Simulation of the Grape Reception at a Winery

Andrés Auger, Juan-Carlos Ferrer*, Sergio Maturana†, and Jorge Vera‡
School of Engineering
P. Universidad Católica de Chile

November 6, 2003

Abstract

The quality and condition of the grape that is received at the winery strongly influences the quality of the wine. We focused on two aspects that depend on the decisions that are made during the vintage: the ripeness of the grape when it is harvested and the premature fermentation it may experience while waiting to be processed. The decision-maker requires accurate and current information on the condition of the grape in the vineyards and the availability of processing capacity at the winery during the vintage in order to make optimal decisions. In a large winery we studied, transportation delays and discrepancies in the amounts actually shipped, resulted in several instances of batches of grapes that were subject to long delays, with the risk of an important loss of wine quality.

We developed a simulation model of the reception of the grape to help redesign the operation of the supply chain of the winery in order to minimize the delays in processing the grapes, by making good use of the existing equipment. By experimenting with the model, we were able to determine that there were certain changes that could reduce these delays. During the vintage, the rapid pace of the events, and the uncertainties of many aspects of the operation, makes it very difficult for management to make good decisions. The development of a simulation model was important for understanding the effects that certain changes could produce during the vintage in order to be better prepared and make better decisions.

1 Introduction

Wine is one of the ancient drinks in the world and constitute today one of the most important consumer products. In Chile, it has become of the leading agroindustrial activities, with a sustained increase in total exports to many countries in the world. Premium and semi-premium wines are the most important part of the market. Making wine is a complex process, traditionally associated with an industry in which the specific know-how of the winemaker is of paramount importance. In fact, the process of grapes selections, adequate fermentation and mixing requires special abilities, many of them involving sensorial aspects. However, on the other hand, wine producing is an industrial process, and as such is subject to many of the problems which traditionally have been analyzed in the Operations Management area. The impact of process variability and uncertainty is important in this industry, having its origin in the biological nature of many of the process, and weather, among other sources. However, many sources of variability are more of an industrial nature and relates to management problems. It is in this context that the use of operations research tools might help to increase efficiency of processes.

The main objective of this work is to help improve the quality of the wine that is produced by the winery. One of the aspects that strongly influence the quality of the wine is the quality of the grape that is pressed to make it. The quality of the grape, in turn, depends on many aspects. We will focus mainly on two which can be affected by harvesting decisions. One is the degree of ripeness of the grape when it is harvested and the other is the premature fermentation it may experience while waiting to be processed. During the harvesting period, the oenologist must try to determine the best moment to harvest different

*Assistant Professor - School of Engineering, P. Universidad Católica de Chile - email: jferrer@ing.puc.cl
†Professor - School of Engineering, P. Universidad Católica de Chile - email: smaturan@ing.puc.cl
‡Associate Professor - School of Engineering, P. Universidad Católica de Chile - email: jvera@ing.puc.cl

vineyard blocks, considering fruit condition, color, tannin, brix (sugar), acid, pH, vine condition, current and impending weather and availability of harvesting personnel. When it rains, for example, the grape may develop a fungus (botrytis) which makes it useless, unless it is quickly harvested. On the other hand, the oenologist must also be aware if there is processing capacity, such as reception pits, presses and vats, to receive the grapes that arrive. Otherwise, the grape may have to wait a long time to be processed. This may lead to premature fermentation of the grape, which degrades the quality of the wine. It is difficult to determine exactly how long it takes for the grape to start fermenting, since it depends on the temperature, the condition of the grape, and how it is stored. In the case of the winery we studied, the grape had to travel by truck, sometimes for several hours, so further delays were very risky, particularly in the case of white wine which must be fermented at low temperatures, and without skin. This problems is similar to many in other industrial sectors, in which disordered arrivals of products and components generate congestion and delays. However, the deterioration of the grapes that may occur due to the delays adds an additional aspect to the problem.

Reception and processing capacity are related not only to the available capacity in the fermentation tanks, but also to availability of presses, pits, the kind of grape to be processed, processing speed, and decisions involved. Reception capacity will be determined by a combination of factors, many of them affected by earlier decisions. The grape arrival schedule, as well as the number of kilograms in each delivery, will be of vital importance for an efficient management of the initial stages of wine production, especially for white wines, which require speedy processing.

In the winery we studied, the oenologist specified the day before, which vineyard blocks should be harvested and sent to the winery facilities. The grapes arrived, during the next day, but at unspecified times. Many times, the trucks tended to arrive around the same time, which caused congestion at the reception facilities. Also, the amounts of grapes that arrived were not the amounts ordered. This was usually the result of errors in the estimation of the amount of grape that a particular vineyard block would produce. The combination of the random arrival time of the trucks and the difference between the amounts ordered and those received, sometimes produced congestion which caused the grape to wait for many hours to be processed.

In order to understand better the reception process, we developed a simulation model, given the complexities and uncertainties present in the problem. The model used to study the following factors of the process:

1. To estimate of the winery daily reception and pressing capacity.
2. To estimate of the waiting time for the trucks transporting grapes to the winery.
3. To determine a schedule of deliveries during the day and evaluate alternative combinations of suppliers for that day, so as to obtain the best use of daily processing capacity.

