EVALUATION OF ALTERNATIVE CONFIGURATIONS FOR A MANUFACTURING PLANT: THE CASE OF AN ITALIAN COMPANY IN THE BUSINESS OF OIL AND FUEL ADDITIVES

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KEYWORDS

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ABSTRACT

This paper describes a simulation study conducted on an Italian firm involved in the production and packaging of fluid mixtures, such as motorcycle and automotive lubricating oils and fuel additives. This Italian company needs to expand its production capacity, which is now close to saturation point, with the aim of being able to meet growing future demand. Using AnyLogic® commercial simulation software and in particular its Fluid Library, the manufacturing plant in its current configuration was modelled and studied. After addressing the initial transient problem and validating the model, the maximum increase in demand that can be met by the actual plant and an alternative configuration of the manufacturing plant were analysed. Thanks to results of the simulation study, it was possible to help the company management in the selection of the new manufacturing plant configuration by providing key performance metrics predicted by simulation.

INTRODUCTION

When one wants to make critical choices that lead to the modification of complex systems, such as logistics and production systems, it seems obvious to want to analyse in advance the consequences that these choices have on the behaviour and performance of the modified system. Often, when one wants to analyse a real system, it is often not possible to observe it directly, i.e. it is not possible or not feasible from a cost and/or time perspective. In such cases, the study of a model of the real system is used. A model is a simplified representation of a real system and therefore can be used to study the behaviour of the associated system without necessarily analysing the system itself. Simulation modelling generally involves mathematical models which can be described as a series of logical and mathematical relations. Relatively simple mathematical models can be solved by analytical methods to obtain a so-called analytical solution. However, when the system to be studied is very complex, the resulting model may itself be too complex to be solved by analytical methods. In such cases, one can employ simulation and the model studied is referred to as a simulation model.

This paper describes a simulation study for the evaluation of alternative configurations of a production plant of an Italian company involved in the production and packaging of lubricating oils and fuel additives. With the aim of satisfying an increasing demand, the company management wishes to modify the current production facility in order to create more production capacity. After analysing possible solutions by means of qualitative and semi-quantitative techniques, the company management identified some possible new configurations. Since a production plant is a very complex system, numerous simplifications were made in the analysis of its possible new configurations. The company management, before making the final choice, wished to analyse the results of a study conducted with more precise quantitative techniques. According to what has been explained above, the simulation of the production plant model is therefore the most suitable tool for this purpose. Using simulation, after having modelled the current configuration of the plant and having successfully passed the validation phase (i.e. one is reasonably sure that the model describes the behaviour of the associated system sufficiently well), one can go on to modify the model according to the new configurations to be studied and thus predict with a certain degree of certainty what the performance of the plant might be depending on whether it assumes one configuration or another.

In the remainder of the paper, the production plant subject of the simulation study will first be described. Then the work carried out during each step of the simulation study will be examined. After clearly defining the problem and the scope of the simulation study, in a brief parenthesis will be motivated the choice of AnyLogic as the simulation software and hybrid simulation as the simulation paradigm. Then we will proceed to construct a conceptual model, utilizing AnyLogic key characteristics. Input data needed to construct the model will be analyzed using Minitab® statistical software and finally the model of the current

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production plant configuration was programmed. After numerous tests had been conducted on the model and we had built up some confidence in the programmed model, we moved on to address the initial transient problem. After that we proceeded to the validation phase through statistical comparison between simulation runs results and real data from the actual system using Minitab. Finally, the alternative scenarios were modeled and their respective performances were analyzed, producing key information for management decision-making. The general methodology briefly described above and used during this simulation study is the result of the reworking of the steps of a simulation study described in various books regarding the simulation (Law, chapter 1.7, 2014; Kelton et al. 2002; Rossetti 2021).

DESCRIPTION OF THE CASE STUDY

We will now proceed with a brief description of the manufacturing plant, listing each of its main elements and with an explanation of how the production process takes place. Having a deep understanding of how the manufacturing plant work is necessary to the develop of the model that will be studied with simulation.

