MIXED-SIMULATION DECISION-SUPPORT SYSTEM FOR SEQUENCING

JAVIER OTAMENDI

Universidad Rey Juan Carlos, Campus Vicálvaro
Facultad de Ciencias Jurídicas y Sociales
Paseo Astilleros s/n
28032 Madrid, Spain
E-mail: francisciojavier.otamendi@urjc.es, jotamendi_30@yahoo.com

Abstract: A simulation model that represents a production and packaging factory is presented. The objective of the study of the system is to develop weekly plans both for the production lines and for the packaging stations in order to increase throughput while meeting customer demands. The model is a mixed model, with inclusion of both continuous elements to model product flow and discrete-event stations to model logic and fulfillment of orders. The model is part of the decision support system designed and built to help the programmers develop weekly plans. The DSS is a mixture of spreadsheets and the simulation model where the worksheets act as the interface between the factory database and the model. The paper presents as well how the different knowledge groups (simulation specialists, production planners, in-house system developers, plant and factory managers) interact in the development and the maintenance of the application.

Keywords: DSS, discrete event, continuous modeling, sequencing.

INTRODUCTION

There is a clear distinction between continuous and discrete event simulation modeling. The first one is associated with the flow of fluids or liquids, or, in another words, with rates of flow. Examples are numerous, ranging from oil production, soap manufacturing, fire expansion, …

Discrete-event modeling is usually attached to queueing systems, that is, parts waiting in queues until the stations free up and service is given. Queues at banks, an airplane (unit) trying to take-off in a given runway (service station), a vehicle trying to refuel at a gas station, a customer trying to make a deposit… They are all examples of real systems, in which if the service station does not have enough capacity, queues are formed with the corresponding hassle for the customers.

And there are rare occasions in which both approaches are used in combination to model one system [Pidd 1987, Arer and Ozdemirel, 1999]. Mixed models are not developed because the system usually calls for either continuous or discrete-event modeling, or that is what the modeler thinks. Sometimes the combination of product-process calls for a mixed model or for the use of discrete event in a continuous situation or viceversa.

This is the situation in hand: a discrete-event problem, in which the product is an individual unit that is finally packaged with others. But the rate of production and the simplicity of the units call for a mixed model in which rates are used as in the continuous case and delivery units are used as in the discrete-event case.

It is necessary also to mention that the whole purpose of developing the model is to study the system in order to increase throughput maintaining the current level of completion of delivery dates. The outcome of the model must be the weekly production schedule that operators will use to run the factory. This sequencing problem has been repeatedly studied via simulation in the literature (for example, [Fisher and Ittner, 1999], [Hershauer and Ebert, 1975], [Hollier, 1968], [Macaskill, 1973], Moccellin and Nagano, 1998], [Udo, 1994], [Wein and Chevalier, 1992]).

The development of the model has made management also believe that it was the proper time to incorporate the electronic knowledge obtained from the planners. The outcome has been a decision support system (DSS) that proposes weekly plans that result in a larger throughput.

THEORETICAL ABSTRACTION OF THE PROBLEM

Let us use this section to describe the system under study. It is a continuous process at first with the product flowing through a system of tanks and pipes, until it is packaged into different size bags (Figure 1).

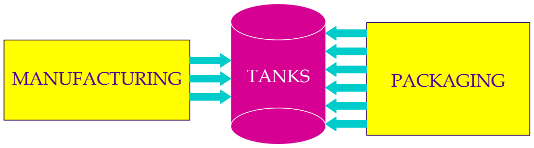


Figure 1: Flow of Products

The unique characteristics of the product is what makes the process distinct. The product is a small piece with very high rotation or volume of production. Nuts and bolts, pencils, golf balls… The number of references is usually small, that is, up to 15 different types of products (for example, white, yellow, orange or pink golf balls).

Once in its final manufactured form, the product must be packaged for shipping. A few different formats may be used for packaging (for example, bags, boxes, each with different amount of balls).

So what makes the process different is that a continuous flow of product is being manufactured and then converted into a different unit, in this case, bags of products.

There exist several manufacturing lines in parallel, which process one lot of a specific product at a time. Then, the finished product is pushed forward and stored in tanks, from which the product is pulled into the bags according to customer specifications. The bags are formed in several packaging stations set in parallel.

There are some restrictions in the process. The most important one is that different products (white and orange balls, for example) cannot be mixed at any time. That calls for the necessity to correctly schedule the lots of both the manufacturing stations and the packaging ones.