The current research considers only white wine production, as grapes for white wine must go quickly through several limited capacity stages (pressing and decanting) before fermentation begins. In this stage, the production of white wine is more complex than that of red wine.

2 Simulation of Supply Chain

Simulation has been extensively used to model different parts of the supply chain. However, in the case of the agrifood industry, there is relatively little research. Operation planning within a given manufacturing process has also been deeply discussed. In [1] an introduction to operation planning via simulation is described, emphasizing the utilization of this tool in the short term scope. Samples of operation planning researches have been published in [2], [3] and [4]. The latter corresponds to a very interesting case because a simulation model is used as an operational planning tool.

On the other hand, material supply and transportation are topics regularly studied when analyzing Supply Chain Management (SCM) models [5]. A review of the most frequently used methods and models when studying SCM is to be found in [6]. In [7] and [8] the advantages of simulation for SCM analysis are explained, the main one being the capacity to manage and represent variabilities within the system, providing in many cases stronger answers and solutions than those obtained via classic optimization. In [9] a link between SCM study and production planning is established. The importance of this research comes from the fact that different planning alternatives can affect the performance of the whole chain to a considerable extent. Finally, a decision support system for daily supply and transportation decision-making appear is presented in [10] and [11].

2.1 Simulation of the Wine Supply Chain

In a recent study [12] only 123 formal, peer reviewed journal articles relating to chain management in the agrifood industry. The papers, published from 1987 to August 2000, were distributed unevenly across industry sectors and parts of the world. In the case of the wine industry, only two papers were found.

In [13] a simulation model for the management of fermentation tanks and wine transfers is presented as an example of the important role of the oenologists and how technology should support their activities.

2.2 Other methodologies applied to wine planning

2.3 Simulation and similar approaches applied to other problems

In [14] a model is proposed to analyze processing capacity of an olive processing facility and the system improvements that should be made to increase capacity. A simulation to analyze a car factory throughput measured in terms of work per hour can be found in [15]. In [16], a simulation study was used to determine the best production model so as to optimize a factory throughput.

3 White Wine Production

The most important limits and aspects of the analyzed system, involved processes, and those decisions determining process flow will be stated firstly.

3.1 Production process

3.1.1 Grape purchase programming and supplier response

The productive process begins with the follow-up the oenologist makes of the ripeness level of the grapes in each block, both the vineyard's own and those of external suppliers based on tests and tasting. Thus, harvest planning of certain blocks can begin several days in advance.

When placing an order the oenologist does the following: depending on the number of kilograms he wants to be harvested, the number of necessary bins is calculated, provided that each bin has a 500 Kg capacity; e.g. if the oenologist wants 20,000 Kg, the supplier borrows 40 bins from the wine factory, which should be sent back during daytime. However, most daily shipments made by suppliers do not match the required ones. This necessarily means that a significant percentage of the planning design regarding press utilization and vat allocation is void, and remedial measures must be taken on the run so as to free receipt capacity.

Regarding grape dispatch, responsibility for delivery schedules, number of daily shipments, and kilograms in them is entirely the supplier's. Most suppliers send one to three shipments a day. For each shipment, truck arrival schedules are pretty different and variable. Truck traffic is heavier at certain hours, and the number of bins delivered depends on the number of daily shipments.

3.1.2 Wine factory processing

Processing at the wine factory both starts and ends with truck weighing (see Figure 1).

Once weighed using scales, grapes are unloaded, and trucks are loaded with empty bins. Outbound trucks are weighed once again (see Figure 2).

Incoming grapes are graded in the sampling area according to producer, variety, and number of kilos to form the lots to be pressed. Once the lots are formed, they might be processed in the dumping pit or not, according to the availability of presses and the pit itself (see Figure 3).

Figure 4 shows grape crushing process. As they are dumped into the pit, grapes are steeped and crushed, cooled and finally pressed. Before dumping takes place, a press has already been allocated to that lot. Before