Key Elements of the Manufacturing Plant

In the manufacturing plant, mixtures of lubricating oil and fuel additive are produced through blending and then later packaged. Schematically the production plant consists of these key elements: one mixer having a capacity of 5000 kg, twenty-seven metal cylindrical tanks, and six packaging lines. Of the 27 metal tanks, having different capacities:

- 16 are used for the storage of the raw materials of greatest interest. These tanks are referred to as raw material tanks.
- 11 are used for the storage of ready-to-pack mixtures. These tanks are termed semi-finished product tanks. Each of these tanks is used to store a specific and unique family of mixtures (2-stroke or 4-stroke engine oil, fuel additive).

In addition to semi-finished tanks, raw materials are also stored in cubic containers with a capacity of 1000 kg, referred to as IBCs, and in metal drums with a capacity of 200 kg. All raw materials IBCs and drums are located in two separate areas in close proximity to the mixer. IBCs can also be used for storage of ready-to-pack mixtures. Ready-to-pack mixtures contained in semi-finished products tanks or IBCs can be packaged in the six packaging lines. In general, the packaging lines consist of conveyor belts, a filling machine that is responsible for filling the final mixture packaging, and a system for screwing the caps onto the mixture packaging. At the end of the conveyor belts, the box construction operation can be manual or automated. In any case, the final palletizing of the boxes on the pallet is manual. Packaging lines are divided as follows:

- One used for packaging metallic cans.
- Two used for packaging one-liter bottles.
- One used for packaging bottles smaller than 1 liter.
- One used for packaging bulky packages, such as 200-liter drums, 60-liter drums, and so on.
- One used for packaging multiple types of packages.

The company works 5 days a week on a single work shift. Work shift lasts 8 hours, with an hour lunch. During the work shift there are two operators who handle only the processes involved in the mixer, while six operators work on the packaging lines. Before the start of the working shift, a maintenance team performs maintenance operations on packaging lines. During the working shift the same team resolves any packaging line failures. Packaging lines are only partially automated, so they need operators to work. Each packaging line requires two operators, with the exception of the one used for bulky packages which requires only one operator.. To transport pallets with IBCs, barrels, cartons, cans, bottles and so on, operators use forklifts and if necessary, hand pallet trucks. Finally, the manufacturing plant is connected to a raw materials warehouse that contains cans, bottles, boxes, etc. all the necessary for the final filling of mixtures and the final assembly of finished product boxes on pallets. It is also connected to a finished products warehouse where all pallets of finished products are stored.

How the Production Process Works

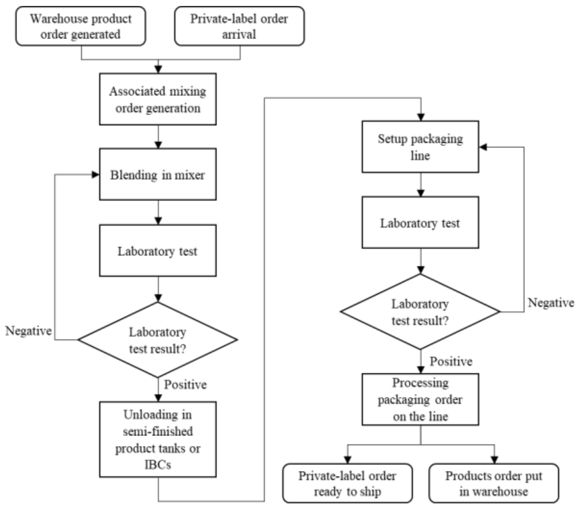

Figure 1: Flowchart of Production Process

In Figure 1 the flowchart of the production process is presented. The production process begins with:

- Following a shipment from the warehouse, the stock level has fallen below the reorder point defined for a particular reference. A packaging order is issued to restore stock in the warehouse.
- An order arrives from the outside, a so-called private-label order. The company has agreements with third-party firms to package some of their products.

Packaging order, regardless of its "origin," is transformed into the corresponding mixing order. Mixing order is processed in the mixer. A team of operators schedules the automatic loading of raw materials contained in raw material tanks and performs manual loading of raw materials contained in IBCs or drums. After mixing, a laboratory test is performed on the mixture to ensure that the correct amounts of raw materials in the formula have been met. If the test outcome is positive, the mixture is unloaded into semi-finished product tanks or IBCs. Otherwise, the wrong amounts of raw materials in the mixer are corrected and further mixing is carried out and another test is repeated.