If the size of the manufacturing lot is too large in all of the manufacturing lines, it is possible that the not all the customer orders are fulfilled since some of the products are not being manufactured. If the size of the lot is small, then the setup times to change between products to initiate a different lot may be too long, with the system becoming unproductive.

The selection of the packaging format is also critical, since it influences the emptying rate of the buffers. Large formats (bags of 1000 balls) call for faster emptying of the tanks than small formats (boxes of 6). Again, set up times for the packaging stations may negatively influence in the performance of the whole system.

So let us discuss the crucial influence of the tanks. They cannot be neither totally empty nor full. If the tanks are full, the manufactured product cannot be put into the tanks, blocking the manufacturing lines with the corresponding loss in throughput. On the other hand, if the tanks are empty, there is no product to be packaged, losing the possibility to increase throughput.

Therefore, the sequencing problem to be solved is one in which the emptying and filling rates of the tanks is intelligent to be able to maintain the tanks with product at all times.

DESCRIPTION OF THE REAL SYSTEM

Let's consider a real factory (Figure 2) in which 13 products are to be manufactured and packaged in 6 different formats with different types of wrapping for a total possible of 297 different combinations or references.

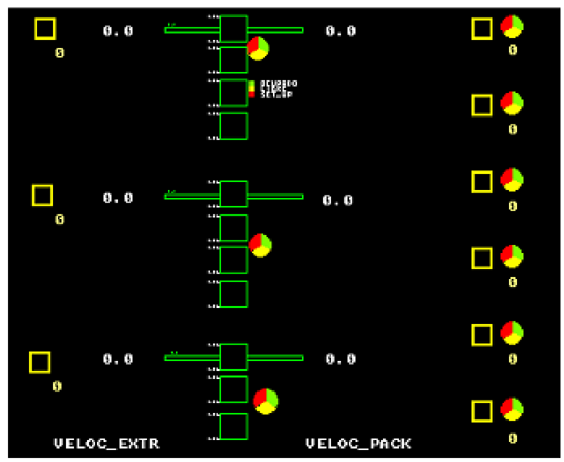


Figure 2: Layout

There exist three parallel manufacturing lines, although not all of them can handle all the products.

The 11 available tanks are organized in three groups, one per manufacturing line. The first line pushes the product into four different tanks, the second into a different four and the third into a new group of three buffers.

There are six packaging stations, each connected via pipes with all of the 11 tanks. Whenever there is an order in place to package product, the corresponding connection is opened and the product pulled into the packaging bags. There exists restrictions, however, on the formats that can be packaged at the different stations.

DESCRIPTION OF THE MIXED MODEL

The first important step of the project is to develop the simulation model that represents the previously described system. What follows is the explanation of the necessity to combine continuous and discrete-event simulation modeling to not only reliably represent the system but also to do it more quickly. Not the whole model is explained in detail, but only its unique features.

The Flow of Product

The manufacturing and packaging processes are modeled as continuous processes both for logical and visual representation purposes. Pipes are used to model any movement whereas tanks are used for the intermediate storage areas.

The justification for the logical representation comes from the available databases, which quantifies the production in rates and not in times to produce one individual unit. Even in this last case, this unit production time would be very small, thus inducing calculation errors.

In terms of visual appearance, the model looks cleaner on the screen when a continuous flow of product is shown, both through the pipes and inside the tanks.

However, it has been easier to model the orders with discrete-event philosophy and elements. More specifically, the start and finish of both production and packaging orders determine an event, that is, a point in time where the status of the system changes.

A discrete-event model has then been set in parallel to the continuous model in what is from now on called a mixed model. The difficulty to set specific, clear-cut moments in time in which orders are declared opened or finished when a pure continuous model is used is solved by directing the simulation with pure discrete-event modeling.

The logic therefore is carried by the discrete part and the flow by the continuous part, using the strength of each modeling tool. The routines to select the following order to be started are better executed at controlled points in times, whereas the information about the product is given in terms of continuous rates. The orders are usually stacked in a queue whereas the product is stored in tanks.

The connection between the two models is carried out when an order finishes. A manufacturing or packaging order is fulfilled whenever enough continuous product has been process through the continuous element. One easy way to determine the happening of the event is to have a fake tank that has the capacity of the quantity of the order. Once the tank is full, the order is fulfilled, the databases are updated and a new order might be initiated.

At that discrete event, there exist the easy possibility to use routines to do all the necessary calculations to create a new order.

