The layout redesign may have an effect in forklift travel times, so it may affect other products. Also, the new activities might be assigned to available workers or to new ones. Other decisions that could be addressed were the capacity of the wagons and the frequency of the transport departures.

The new processes were added to the model. The library of simulation objects implemented avoided writing new scripts or creating many new process flows, so the development time was sharply reduced.

The model results showed that it was possible to add the new synchronous supply process increasing by two the number of workers and sharing the workload of some tasks with other previously existing operators.

8. Towards the digital twin of the process

The simulation model developed was designed and parameterized from the beginning to be the basis of a DT of the process. To achieve this goal, the tables, model variables and data structures were defined to ensure interoperability with the information systems of the company.

The key data that will be exchanged with the information systems of the company are:

- The sequencing orders for each SKU. They are issued when the vehicles arrive to the assembly line joining the pre-assembly buffer.
- The information about the current stock in each location of the plant (storage areas, picking areas and so on).
- Short term production plans generated by the car manufacturer.
- Bar code scans that signal different events in the real system such as the time in which one item is loaded in a wagon or a towing tractor departs.
- Truck arrivals.

Another complementary, but necessary, step to advance in the goal of implementing a DT was training a team of engineers from Maviva in the use and development of simulation models. Three members of the methods department were selected and trained in Flexsim as well as the specific library of simulation objects developed in this project. They are currently capable of autonomously developing simulation models for other facilities of Maviva and updating the model to reflect changes in the real plant. This capability is essential to achieve the long-term success in a simulation project and is a must step to achieve the development stage of a DT.

9. Conclusions

A simulation model of a synchronous supply process for a 3rd party logistics operator in the automotive sector has been presented. The model architecture and parameterization has been designed to serve as the backbone of a process digital twin. The simulation model was initially validated combining real data and expert judgement. Four scenarios of decision problems faced by the company where simulation was applied have been described which further validates the practical utility of the model.

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