Having reached this point of the process, the mixing order is now complete and the processing of the packaging order can proceed. Operators perform the setup of the correct packaging line: bring all the necessary materials, connect the correct semi-finished product tank or IBC and clean the filling system of the line. A laboratory test is performed to ensure that possible residues of previously packaged mixtures have been eliminated during the setup. If the test is negative, the part of the setup involving cleaning the line is repeated and another laboratory test is performed. Once a positive outcome is obtained, operators proceed with the packaging of the mixture contained in the tanks or IBCs. Packaging process is done by building one pallet at a time of packages of finished products. When the packaging is finished, pallets of finished product are taken to the warehouse for restocking or, in the case of a private-label order, are sent to the customer.

PROBLEM FORMULATION

The company management wishes to evaluate the possible alternative configurations they have identified for the manufacturing plant using quantitative techniques. The system to be studied is therefore the company's manufacturing plant. In particular, company management would like a flexible simulation model that would allow them to study different scenarios of the manufacturing plant configurations compared to the current one. The model must be able to predict with sufficient accuracy the main performance of the plant if the number of mixers, number of tanks, number of operators, and production speed of the packaging lines are changed.

The most urgent configuration to be represented is a manufacturing plant with two mixers in parallel (the mixer has been recognised as the main bottleneck of the production system). In a two-mixer configuration, it is necessary to provide rules for assigning mixing orders in order to maximise the volumetric utilisation of the mixers. It's therefore necessary to program a model that incorporates within it rules representing the decision-making process for assigning mixing orders.

The main performance metrics of interest identified are:

- The average number of monthly stockouts for finished products stored in the warehouse, which is not permissible as all products are sold as ready for delivery. This KPI is measured in stockouts/month.
- The average duration of stockouts for finished products stored in the warehouse. This KPI is measured in days.
- The average number of delayed private-label orders per month. This KPI is measured in delays/month.
- The average length of production delay of private-label orders. This KPI is measured in days.
- The utilisation of every key resource in the system. This KPI is measured as the ratio of the working time of the resource to the maximum time the resource could have worked (equal to the plant opening time).

CHOICE OF SOFTWARE AND SIMULATION APPROACH

Once we know the context of the real system well enough and have discussed with the major stakeholders of the project, it is understood that no one in the company has a good understanding of the simulation tool. Therefore, the validation stage and the description of the assumptions made for model construction turn out to be of great importance. Sufficiently accurate animations can therefore be an excellent tool for conveying how the model and its outputs work, particularly when most stakeholders are not familiar with simulation modelling (Law, 2019).

It's necessary to use software that allows:

- Display good quality animations, particularly for processes involving fluids.
- Develop a highly flexible model with which it is easy to represent different configurations of

the production plant (and not only those specifically addressed in this paper).

- Represent the rules by which the unloading of fluids into certain ready-to-pack mixtures tanks is selected.
- Represent the complex rules for assigning mixing orders to mixers in the case of multiple mixer configurations.

Commercial simulation softwares available for authors were Arena® and AnyLogic®. After evaluating the two available options, AnyLogic was chosen as the simulation software and simultaneously an HS (hybrid simulation) simulation paradigm (Brailsford et al., 2019) to get the greatest modelling freedom.

AnyLogic works through the Java language and allows complex functions to be written through this language. The idea is to exploit this feature to describe the rules for assigning ready-made mixtures to tanks and for assigning mixing orders to a set of n mixers. Furthermore, AnyLogic was purposely designed from his origin to allow modellers to develop practical HS models using all three main simulation paradigms: DES (discrete-event simulation), SD (system dynamics) and ABS (agent-based simulation). Because of this feature AnyLogic in last years is resulted the most used simulation software for HS (Brailsford et al. 2019). Choosing AnyLogic, one is free to use any paradigm to represent the different parts of the model. The authors can use the classic blocks typical of the DES paradigm to describe production processes and the modular approach of the ABS paradigm to create sets of agents representing different key system resources such as tanks, mixers and packaging lines. AnyLogic also includes a library dedicated to fluid processes. Using this so-called *Fluid Library* good animations can be visualised and metrics associated with tanks can be continuously updated.