Selection of the Manufacturing Order

As previously mentioned, the main objective is to satisfy customer orders, which are not in terms of manufacturing orders but in terms of packaged format quantities. In this case, it is necessary to keep track of the two quantities: the quantity already in stock and the demand both total and in for the upcoming 7 days.

The highest priority is obviously for those products whose stock level is below the ordered quantity. Among them, there is a priority for those with the highest shortage. Ties are broken with the product whose demand for the following week is higher.

In terms of production quantity, there exists a table of Economic Order Quantities (EOQ) for each of the products. Manufacturing orders must always be a multiple of the EOQ. So the selected quantity is the smallest multiple of the EOQ that is above the required production quantity to fulfill the demand.

Selection of the Packaging Order

The importance of this selection procedure has already been explained. The choice determines the packaging rate, which is the emptying rate of the tanks. The rhythm should be low when the tanks are almost empty, that is, the selected format should be one with a small rate. On the other hand, if the tanks are almost full, the selected format should be the one with the highest possible rate to try to empty the tanks.

Therefore, the routine has been designed to select the packaging order with the corresponding more appropriate rate among the still available packaging orders.

It is worth mentioning at this point that it is necessary to relate the manufacturing and the packaging orders in the model, since any product is not available in all the formats. The modeling trick model is to use a dummy discrete-event step to split the manufacturing orders into the corresponding packaging ones at the same time as the manufacturing order is being started.

THE DECISION SUPPORT SYSTEM

Due to the new change in philosophy that comes with the introduction of a modeling tool to help with the sequencing, it was the proper time to come up with a robust tool that helped the weekly planning of the line. The managers then launched in parallel the project of developing a simulation-based decision support system for sequencing.

The implementation of the DSS involved the combined work of four main groups: management, production planners, simulation specialists and system developers. The first and important step was to define the tasks to be performed by each group and all the possible interactions (see Figure 3).

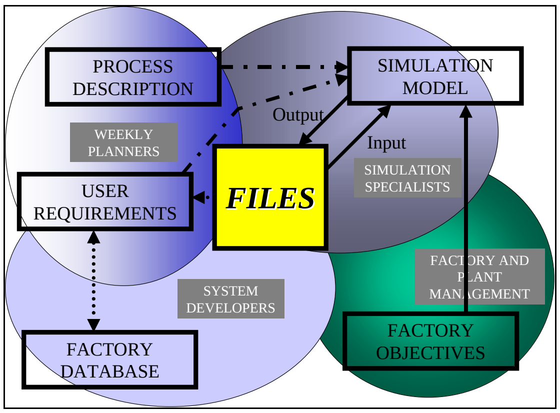


Figure 3. Implementation of the DSS

The production planners had to perform two complementary tasks. In order for the simulation specialists to create a simulation model, they had to put into words all of the knowledge they had not only in terms of the description of the necessary tasks to manufacture and package the product, but also in terms of the algorithm they use to develop the weekly plan. As it turned out, this last step was critical as it had more restrictions than previously foreseen. Also, as final users of the software application, they had to define the charts and output lists they will be using in the line: Gantt charts, screen layout…

In terms of the software development, two different groups performed the work. On one side, the factory systems development group was given the task to generate in simple files all the necessary information to manage the line: processing rates, the production orders, the capacity of the tanks… They had to combine the information coming from engineering with the one coming from labor unions, and also with the one coming directly from the line. They also had to create the output reports needed by the final users, taking as a primary input the information and the reports that come from the execution of the simulation model.

So, on the other side of the files line, the simulation specialists had to develop the model so it correctly represented the system. Also, the model had to take the necessary values from the files produced by the system developers to generate a set of files with all the necessary output values to produce the plans.

Management, besides overlooking the whole process, also had to set the objectives of the production plan. The main criterion is obviously to maximize throughput, but there is also the necessity to measure the timeliness or punctuality to deliver the orders to the customers. Plant managers had also the important task of maintaining the DSS.

The production planners had at this point something to say as experts, providing insights about the restrictions on the sequence of orders or the way they are producing the plan.

Then, a sound sequencing routine might be developed by the simulation specialists, coupling the experts knowledge with management requirements, as well as some production control theory that might come from any of the groups involved.

It is therefore important that the simulation specialists also have a good engineering knowledge to not only program the simulation models but also help in the development of the sequencing shell. In this particular case, an according to management's main objective of maximizing throughput without incurring in delays, the shell produces plans in which a combination of production variables like slack, tardiness and criticality [Bedworth, 1987] is included in the algorithm.