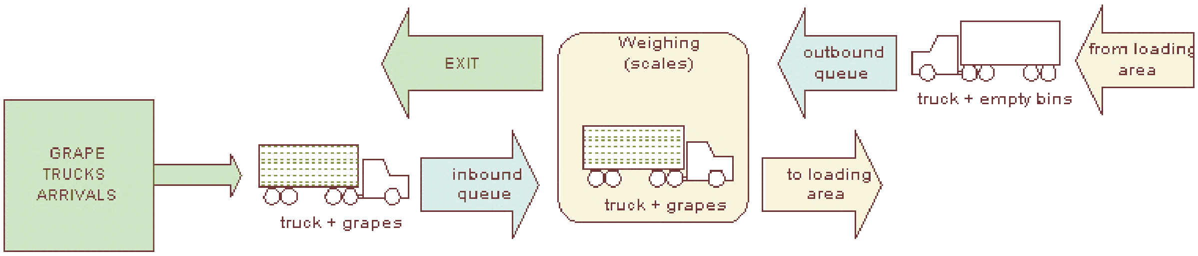

Figure 1: Truck Weighting

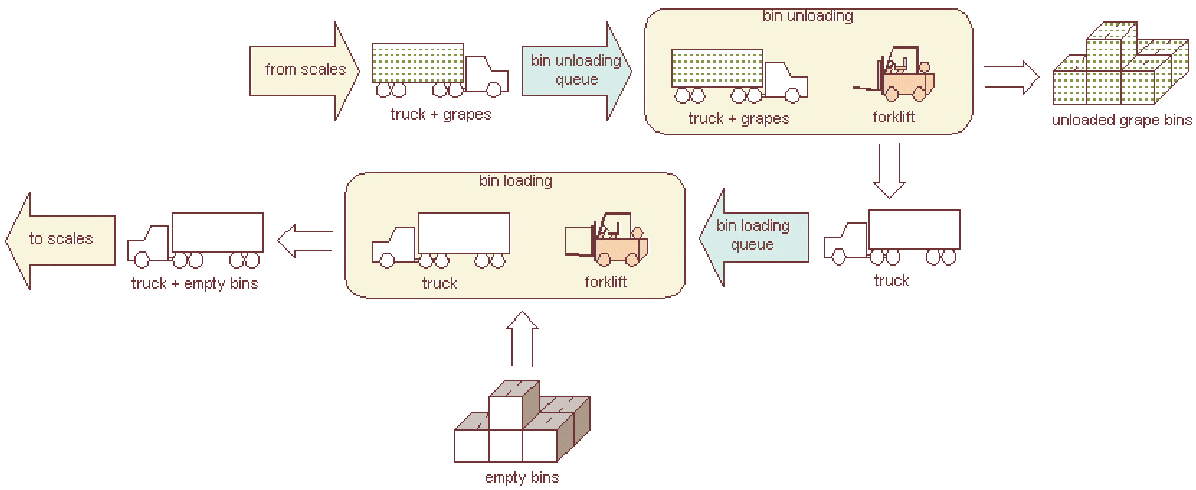

Figure 2: Truck Unloading

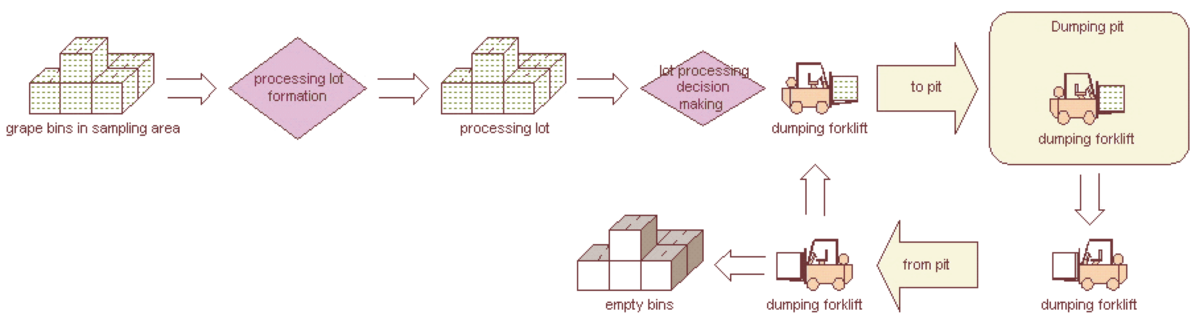

Figure 3: Lot Formation & Bin Dumping

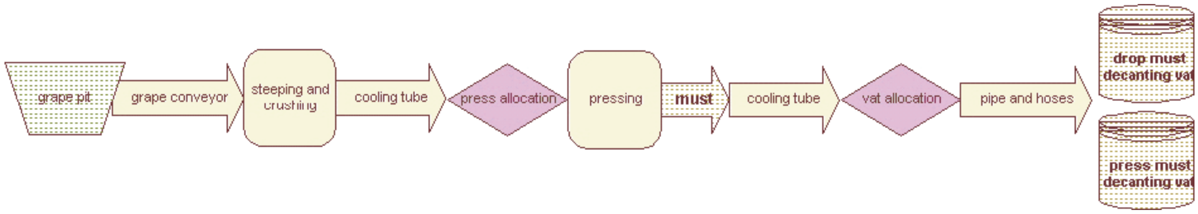

Figure 4: Grape Crushing

and during the pressing cycle, the different musts are obtained (drop, press 1 & press 2), which are taken to their corresponding decanting vats.

The differentiation between different musts obtained from the same lot is made by the oenologist via tasting. That is why the current research will go no further with regard to this aspect, as oenologic criteria stand above productive ones.

3.2 Problems detected in process

In the initial diagnosis it was determined that harvest planning, grape receipt and grape early processing must be done in such a way that the capacity of the factory is not exceeded, thus avoiding unnecessary delays.

However, regarding the above facts, the following problems were detected:

- The exact daily grape receipt and processing capacity is unknown. There is only an estimation of the total amount of kilos that could eventually be processed a day, based on the oenologist's experience.
- Many times suppliers do not deliver the number of kilos purchased by the oenologist. There is an expected margin of error as it is difficult to get exactly 500 kilos per bin. Nevertheless, main explanation for the inaccuracy is that the actual number of bins arriving at the factory differs to a significant extent from the one requested.
- Grape arrival schedule, that is to say the number of trips per supplier, number of bins sent in each trip, and trip schedules depend exclusively on the supplier, which in turn means disorderly deliveries. Wine factory only imposes receipt start-up and end schedules, which many times are not considered at all.