CONCEPTUAL MODEL

A conceptual model is a simplified representation of what will be the simulation model programmed on software, but usually includes all the elements that characterize the model itself and illustrates which are the assumptions and simplifications made during the abstraction process (Ferrari et al. 2020). Therefore, a conceptual model must be functional for the next stage of actual modelling on software and must be able to convey how you want the model to work (Robinson et al. 2015). We briefly summarize the most important assumptions made for the construction of the conceptual model:

- The amount of goods leaving the warehouse each day is the result of a large number of orders with random composition. In accordance with the central limit theorem, assuming that the number of packages according to different references ordered by each customer are independent random variables, the average number of packages ordered assumes normal distribution. This has been proven through statistic testing on Minitab for major items. Figure 2 below shows an example of a normality test performed on the number of packages leaving the warehouse daily.

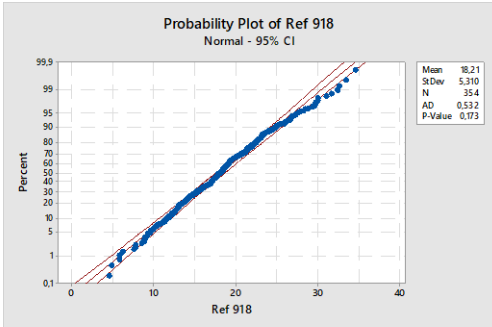

Figure 2: Probability Plot for the Daily Demand of an Article

- Multiple shipments occur per day, however for the purpose of creating packing orders it is sufficient to aggregate all items leaving the warehouse at one time according to the estimated daily demand as written above.
- Productivity losses due to beginning and end of work shift and beginning and end of lunch break are neglected. Thus, the choice is made to simulate only continuous working hours, as if upon resumption of interrupted work, resources resume working right where they left off.
- Given that operators for transporting pallets of raw materials and finished products can use forklifts, hand pallet trucks, and if necessary, also use those dedicated to other departments, we choose to overlook the possible logistic delay due to the lack of such resources.
- The company's process experts report the fact that rarely in the past two years have there been production problems related to raw material shortages. This is because the company has the ability to stockpile large quantities of raw materials at low cost, so they would rather have a surplus than delay some blending or packaging due to a lack of raw materials. It is therefore assumed that as soon as possible, based on the availability of resources, an order is immediately processed, without any control of raw materials. In accordance with this

assumption, we choose to neglect the modelling of raw material inventory.
- It is assumed that the finished goods warehouse has no storage problems for pallets of finished product from the production plant. In accordance with this assumption, we choose to neglect also the modelling of finished goods inventory.
- It is assumed interarrival time of private label orders are well approximated by an exponential distribution with average the mean interarrival time.

Based on the assumptions and simplifications made, before proceeding with the software modelling phase a graphical representation of the conceptual model was constructed using flowcharts and activity cycle diagrams (Robinson, chapter 5.5.2, 2014). The conceptual model describes the flow of the main processes and the interactions between the various key elements of the production plant.

INPUT DATA ANALYSIS

A lot of care was taken throughout the simulation study not to fall into one of the most common pitfalls to the successful completion of a simulation study (Law, chapter 1.8, 2014). In particular, a great effort was made on the analysis of the model's input data. The objective is simulating a stochastic model in order to account for variability of the input data. Therefore, much energy was put into statistical analyses to obtain statistical distributions from which to sample the random input data during the simulation.

All the necessary data to be used as input for the simulation model were extracted from the company database: production logs of mixers and lines, orders from customers, recorded line failures, and so on. If necessary, additional data were recorded directly on the field. All data taken from databases came from the last two years, as according to the in-house process experts during this period the company did not undergo substantial changes, and therefore it can be assumed that data from the last two years can be compared and processed together. The data were processed directly on databases with the help of company IT managers and finally processed using Microsoft Excel® spreadsheets and statistical analysis by Minitab. Not only, as shown above, statistical tests were performed in order to find the correct distribution of aggregate demand for the various finished products, but many more were performed in order to:

- Find the correct distribution of production times per pallet for each line.
- Find the correct distribution of setup times for each line.
- Find the correct distribution of lab test times, distinguishing mixer from packaging line.
- Find the correct distribution for repairing time of packaging lines after failure.

The preceding list is only for example purposes because almost all times were treated as stochastic variables and thus numerous other tests were performed. In addition to the already mentioned statistical tests to identify the correct distributions, Anova One-Way tests (with comparison methods) were also performed in order to determine whether data apparently belonging to different distributions were in fact not part of a single distribution. An example of a graphical output for Anova One-Way Test is shown in Figure 3. In case of hypothesis of belonging to the same distribution, further tests by aggregating the relevant data were carried out.