So, as it turned out, and it is clearly shown in the interactions diagram (Figure 3), in order to bring all the skills and expertise of each of the groups and develop a sound and robust application, what is crucial is the detailed definition of the common files, which are just Microsoft Excel and plain text files. The factory developers stand on one side of the line, the simulation specialists in the other, and the managers and the planners indicating what should be included in the DSS to manage the factory.

THE APPLICATION

Three types of files are needed to run the application:

- The spreadsheets that includes some input and output files

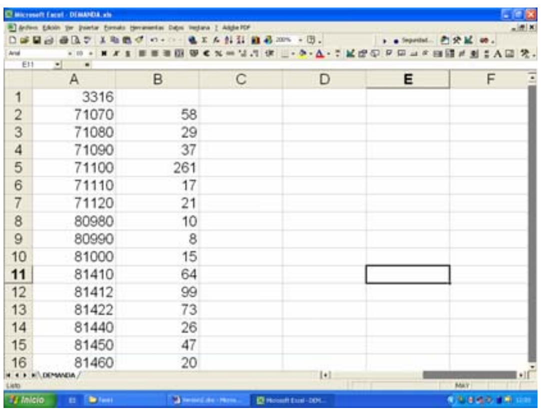
- The simulation model
- The ASCII files that contains some other input and output files

Input Data

What follows is a description of the set of files that are needed to run the model. The MSExcel spreadsheets contains different worksheets that are required by the simulator at run time. These worksheets might be manually or automatically updated by engineering or by the production management itself.

Demand

This file (Figure 4) includes the packaging orders that are already in place. Its first record includes the number of pending orders to facilitate the dimensioning of the database of the model. Then, each record includes one order with two necessary values: the first one indicates the packaging code, the second the quantity of the order.



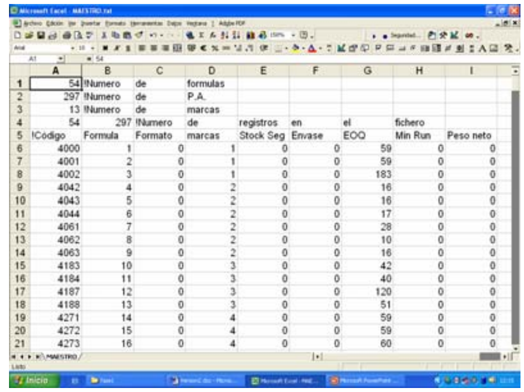
	A	B	C	D	E	F
1	3316					
2	71070	58				
3	71080	29				
4	71090	37				
5	71100	261				
6	71110	17				
7	71120	21				
8	80980	10				
9	80990	8				
10	81000	15				
11	81410	64				
12	81412	99				
13	81422	73				
14	81440	26				
15	81450	47				
16	81460	20				

Figure 4: Demand File

Master file

Its first three records (Figure 5) indicate:

- the total number of formulas
- the total number of references
- the total number of products



	A	B	C	D	E	F	G	H	I
1	54	!Numero	de	formulas					
2	297	!Numero	de	P.A.					
3	13	!Numero	de	marcas					
4	54	297	!Numero	de	registros	en	el	fichero	
5	!Código	Formula	Formato	marcas	Stock Seg	Envase	EOQ	Min Run	Peso neto
6	4000	1	0	1	0	0	59	0	0
7	4001	2	0	1	0	0	59	0	0
8	4002	3	0	1	0	0	183	0	0
9	4042	4	0	2	0	0	16	0	0
10	4043	5	0	2	0	0	16	0	0
11	4044	6	0	2	0	0	17	0	0
12	4061	7	0	2	0	0	28	0	0
13	4062	8	0	2	0	0	10	0	0
14	4063	9	0	2	0	0	16	0	0
15	4183	10	0	3	0	0	42	0	0
16	4184	11	0	3	0	0	40	0	0
17	4187	12	0	3	0	0	120	0	0
18	4188	13	0	3	0	0	51	0	0
19	4271	14	0	4	0	0	59	0	0
20	4272	15	0	4	0	0	59	0	0
21	4273	16	0	4	0	0	60	0	0