Presence of one or many of the above problems means constant delays in the grape process start-up, as the amount of grapes frequently exceeds receipt and processing capacity, due to an inaccurate estimation made by the oenologist of the above, because more grapes than expected arrived, or simply because all grapes were delivered within a narrow time window.

Consequently, the following questions arise:

1. Is it possible to determine or estimate more exactly the factory's daily receipt and early processing capacity for white wine?
2. Does the way suppliers respond to grape purchases made by the oenologist (delivered kilos and delivery schedules) affect the factory's capacity?
3. Is it possible to increase the factory's processing capacity while reducing or avoiding grape queuing time?

4 Simulation Model

As the nature of the problem is basically lack of knowledge (or experience-based estimation) regarding several of the most relevant system factors (processing capacity, grape availability schedule, average grape queuing

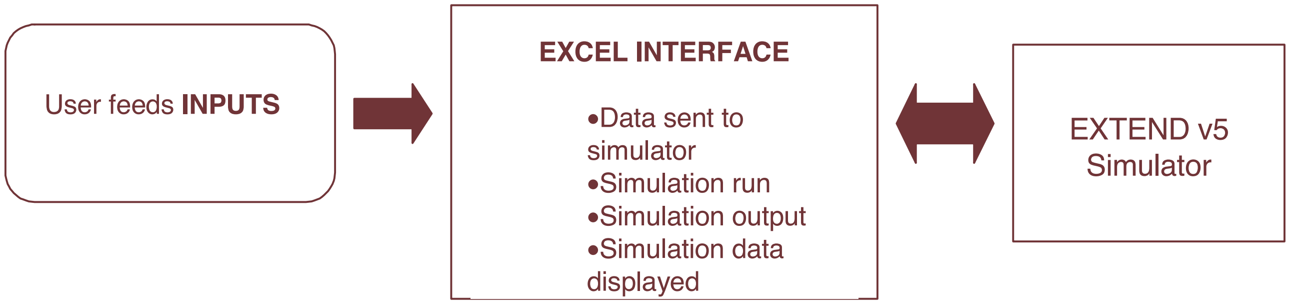

Figure 5: Schematic diagram of designed system

time, etc.) a tool that sheds some light on what would happen at the wine factory given an specific harvest planning becomes necessary. Besides, most factors are random in nature, that is to say, they never behave regularly.

Because of the kind of problem to be faced –estimation of the behavior of a variable multiple related factor system- the utilization of a simulation model is one of the best choices ever.

The model main target will be to deliver a quantitative estimation, as accurate as possible, of the wine factory daily installed capacity and the average grape queuing time, for a defined time window, given an specific harvest planning, so as to provide an answer to the questions in §3.2:

1. Is it possible to determine or estimate more exactly the factory's daily receipt and early processing capacity for white wine?

2. Does the way suppliers respond to grape purchases made by the oenologist (delivered kilos and delivery schedules) affect the factory's capacity?

3. Is it possible to increase the factory's processing capacity while reducing or avoiding grape queuing time?

Because the current research focuses on the factory's daily operation, and harvest planning is pretty uncertain as the planning target period moves further, the maximum period able to be analyzed is 5 days for processing and 3 days for grape receipt.

The model is divided into two large blocks: Grape truck arrival generator and the wine factory block.

The first block represents the suppliers' response to the grape orders. It encompasses from grape receipt schedules to number of kilos per supplier. The second block represents the factory itself. It encompasses inbound and outbound truck control, and grape processing.

The model works the following way: Up to 3 harvest days can be planned rather accurately. Harvest day (1, 2, or 3) input for each producer-variety-kilos purchased are fed. Then the simulation model is run. Once simulation is over, the model provides 3 very specific data: estimated finish time of the last pressing cycle of all the grapes purchased, that is to say the moment when all the grapes will already be processed; average grape queuing time in the sampling area before processing; and the average throughput in terms of processed kilos per hour.

Figure 5 shows a diagram of the utility.

Regarding questions in §3.2, they will be answered as follows:

a) Is it possible to determine or estimate more exactly the factory's daily receipt and early processing capacity for white wine?

Based on a number of experiments we will determine for an improved or ideal grape dispatch situation the maximum number of kilos that could be received and processed in approximate 24 hours, timing the expected finish hour for pressing cycle and gauging the amount of processed kilos. This way the number of kilos to be processed per hour could be estimated.

b) Does the way suppliers respond to grape purchases made by the oenologist (delivered kilos and delivery schedules) affect the factory's capacity?

Highest Score	Lowest Score	Avg. Queuing Time	Std. dev.	Avg. pressing cycle time	Std. dev.
60	-40	6.52	2.08	61.97	4.86
30	-20	7.70	1.46	64.51	3.14
15	-10	9.49	2.45	67.96	4.48
5	-5	10.20	1.05	70.08	2.18
1	-1	11.02	0.18	71.70	0.30

Table 1: Inaccuracy in shipment analysis results

Two answers will be given to this question: firstly we will appreciate the variability in the system introduced by the current grape delivery method, based on an analysis of factors involved in delivery. The aforesaid variability will be compared to the whole system variability and that introduced only by the factory. Afterwards, two different delivery methods for the same planning will be compared; in one of them the current delivery method will be used, and in the other one an alternative situation.