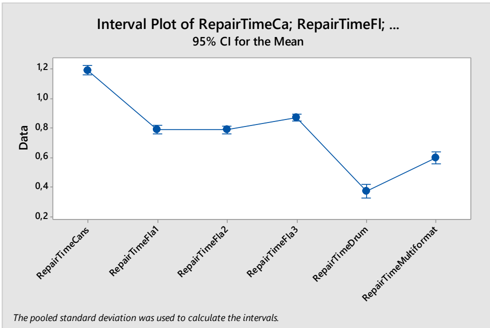

Figure 3: Graphical Output for Anova One-Way Test on Repairing Time for Packaging Lines

SIMULATION MODEL

Simulation model description

AnyLogic models are distinguished by a hierarchical structure formed by agents. There is always a top- level agent that constitutes the roots of the tree formed by all agents in the model. Each agent can incorporate inside itself another agent resulting in a branched structure composed of agents disposed on various levels. Each agent can act independently and communicate with others only when necessary. Inside an agent you can define variables, events, statecharts, stock and flow diagrams, flowcharts composed by process blocks and as mentioned before you can embed in other agents. In the model different agent types can be defined. An agent type can represent a single agent or a population of agents. A population represents a collection of agents of the same type.

The following is the hierarchical structure of the agents in the model.

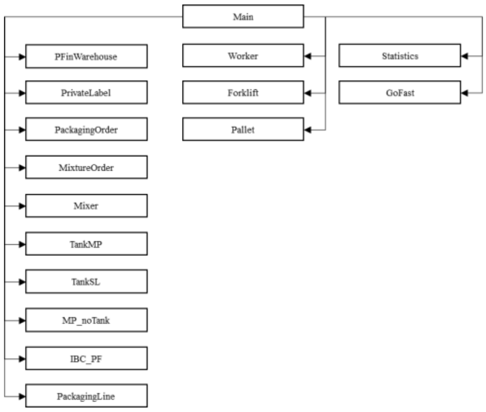

Figure 4: Hierarchical Structure of Agents in the Model

All agents are all embed in *Main* agent, the top-level agent and so there are no second level agents. Only the agents on the left in Figure 4 are really necessary for the functioning of the model. Agents in the centre are only for animations: *Worker* agent is used to animate moving packaging workers, *Forklift* agent serves to animate moving forklifts and finally *Pallet* agent is used to animate raw material and finished product pallets. The *Statistics* agent is used to contain all graphical data analysis elements offered by AnyLogic utilized in the model. Since AnyLogic only animates the content of the agent that is being displayed on the screen, and since animations slow down the model a lot, the *GoFast* agent is an empty agent that can be used when you don't want to monitor the simulation run, but just want to make the simulation run as fast as possible.

For the construction of the simulation model, massive use was made of the option “loaded from database” in agent population properties. We have placed an agent population for each type of agent on the left in Figure 4 on the Main agent. The option "loaded from database" allows you to set the number and characteristics of the agents that are part of a population from the data contained in AnyLogic's databases when you run the simulation run. AnyLogic databases are a kind of table containing data of various kinds.

	id	tank_name	tank_type_content	tank_fluid_content	tank_capacity_kg
1	1	tankMP1	solvent	S1	15,000
2	2	tankMP2	base	B1	30,000
3	3	tankMP3	base	B2	30,000
4	4	tankMP4	base	B3	30,000
5	5	tankMP5	base	B4	20,000
6	6	tankMP6	base	B5	20,000
7	7	tankMP7	base	B6	20,000
8	8	tankMP8	base	B7	30,000
9	9	tankMP9	base	B8	30,000
10	10	tankMP10	base	B9	30,000
11	11	tankMP11	baseAdditive	A1	15,000
12	12	tankMP12	baseAdditive	A2	15,000
13	13	tankMP13	baseAdditive	A3	15,000
14	14	tankMP14	baseAdditive	A4	20,000
15	15	tankMP15	baseAdditive	A5	20,000
16	16	tankMP16	baseAdditive	A6	20,000
*					