Figure 5: Master File

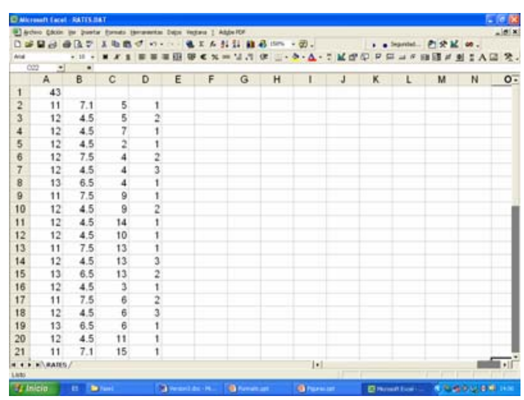
Then, for any reference, there exists one record, with the following information:

- code
- formula: from 1 to number of formulas
- format: from 1 to number of formats
- product: from1 to number of products
- safety stock
- wrapping
- EOQ
- MinRun
- NetWeight

Rates

This file (Figure 6) includes the processing rate of each of the lines. After indicating in the first line the number of records, each record includes:

- Line code
- Rate
- Product
- Line of preference



	A	B	C	D
1	43			
2	11	7.1	5	1
3	12	4.5	5	2
4	12	4.5	7	1
5	12	4.5	2	1
6	12	7.5	4	2
7	12	4.5	4	3
8	13	6.5	4	1
9	11	7.5	9	1
10	12	4.5	9	2
11	12	4.5	14	1
12	12	4.5	10	1
13	11	7.5	13	1
14	12	4.5	13	3
15	13	6.5	13	2
16	12	4.5	3	1
17	11	7.5	6	2
18	12	4.5	6	3
19	13	6.5	6	1
20	12	4.5	11	1
21	11	7.1	15	1

Figure 6: Rates File

This file is the result of combining five different company files in such a way that only the necessary information is read by the simulation software.

Measures of Performance

In this section, the most important measures of performance are defined, quantified and related mathematically.

Throughput and Timeliness
Let us define throughput as the number of tons that are produced per week, regardless of the type of product and timeliness as difference between the time when packaging is finished and the required customer delivery date.

Throughput and timeliness might not always be working in the same direction. Since throughput is trying to be maximized, it might very well happen that some products are scheduled some days ahead of time and finished well ahead of their delivery date. On the other hand, the EOQ restriction might increase the quantity of an order well above its real demand, pushing some orders back in the schedule list, thus committing some delays. Delays can also occur if the intermediate tanks are full and collapse the manufacturing line.

Management is trying to increase the throughput above is actual level of 1800 tons, while incurring in no delays. The only possibility is to manufacture ahead of time, with the obvious penalty of having to store the packaged product. The factory already has a large warehouse that facilitates the possibility of not incurring in delays and maximizing the throughput.

Figure 7 includes a screen shot that summarizes these two measures. TON_TOTALES is the total number of tons or throughput. The timeliness measure is included in the next two indicators. TON_DIA_RETRASO, or the number of tons per day that suffer a delay, that is, whenever the order arrives late to the customer, and TONS_DAY_ADELANTO, or tons that are finished ahead of time, whenever the order is finished before it needs to be delivered. Timeliness is weighted with the number of days, that is, it is not the same to finish 4 tons one day or two days late.

Figure 7: Screen Shot of the Measures

A histogram is also presented to understand the whole timeliness distribution. In the case presented, the distribution is skewed to the left, meaning that it is more likely that the orders are finished ahead of time.

Line Utilization
Another measure that will help understand the behavior of each of the two processes is the percent utilization of the available resources. Pie charts are used to visually determine the usage, both in general for the two processes and individually for the manufacturing lines and the packaging lines.

Figure 8 shows an example for the two processes. The green pieces show the busy time, the yellow ones the idle time and the red part the sum of the setup time and the blockage time.

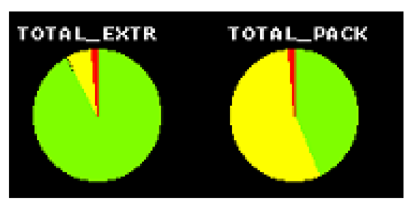


Figure 8: Screen Shot of Line Utilization

The indication of a good sequence will be that the busy time of the manufacturing process is very high, since this process is the bottleneck. The packaging stations are able to free the tanks quickly since the emptying rates are usually higher than the filling rates of the manufacturing processes.

Tank Utilization
Figure 9 shows the evolution of the contents of the intermediate tanks. Each group of tanks has its own line, in this case, three groups, the pink, the blue and the white.