Variability will be measured on pressing cycle finish time and on average grape queuing time.

c) Is it possible to increase the factory's processing capacity while reducing or avoiding grape queuing time?

To answer this question a small alteration of the above experiment will be used, and the number of processed kilos per hour will be measured, comparing the current situation to the alternative one (in which only grape delivery method has been modified)

5 Analysis of computational experiments

5.1 System relevant factor analysis

As the model is divided into two large blocks – suppliers and wine factory- they will be analyzed separately, focusing on the most relevant factors in each case.

To avoid wrong conclusions when analyzing each factor and appreciate its actual impact on the system, the Common Random Number (CRN) variance reduction technique suggested in [17] will be used, fixing the seed value for the random number generation for all random factors not being analyzed. Thus, all model variance generated by factors we are not interested in will be avoided.

The whole analysis will be done using only one input. This will be an actual situation that took place on March 1 and 2, in which a total amount of 460,000 Kg of grape was requested from 7 different suppliers. Processing of grape ended approximate. at 18 hours of March 3.

Regarding suppliers, all factors suitable of actual change or improvement will be analyzed, that is to say, the impact caused by the attempt to modify some of the suppliers' practices specifically inaccuracy in daily grape shipments, delivery schedules, and number of trips per supplier- will be gauged.

5.1.1 Inaccuracy in shipment

Base case corresponds to actual inaccuracies regarding bins, having 60 as highest score and -40 as lowest score. A series of experiments were carried out in which the scores were reduced.

Frome the results shown in Table we can conclude the following:

1. Inaccuracy trend is that suppliers –as an average situation- send less bins than expected per day. This is shown by the highest and lowest scores (60 and –40) in which bin number differs, which means that 60% of times the supplier will send less bins than requested and 40% of times more bins will arrive in a day.

2. The above means that, as a daily average, less grapes than expected arrive. This situation causes non-planned grape arrivals, corresponding to missing grapes from the shipment sent the day before.

3. This phenomenon is clearly appreciated when observing data of interest averages in each of the above experiments. As inaccuracy margin for the number of bins diminishes (i.e. suppliers stick to the order) grape queuing time and pressing cycle finish time increase notoriously for the same daily grape receipt

planning; this is because more grape is arriving as an average, and consequently, grape processing takes longer.

4. As inaccuracy margin diminishes, variability in data of interest gets drastically reduced, not as notoriously as in the first cases, but pretty clearly as margin is reduced to narrower values; in the last case almost all variability disappears. So, we can conclude that inaccuracy in the daily supply of grapes is an important variability source in the whole system. This is a partial answer to the question in 3.2: Does the way suppliers respond to grape purchases made by the oenologist (delivered kilos and delivery schedules) affect the factory's capacity? as we are considering only part of the ways in which suppliers respond to grape purchase orders.

5.1.2 Grape delivery schedules

In this case only system variability introduced by random delivery schedules will be analyzed. Distributions giving origin to delivery schedules will not be altered. If inaccuracy regarding bins is present, then we will go back to the base case (60 and –40)

As the rest of the random number generating seed values are fixed (with the exception of those that generate random numbers to calculate delivery schedules) it is of no consequence to consider data of interest averages, but the variability shown by data.

Standard deviations for data of interest are:

- Average grape queuing time, 0.74 hours
- Pressing cycle finish time, 1.30 hours

If we compare these values with those in the first case in the previous analysis (Inaccuracy in shipment) it can be noticed that variability in this case is much smaller (0.74 vs. 2.08 and 1.30 versus 4.86) and we can conclude that delivery schedules are not a significant source of variability in the system when compared to the above inaccuracy in shipments.

5.1.3 Number of trips per supplier

Here we will analyze only system variability introduced by the random number of trips per supplier. If inaccuracy regarding bins is present, then we will go back to the base case (60 and –40)

Standard deviations for data of interest are:

- Average grape queuing time, 0.69 hours
- Pressing cycle finish time, 1.08 hours

Results are similar to those obtained in the previous case, so we can conclude that the number of trips is not a significant source of variability when compared to inaccuracy in shipments.

Now we will analyze the effect on the system of delivery as a whole, i.e. delivery schedules and number of trips per supplier. This way we can have a more realistic view of how delivery affects the variables of interest. As we did before, we will focus on variability and not on averages, because, once again, we are not comparing different configurations for the same system.

Standard deviations for data of interest are:

- Average grape queuing time, 0.98 hours
- Pressing cycle finish time, 1.26 hours

Funnily enough, data are very similar to those obtained in the two previous cases, that is to say, variability is reduced when compared to base case regarding grape delivery inaccuracies. So, we can conclude that neither delivery schedules nor the number of trips per supplier are significant sources of variability in the system when compared to the inaccuracy in shipments.

Finally, we will analyze the effect on the system of the whole block of suppliers, that is to say, considering variability due to inaccuracy in shipments, delivery schedules, and the number of trips per supplier. This

Variable	Variance by suppliers	Variance by wine factory	F	Critical Value
Average queuing time	3.46	0.92	3.74	1.61
Expected finish time	9.37	3.96	2.36	1.61

Table 2: Variance comparison: Suppliers vs. Wine factory

way we will be able to evaluate how suppliers' response affects the system as a whole, specifically data of interest. Besides, an answer will be given to question b) in 3.2: Does the way suppliers respond to grape purchases made by the oenologist (delivered kilos and delivery schedules) affect the factory's capacity?