Figure 5: Database for Raw Materials Tanks

In this way, every relevant characteristic of every key entity in the system (such as names, kind of fluid raw material in the tanks, parameters of distributions assumed by times, etc.) was entered into a database. We have a database for raw material tanks (in Figure 5), a database for semi-processed product tanks, a database for packaging lines, a database for stock products in finished goods warehouse etc. This approach was used to create a very flexible modular model. Changing the content and/or the number of rows (e.g. one more row in the raw material tank database corresponds to one more raw material tank) of a database actually creates different agents in the model. Each agent within a population is characterised by the same behaviour, described by flowcharts and events, with due differences dictated by the characteristics set by the database, while the *Main* agent serves mainly to enable communication between the agents of the various populations and shows some data of populations. The functions that handle the interactions between the agent populations set at the beginning of the simulation run on the *Main* have been parametrically programmed so that they are suitable for populations consisting of n-agents and not just for populations describing the current plant configuration. All graphical data on the *Main* and statistics objects in the *Statistics* agent have also been parametrically programmed (mainly with the “Replication” advanced function using the size of populations as parameter) so that they self-modify at the beginning of each run depending on the information contained in the databases.

In conclusion, a model was constructed that is as self-programming as possible. Only at the time of simulation launch populations of agents corresponding to key entities of the model (e.g. tanks, packaging lines…) and graphical data related to agent populations are created.

Simulation model animation

The only non-parametric and therefore not self-programming element at run time are the model animations. Since AnyLogic returns an error by stopping the simulation run if it does not find the graphic entities delegated to the animations, the latter have been decoupled from the operation of the model and are therefore only useful for the communication purposes of the model. Before launching a run, it can be decided whether or not to consider the animations setting a parameter on *Main* agent. In this way the model does not return an error even if the animation elements for any mixers, lines, etc. added by modification of the databases have not in fact been modelled. In each case, 2D and 3D animations (respectively in Figure 6 and Figure 7) were defined for the current plant configuration.

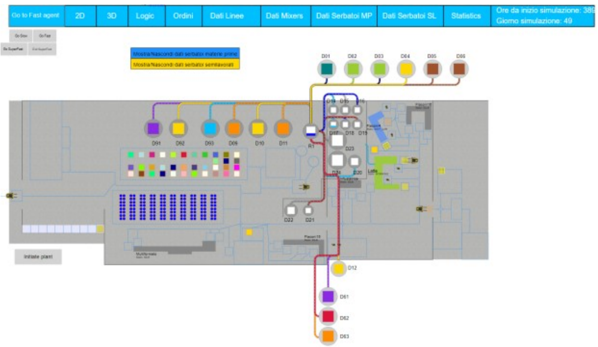

Figure 6: 2D Animation During Run

Figure 7: 3D Animation During Run

For communication purposes and to make it easier to check the various parts of the model, a navigation menu has been created that allows one to switch between the various “View Areas” of each agent on the *Main* agent.

How Simulation Model Works

As described in the conceptual model chapter, only 8-hour shifts are simulated. In the morning, new stock levels are calculated and if it is below the defined reorder point, a *PackagingOrder* agent (agent for packaging orders) is created. If you are already under the reorder point defined for the product an order for that reference has already been created and is in the packaging orders queue and so you update the existing order. This check is performed for each *PFinWarehouse* agent of the stocked finished products population embed in the *Main* agent. Private label orders that have arrived are also added to the same queue. The arrival of these orders is controlled by the *PrivateLabel* agents contained in the population on *Main*. At the beginning of the working week, i.e. once every 40 hours, as many orders as possible are scheduled, starting with the most urgent ones based on resource capacities. For the scheduled orders, *MixtureOrder* (agent for mixture orders) agents are created which will be processed by the mixer. For each mixing order, raw materials are loaded from *TankMP* (agent for fluid raw materials tanks) agents in the raw materials tanks population in Main or from raw materials *MP_noTank* (agent for IBCs or Drums containing raw materials) agents population embed in *Main*. When the mixture order is ready for unloading, it is decided whether the mixture should end up in a tank or IBC through a series of functions. The data for each unloaded mixture quantity is saved in the selected *TankSL* (semi-finished products tanks agent) or *IBC_PF* (IBCs used for finished mixtures agent) agents so that the right mixture can be used for each mixing order. Once all mixing orders associated with a packaging order have been completed, the latter is sent to the correct *PackagingLine* (agent for packaging lines) agent belonging to the line population on the *Main*. The operators get busy, perform the various setups, wait for the outcome of the lab test and if so, start producing one pallet at a time. If the machine breaks down during working operation, the maintenance team (which interrupts its other duties to prioritise line repair) steps in. Once a packaging order is finished, the stock of products in the warehouse is updated or a private label order is considered finished. Functions and statecharts were defined for the measurement of performance metrics of interest. After performing numerous tests on the model or its individual parts, sufficient confidence was achieved to continue with the study.