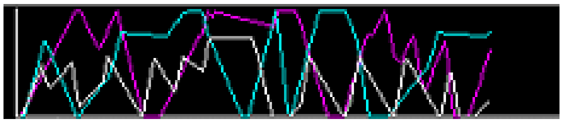


Figure 9: Screen Shot of Tank Utilization

This graph helps determine if there were any problems in the system. The two possible extreme situations are easily detected. If any group of tanks becomes empty, the corresponding line reaches 0. No product is available for packaging. If the tanks become full, thus, blocking the manufacturing line, the corresponding line becomes flat at its maximum level.

Therefore, the indication of a good schedule is a "saw" appearance, with the lines increasing when the product is being packaged in small formats and decreasing with large formats.

Output Data

The information that the line managers are going to use is included in this section. The output of the execution of the model is both graphical and in text format.

Gantt Chart
The graphical output comes in the form of Gantt charts, that is, a series of bars that indicate what is being processed at any resource along the week.

Figure 10 shows an example chart for the first four and a half days of the week, in which there exists three manufacturing lines and six packaging lines.

As in the case of the pie charts, there is a color coding to indicate the status of the line. As before, a green color indicates a busy status and if the bar is yellow, the line is empty. The setup periods are colored in red and a blocking status is indicated in pink.

In this case, the manufacturing lines are busy most of the time, with line 2 being blocked a couple of times as its tanks are full. The idle periods are due to the fact that there are line-product restrictions or that the corresponding tanks are not totally empty and the set up process cannot start.

Packaging line 5 is always empty and line 6 is well under utilized. There are many setup periods, indicating the different changes between formats to facilitate the filling or emptying of the tanks.

Weekly Schedule
In text format, two separate files are created by the simulation model for the line managers to use in their planning routines: one for the manufacturing line (Figure 11), the other for the packaging line (Figure 12).

LINE	START TIME		CODE	QUANTITY
	DAY	TIME		
1	1	0.05	4430	180
2	1	0.10	4405	342
3	1	0.15	4297	313
1	2	11.08	4530	214
3	3	19.71	4352	262
1	4	9.76	4002	197
2	4	19.78	4406	276
1	5	17.27	4313	105
3	5	18.38	4391	109
1	6	17.76	4299	55
3	7	4.92	4356	200
1	7	8.87	4341	137
2	7	16.07	4353	81

Figure 11: The Weekly Manufacturing Schedule

Each record has four pieces of information:

- Line number
- Start time for an order
- Code
- Quantity

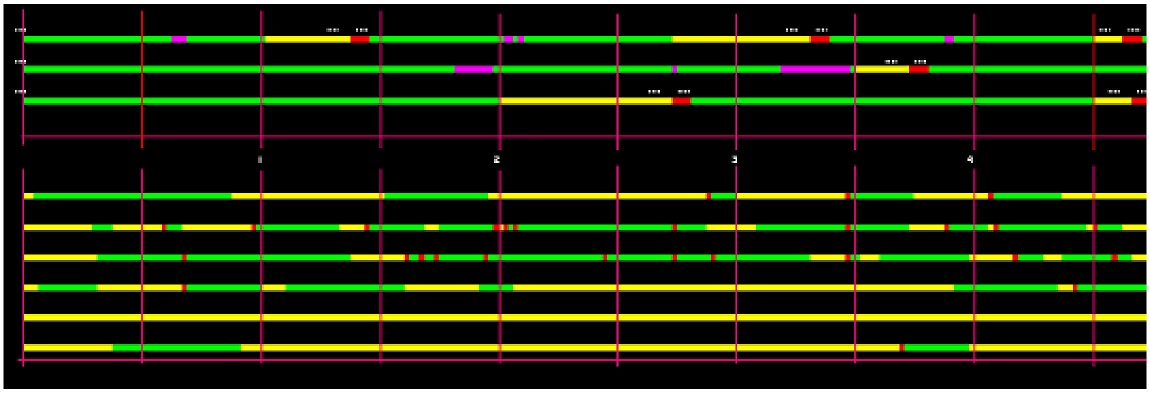


Figure 10: A Possible Gantt Chart

LINE	START TIME		CODE	QUANTITY
	DAY	TIME		
1	1	1.41	4430	102
4	1	1.74	4297	19
2	1	7.04	4297	155
3	1	7.69	4405	168
6	1	9.05	4297	69
2	1	14.61	4297	138
3	1	16.81	4430	78
4	1	16.83	4405	22
2	1	23.56	4297	122
3	2	0.95	4430	39
3	2	2.30	4430	33
4	2	3.00	4405	54
3	2	3.43	4430	27

Figure 12: Top Part of the Weekly Packaging Schedule

Since the number of lines is small, there is no need to indicate the finish time for a given order, as it is easy to locate the next scheduled start time on the list.