Standard deviations for data of interest are:

- Average grape queuing time, 1.70 hours
- Pressing cycle finish time, 3.80 hours

In this case we can see that variability is similar to the one introduced by inaccuracy in the number of bins alone, so the strongest conclusion we can arrive to is that variability in the system introduced by grape delivery by suppliers is due, to a significant level, to inaccuracy (higher or lower number of bins delivered) in daily supply of the grape amounts purchased. So, if the wine factory reduces the inaccuracy margin regarding the number of bins ordered from each supplier, system variability would be notoriously diminished.

5.1.4 Wine factory

So as to have both a clearer picture of system variability introduced by suppliers, and a way to compare or corroborate the above statements, the wine factory will be analyzed in turn. To do that the seed value for the supplier block will be fixed, and the bin number difference variable will always have 1 as highest score and -1 as lowest score. This way the factory's performance will be analyzed with actual grape amounts, not with amounts differing from those purchased.

A run was carried out with all the factory seeds freed, to see the variability introduced by the factory as a whole. Results were the following:

- Average lot queuing time, 10.64,S.D 0.96
- Average pressing cycle finish time, 71.16, S.D. 1.99

We can appreciate that values are quite close to those obtained in the analyzed case where variability introduced by the supplier block was considered, with an inaccuracy margin of ± 1 bin, which is normal. Nevertheless, standard deviations are notoriously smaller than in the previous case.

To corroborate that variance introduced by the wine factory is smaller than that introduced by suppliers a variance comparison F test was applied. Results were the following:

For both variables the test showed with a 5% significance that variabilities introduced by the wine factory are different and smaller than those introduced by suppliers. On the basis of that result it can be stated that much of the system variability is explained to a large extent by the way in which suppliers respond to grape purchase orders, and to a certain degree by the way the wine factory is run, considering in both cases an inaccuracy of ± 1 bin.

The above result is very important as it leads to concluding that to make an appropriate estimation of the wine factory installed capacity, both the analysis and its results depend not that much on the factory itself but on the raw material supply.

5.2 Experiments

As stated above, the system variability depends to a large extent on grape supply by the producers, both in the amount of kilos delivered and truck arrival schedules.

Bearing the above in mind, if we want to determine maximum processing capacity or throughput (TP) for a given time window (e.g. 24 hours) thus giving an answer to question a) in 3.2: Is it possible to determine or estimate more exactly the factory's daily receipt and early processing capacity for white wine? the best

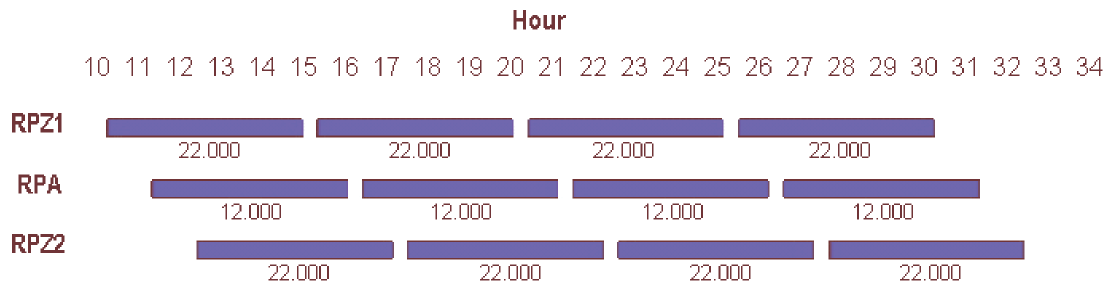

Figure 6: Press processing under ideal delivery and system functioning conditions

grape delivery conditions should be pinpointed, thus maximizing processing capacity while minimizing grape queuing time in the loading area. To do that the number of available presses, their maximum capacity, dumping time for each lot, press allocation to each lot, and pressing cycle duration (from the moment press is loaded till it is cleaned) should all be considered. To do a simple estimation (no random values) we will suppose the following, considering the most common values:

- Number of presses: three (two 150 Hl units; one 100 Hl unit)
- Maximum capacity: 22,000 Kg (150 Hl press); 12,000 Kg (100 Hl press)
- Lot allocation: Same logic used in simulation model
- Dumping time: 1 hour
- Pressing cycle (PC): 5 hours

We will suppose that each bin carries 500 Kg of grape. Thus, the incoming lots will be of 44 and 68 bins, and consequently lots ready to be processed will be of 22,000 and 12,000 Kg. Finally, system failures will not be considered, and delivery schedules will be exact, i.e., they will have not a probability distribution associated to them but a fixed value.

Under ideal delivery and functioning conditions (random factors absent) lot processing order and schedule are shown in Figure 6, supposing that the first lot would be ready by the 10th hour on day 1 till the 34th hour (24 hour time window). To calculate TP the hour from the moment the first truck arrives till the last pressing cycle is over is considered, i.e., the capacity of the whole system will be gauged.

Total amount of lots is 12, corresponding to 224,000 Kg of grape. This way the maximum TP can be calculated: 224,000 Kg in 23 hours (considering the 9th hour as the first truck arrival time), that is to say 9,739.13 Kg/Hr.