WARMUP DETERMINATION

Since we are dealing with a non-terminating simulation (Law, chapter 9.3 2014) it is necessary to consider the problem of the initial transient. For the identification of the initial period of the transient the Welch’s graphical procedure based on moving average (Law, chapter 9.5.1 2014) was used. Excel was used to visualise moving average graphs. Parameters of interest were analysed such as: utilisation of each resource/key agent in the system, average duration of stockouts, average duration of delays for the completion of private label orders, and average monthly number of stockouts and delays. For the estimation of the metrics of interest, 10 replications were made. In conclusion, applying Welch's graphical method, with 2 years of warm-up each monitored output appears sufficiently stable. Therefore, a warmup time for the model was considered to be 2 years. Figure 8 shows one of the moving average graphs as an example.

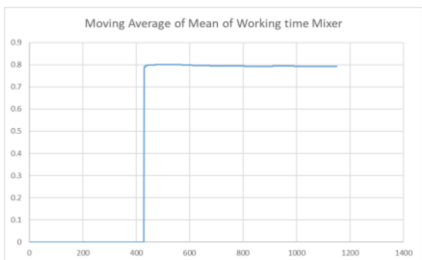

Figure 8: Moving Average of Mean of Working Time of Mixer

In order to remove the warmup period from the simulation model outputs the Replication/Deletion Approach (Law, chapter 9.5.2 2014) was used.

MODEL VALIDATION

Among the methods described to perform validation of the simulation model described in Sargent (2011) and Law (2019), it was mainly chosen to compare the output of the real system with those of the simulation through the use of statistical tests. The output of the actual system was calculated based on the last two years of production. 10 replications with a duration of 4 years each were made, including two years of warmup period, so that the "good" duration of each run was similar to that used to collect data on the real system. Below as example is a table with the data and results of 1-Sample t-tests performed between the output of the real system and the results of the simulation runs for the working time of mixer and packaging lines.

Table 1: 1-Sample t-test Results for Validation

KPI	Real System output	Mean output simulation	Dev St Simulation	95% C.I	P-value
Working Time Mixer	0.7969	0.7968	0.0021	(0.7922 ; 0.8013)	0.955
Working Time CansLine	0.2239	0.2201	0.0041	(0.2171 ; 0.2231)	0.017
Working Time Fla1Line	0.1351	0.1346	0.0048	(0.1311 ; 0.1379)	0.724
Working Time Fla2Line	0.1374	0.1372	0.004	(0.1344 ; 0.1401)	0.896
Working Time InfusLine	0.1775	0.1748	0.0041	(0.1718 ; 0.1778)	0.074
Working Time Fla3Line	0.2817	0.2777	0.004	(0.2748 ; 0.2806)	0.012
Working Time MultiLine	0.1019	0.0995	0.0034	(0.0970 ; 0.1019)	0.052
Working Time Operators	0.3989	0.3997	0.004	(0.3968 ; 0.4026)	0.529

For the data for which the 1-Sample t-test failed, metrics were derived from the real system by dividing by quarters, and a single simulation run lasting 4 years was run, saving the output every three months. Below is a table with the data and results of 2-Sample t-tests performed between quarters output of the real system and quarters output of the simulation runs for the validation of the working time of the cans packaging line.

Table 2: 2-Sample t-test Results for packaging cans line Validation

KPI	Mean output simulation	Dev St Simulation	Estimate for difference	95% C.I for difference	P-value
Real System output	0.22455	0.00657	0.0007	(-0.0055 ; 0.0070)	0.80
Simulation output	0.22381	0.00486			

The number of monthly stockouts, number of delays for delivery of private label orders, average stockout duration, and average delay duration for private label orders were also validated using the 1-Sample t-tests or the 2-Sample t-test.