The Interface

Figure 13 shows the whole interface as it will be seen by the user. It includes the layout screen and the performance measures screens that have been already presented.

For each manufacturing line, the code of the product and the velocity or rate of processing are shown. The product 4002, coded in green, is being processed in line 1 at a rate of 7.5 tons/min. The product 4405, coded in yellow, is being processed in line 2 at a rate of 4.5 tons/min. The product 4352, coded in brown, is being processed in line 3 at a rate of 6.5 tons/min.

The occupation is also presented in a pie chart. The second line has been in process all the time, whereas the other two have been both idle and blocked.

The tanks show the fill level. The first group is coded in pink, and the level of product is rising as shown in the tank utilization graph and by the low rate of packaging.
The same thing happens for the third group, coded in white. The second group, on the other hand, is coded in light blue, it is full, but the level is starting to drop since the rate of packaging is higher than that of manufacturing.

For each packaging station, it shows the code of the product in line plus the format, as well as the occupation. Station 1 is processing the green product 4002 in the small 1.5 kgs. format, station 2 the yellow 4405 in the large format 25 kgs. and station 3 the brown 4352 in format of 10 kgs.

The discrete-event part of the model that shows both the pending packaging orders that correspond to the manufacturing orders being processed (3 green ones and 1 brown) and the ones already delivered (marked just by its code, 4297…) is also shown.

Figure 13: Interface

CASE STUDY

For testing and validation purposes, management selects one of the regular weeks of demand. The minimum required throughput level is 1800 tons/week.

The proposed schedule gives the results shown in Figure 14. The throughput is 2201 tons, that is, an increment of 22.27% over the required minimum.

Only 8 tons are delayed, a small quantity that with minor adjustments of the proposed scheduled by the plant managers or by a prior stock of that small quantity should cover for the deficit.

The production plan looks balanced if the utilization graphs are analyzed. The “saw” appearance of the tank utilization graph indicates that only during small lapses of time the tanks are either full or empty. And almost 80% of the time the manufacturing lines are busy, making it complicated to raise the proposed throughput level.

The last comment relates to the execution time. The results are obtained in less than 2 minutes, making it possible for some trial-and-error runs if the input data files are manually changed.

SUMMARY AND CONCLUSIONS

An application of simulation in a special sequencing problem is presented. Moreover, a decision support system based on a mixed simulation model has been developed to come up with weekly plans. The DSS has been implemented at the factory with satisfactory results.

The application helps on-line programmers with the task of sequencing orders in a two stage production process of multi-product, multi-format products. The two stages are related via intermediate tanks, which must be neither full nor empty. This requisite, which helps increment throughput, is achieved by changing the format of the packaging stage. Therefore, the problem is summarized in the equilibrium of emptying and filling rates of the tanks.

A mixed simulation model is the option selected to reliably represent the situation in hand. Continuous simulation is used to model the flow and to make a fancy representation, and the discrete-event approach is successfully used to represent the completion of the orders and to program the sequencing of orders.

The developed DSS is a mixture of spreadsheets and a simulation model where the worksheets act as the interface between the factory database and the model. In fact, the success of the project has come not only by the art of the simulation specialists to represent the system in hand, but, more importantly, by the ability to bring the knowledge and expertise of all the people involved