We must not forget that a TP value of 9,739.13 Kg/Hr is only theoretical, calculated under ideal conditions, no random factors present. Consequently, it should not be considered as a feasible value. It is significant only from the point of view of its utility to compare different TPs under different conditions.

>From now on, TP value will be calculated using the following formula:

$$TP = \frac{\text{Processed Kg}}{\text{First truck arrival hour - Last pressing cycle hour}}$$

This way we will have a TP value for every simulation run. TP mean and standard deviation will be calculated using these data.

On the other hand, we know that average queuing time variable depends on the loading time of the truck that brought the lot in, truck weighing time, net kilograms transfer from scales to presses, and press availability. That is why making a prior estimation of this variable is far more complex. Anyway, if the lot is queued for less than 4 hours, that is considered an acceptable value.

To elaborate an ideal arrival planning able to create the processing sequence above, we must consider the fact that presses are free every 5 hours approximate., that there are 3 presses loaded from the same pit, and

Arrival time	Bins carried	Kgs. per bin	Total Kgs. in lot
9	44	500	22,000
10	68	500	34,000
11	44	500	22,000
14	68	500	34,000
15	44	500	22,000
16	68	500	34,000
19	44	500	22,000
20	68	500	34,000
Total Kg received			224,000

Table 3: Ideal grape receipt planning to get maximum TP with PC=5

that press loading time is approximate. 1 hour. Then, if trucks arrive according to the following schedule (considering all previous suppositions) we could get a fairly good value for the variables of interest:

Running a simulation with this planning, we get the following values:

- Average queueing time in sampling area: 3.20 hrs, S.D.: 0.27 hrs.
- Expected pressing cycle finish time: 32.16 hrs, S.D.: 0.22 hrs.
- TP: 9,673.88 Kg/hr, S.D.: 92.15 Kg/hr.
- Processed lots: 12.4 per press

The expected TP value obtained was smaller than the ideal one (9,739.13 Kg/hr) though close to it. This means that the supposition that pressing cycles last approximate 5 hours is correct.

Based on the above result, we can give an answer to question a) in 3.2: Is it possible to determine or estimate more exactly the factory's daily receipt and early processing capacity for white wine? It is possible to estimate maximum receipt and processing capacity, which in this specific case is 224,000 Kg for a time window of approximate 24 hours. That value could be obtained under the delivery conditions stated above, with no machine failures.

Finally, two planning for the same grape amount and number of suppliers, differing only in the truck arrival schedule will be contrasted. So as to make a realistic comparison, the random number generating seed will be fixed at the wine factory, and we will be able to appreciate the effect on the variables of interest when using two grape delivery methods. For the base case the actual arrivals will be used. Later, we will carry out the same experiment but regulating truck arrivals to obtain an improvement in the utilization of presses. Inaccuracies in the number of bins will not be considered, and in both cases the total amount of bins requested will actually arrive, to be able to compare equivalent amounts of processed grape. In other words, the current situation at the wine factory (not considering inaccuracies in the number of bins) will be compared to an improved system, where grape receipt is duly planned; in both cases the wine factory response will be the same.

The idea of the above experiment is to give a positive answer to question c) in 3.2: Is it possible to increase the factory's processing capacity while reducing or avoiding grape queuing time? just by regulating truck arrival schedules, not altering production methods. In other words, we want to know if the wine factory productivity could be improved just by programming or planning grape supply.

Planning for a 170,000 Kg order is the following:

Results for the base case were the following:

- Average queuing time in sampling area: 3.57 hrs, S.D.: 1.17 hrs.
- Expected pressing cycle finish time: 35.22 hrs, S.D.: 1.65 hrs.
- Average kilograms actually received: 169,102.74
- TP: 7,275.45 Kg/hr, S.D.: 491.35 Kg/hr.

Supplier	Ordered kgs.
Supplier 1	25,000
Supplier 2	25,000
Supplier 3	20,000
Supplier 4	40,000
Supplier 5	30,000
Supplier 6	30,000

Table 4: Base case (current) planning for variety 1

Arrival time	Supplier	Variety	Ordered bins
9-10	Supplier 1	Variety 1	30
9:30-10:30	Supplier 4	Variety 1	20
10-11	Supplier 2	Variety 1	30
13-14	Supplier 3	Variety 1	40
13:30-14:30	Supplier 4	Variety 1	20
14-15	Supplier 5	Variety 1	30
17-18	Supplier 1	Variety 1	20
17:30-18:30	Supplier 6	Variety 1	30
18-19	Supplier 5	Variety 1	30
21-22	Supplier 2	Variety 1	20
21:30-22:30	Supplier 6	Variety 1	30
22-23	Supplier 4	Variety 1	40

Table 5: Alternative planning

Planning in the alternative case is the same, but every truck will be provided with an arrival schedule. In this case bins (each with 500 Kg) are requested using the current method. One hour time windows were considered for arrival schedules. Planning is the following:

Results for the alternative case were the following:

- Average queuing time in sampling area: 1.51 hrs, S.D.: 0.32 hrs.
- Expected pressing cycle finish time: 30.73 hrs, S.D.: 1.01 hrs.
- Average kilograms actually received: 169,413.4
- TP: 7,996.56 Kg/hr, S.D.: 424.26 Kg/hr.