ALTERNATIVE CONFIGURATIONS SIMULATION

At the time of writing this paper, only two of the required alternative scenarios have been simulated and studied. Simulating alternative configurations is relatively straightforward due to the fact that the model is largely programmed to self-configure when the run is launched, animations or not set. The first scenario, not really an alternative, is to analyse manufacturing plant while having to meet an ever-increasing overall demand. The second, since the single mixer is the bottleneck of the system, is to add a second mixer in parallel with a capacity of 10000 kg and increase the overall demand by 50%. A warmup time similar to that of the as-is configuration was assumed for each scenario.

Actual Configuration with Increasing Demand

Through a variable placed on Main agent the demand for each stock reference was increased equally. At the same time, the average interarrival time of private label orders was also reduced. During the system analysis, the number of monthly stockouts, number of delivery delays of monthly private label orders, and average duration of stockouts and delays were closely monitored. Ten replications with a duration of 11 years were run, including 2 years of warmup for each increase in demand. Demand was increased by 2.5% per simulation. Data were collected and analysed on Excel and Minitab. As an example, a boxplot with associated conditional intervals for the average number of monthly stockouts is shown in Figure 9.

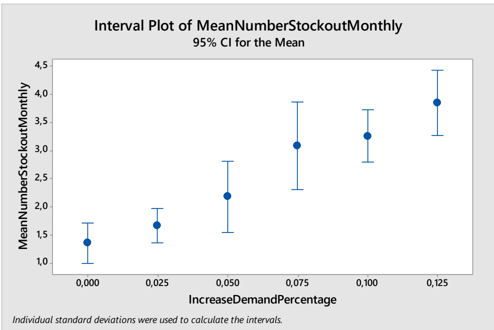

Figure 9: Boxplot for Average Number Monthly Stockouts

The analysis was done not only by graphical means, but also by statistical tests. It turned out that a with a 12.5

percent increase in overall demand KPIs are no longer acceptable to corporate management.

Configuration with Two Mixers

Because of what was explained above, modifying the model by adding a mixer was easy. All that was needed was to add a line on the database that governs the population of mixers and enter the characteristics of the new mixer. Since the scheduling functions already provided for a number of n mixers, nothing else needed to be changed. The products/private label orders demand has been modified in a similar way as described above Ten runs with a duration of 11 years were run, each one including 2 years of warmup. Data were collected and analysed on Excel and Minitab. The output simulation analysis shows that already with the addition of a mixer the system can handle such a large increase in demand. Below is the working time of the two mixers and, as an example, the mean number of monthly stockouts.

Table 3: Working Time Mixers, Two Mixers Scenario

KPI	Mean output simulation	Dev St Simulation	95% C.I
Working Time Mixer1	0.6055	0.0112	(0.5974 ; 0.6135)
Working Time Mixer2	0.5864	0.0130	(0.5777 ; 0.5958)

Table 4: Average Number Monthly Stockouts, Two Mixers Scenario

	Mean output simulation	Dev St Simulation	95% C.I
Average Number Monthly Stockout	1.559	0.0266	(1.5 ; 1.62)

CONLUSIONS

A simulation study was conducted on a production plant of an Italian company dealing with lubricating fluids and fuel additives in order to study possible alternative configurations. The plant was analysed and a conceptual model was built from the analysis. The input data needed for the simulation model was then analysed using Minitab, and the model was modelled using AnyLogic. Through the use of AnyLogic, a parametric modular model was built. Using AnyLogic's Fluid Library, it was possible to accurately represent the logic and process animations regarding mixers and tanks. Using the model different configurations of the manufacturing plant can be simulated modifying the input data contained in AnyLogic databases without altering the model itself. Sufficiently accurate animations were also produced, which contributed greatly to promoting confidence in the simulated model. The warmup time of the model was detected by Welch's graphical method and finally it was validated by statistical tests comparing output of the real system with that of the simulated model. Results produced by the analysis of the scenarios tested led to an understanding of the maximum increase in demand that the current system can absorb and produced a sufficiently accurate estimate of performance in the case of a configuration with an additional mixer. The entire simulation study required about six months of work. Most of the time was spent on data collection and analysis and model programming. Since the model was programmed in such a way that performance could be estimated for any possible change in the production facility, the company management has requested to continue with the study of other alternative configurations by simulation so as to make the most informed choice possible before proceeding with the plant modification.

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