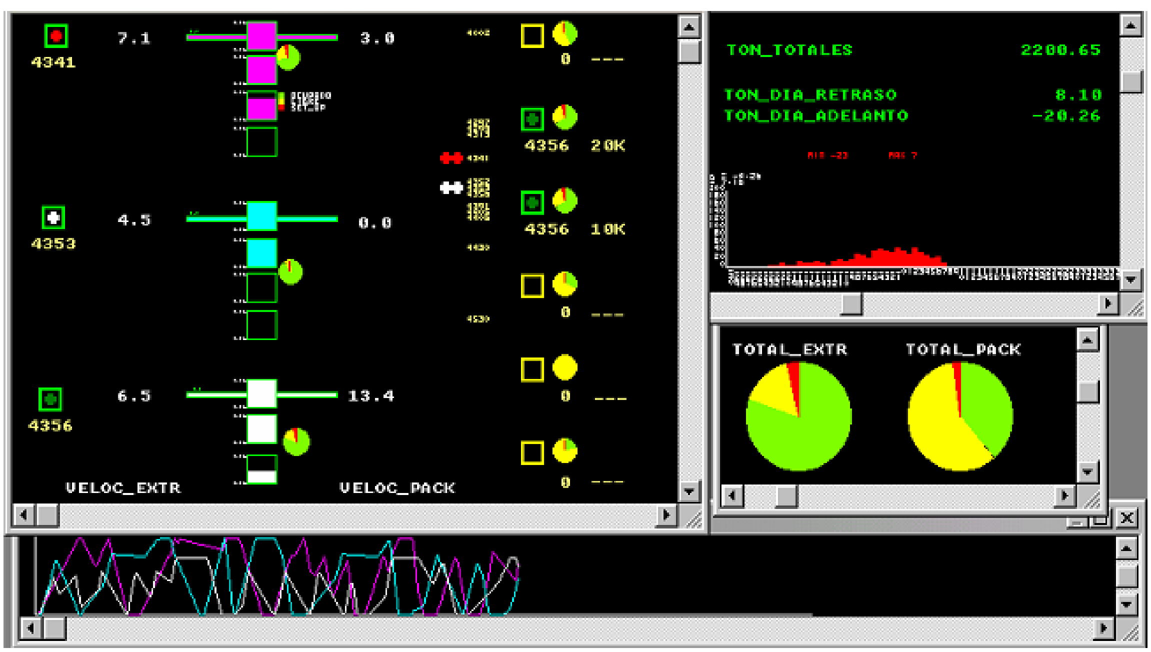


Figure 14: Results of the Proposed Schedule

in the decision system into a common set of spreadsheet files.

Once a consensus has been reached on the format of both the input and output files, each knowledge group is responsible for either inputting data into the common files or reading from them. Each group is to maintain also its own part of the system.

The applications software is then for planners to use, but it has been the result of a combined effort of management and developers, which have conveniently defined a set of files to interchange information, in order to represent the expert knowledge in a simulation –based DSS.

REFERENCES

Arer, M.M. and Ozdemirel, N.E. 1999. "Simulation of Capacity Expansion and Sequencing Alternatives for a Sheet Metal Producer" *The Journal of the Operational Research Society*, Vol. 50, No. 6 (Jun., 1999), pp. 596-607.

Bedworth, D.D. and Bailey J.E. 1987. *Integrated Production Control Systems.* John Wiley and Sons, New York, NY.

Fisher, M.L. and Ittner, C.D. 1999. "The Impact of Product Variety on Automobile Assembly Operations: Empirical Evidence and Simulation Analysis". *Management Science*, Vol. 45, No. 6 (Jun., 1999), pp. 771-786.

Hershauer, J.C. and Ebert R.J. 1975. "Search and Simulation Selection of a Job-Shop Sequencing Rule". *Management Science*, Vol. 21, No. 7, Theory Series (Mar., 1975), pp. 833-843.

Hollier, R.H. 1968. "A Simulation Study of Sequencing in Batch Production". *Operations Research*, Vol. 19, No. 4 (Dec., 1968), pp. 389-407.

Macaskill, J.L.C. 1973. "Computer Simulation for Mixed-Model Production Lines". *Management Science*, Vol. 20, No. 3, Theory Series (Nov., 1973), pp. 341-348.

Moccellin, J.V. and Nagano M.S. 1998. "Evaluating the Performance of Tabu Search Procedures for Flow Shop Sequencing" *The Journal of the Operational Research Society*, Vol. 49, No. 12 (Dec., 1998), pp. 1296-1302.

Pidd, M. 1987 "Simulating Automated Food Plants". *The Journal of the Operational Research Society*, Vol. 38, No. 8, Current Simulation Research (Aug., 1987), pp. 683-692.

Udo, G.J.A. 1994. "Simulation Study of Due-Date Assignment Rules in a Dynamic Job Shop". *The Journal of the Operational Research Society,* Vol. 45, No. 12 (Dec., 1994), pp. 1425-1435.

Wein, L.M. and Chevalier, P.B. 1992. "A Broader View of the Job-Shop Sequencing Problem" *Management Science*, Vol. 38, No. 7 (Jul., 1992), pp. 1018-1033.

BIOGRAPHY

JAVIER OTAMENDI received the B.S. and M.S. degrees in Industrial Engineering at Oklahoma State University, where he developed his interests in Simulation and Total Quality Management. Back in his home country of Spain, he received a B.S. in Business Administration and a Ph.D. in Industrial Engineering. He is currently a simulation and statistics consultant and university professor. His e-mail address is: jotamendi_30@yahoo.com