When statistically comparing the difference between the three sets of data we can notice:

- Average queuing time is shorter in the alternative case, with a confidence range at 95% for the difference of [1.72, 2.41]
- Expected pressing cycle finish time is smaller in the alternative case, with a confidence range at 95% for the difference of [3.94, 5.03]
- TP is higher in the alternative case, with a confidence range at 95% for the difference of [-903.34, 538.88]

We can conclude that using an adequate schedule for grape shipments arrival, and avoiding inaccuracies in bin deliveries, specifying the highest and lowest scores for inaccuracies in the number of kilos per bin, the wine factory installed capacity can be remarkably improved, being able to process a larger amount of grape in less time, reducing grape queuing time. Thus, the answer to question c) in 3.2 is that is definitely possible to be more productive, under the current factory running conditions, just regulating grape receipt.

6 Conclusion

Experiments carried out, 2002 harvest season data analysis, and model sensitivity analysis led to concluding that improvement of grape supply management –in terms of amounts and availability schedules- is of paramount importance.

Firstly, a policy stating strict daily compliance with the number of kilos requested from each supplier should be defined, so as to avoid inaccuracies in deliveries, which are a significant source of system variability, as it was noticed throughout the research.

On the other hand, if the above inaccuracies are reduced, long term harvest planning could be done earlier. As inaccuracies necessarily mean that the missing kilos have to be delivered presently (usually the following day) many of the planning made by the oenologist get frequently altered. At a point, grape shipments could exceed the factory capacity, causing delays in the processing of grape, and the closest harvest schedule would need modification; all due to lack of capacity.

Regarding grape availability schedule, in the last experiments it was easily appreciated that through adequate programming of grape receipt and the number of kilos in each shipment, it is possible to increase, to a remarkable extent, the number of kilos processed per day. This way, the number of wine liters produced from the grapes of a whole vineyard could be increased just by regulating grape receipt, a rather attractive idea, as it implies no additional costs but only negotiating with suppliers the daily delivery of grapes.

References

[1] M. J. Sims, An introduction to planning and scheduling with simulation, In Proceedings of the 1997 Winter Simulation Conference, ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson .

[2] B. S. Vaidyanathan, Y. H. Park, Application of discrete event simulation in production scheduling, In Proceedings of the 1998 Winter Simulation Conference, ed. D. J. Medeiros, E. F. Watson, J. S. Carson, and M. S. Manivannan .

[3] E. J. Williams, R. Narayanaswamy, Application of simulation to scheduling, sequencing, and material handling, In Proceedings of the 1997 Winter Simulation Conference, ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson .

[4] G. D. Rehn, Simulation in dialy factory operation: Śsetting the line bogey in augustaŠ, In Proceedings of the 2000 Winter Simulation Conference, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick .

[5] D. Simchi-Levi, P. Kaminski, E. Simchi-Levi, Designing and Managing the Supply Chain: Concepts, Strategies, and Cases Studies, Irwin McGraw-Hill, New York, NY, 2000.

[6] B. M. Beamon, Supply chain desing and anlysis: Models and methods, International Journal of Productions Economics (55) (1998) 281–294.

[7] R. G. Ingalls, The value of simulation in modeling supply chains, In Proceedings of the 1998 Winter Simulation Conference, ed. D. J. Medeiros, E. F. Watson, J. S. Carson, and M. S. Manivannan .

[8] D. Schunk, B. Plott, Using simulation to analyze supply chains, In Proceedings of the 2000 Winter Simulation Conference, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick .

[9] D. J. Parsons, R. A. Phelps, Production scheduling validity in high level supply chain models, In Proceedings of the 2001 Winter Simulation Conference, ed. B. A. Peters, J. S. Smith, D. J. Medeiros, and M. W. Rohrer .

[10] A. Weintraub, R. Epstein, R. Morales, J. Seron, P. Traverso, A Truck Scheduling System Improves Efficiency in the Forest Industries, Interfaces 26 (4) (1996) 1–12.

[11] J. A. Diaz, I. G. Perez, Simulation and optimization of sugar cane transportation in harvest season, In Proceedings of the 2000 Winter Simulation Conference, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick .

[12] D. Cunningham, The distribution and extent of agrifood chain management research in the public domain, Supply Chain Management: An International Journal 6 (5) (2001) 212–215.

[13] G. Hansen, Cognitive process simulation in wine making: Determining the best route for wine transfers, Report, Computer Aided Process Improvement Inc. (2000).

[14] M. M. Barnes, R. A. Phelps, R. Rugeroni, Capacity planning simulation of an olive processing plant, Report, Simulation Dynamics Inc.

[15] E. J. Williams, A. Gevaert, Pallet optimization and throughput estimation via simulation, In Proceedings of the 1997 Winter Simulation Conference, ed. S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson .

[16] T. A. Dahl, B. F. Jacob, Confident decision making and improved throughput for cereal manufacturing with simulation, In Proceedings of the 2000 Winter Simulation Conference, ed. J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick .

[17] A. M. Law, W. D. Kelton, Simulation Modeling and Analysis, McGraw-Hill Inc., New York, NY, 1991.