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LINE AVAILABILITY AND MATERIAL SYNCHRONIZATION IN LIQUID PACKING LINES: A SIMULATION STUDY

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KEYWORDS

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ABSTRACT

Increasing the number of product variants in line production usually shortens the average batch run lengths and consequently increases the number of changeovers. If new equipment has to be installed the line performance may change. In this paper a case is discussed concerning the modification of a production line of bottles with liquid due to the introduction of a new product variant. Simulation has been used to determine the new line availability, to asses the changeover losses and to improve material synchronization.

INTRODUCTION

A significant trend in the Fast Moving Consumer Goods business is the increase in the number of product variants, accompanied by a decrease in production volume per variant. The result is an increased complexity in the production environment. In case of the introduction of a new product variant, additional machines might be necessary on the production line. An increasing number of product variants will trigger a movement from "produce to stock" to "produce to demand".

In a "produce to stock" environment, product variants are made in large production runs, based on a demand forecast. Changeover of the production line occurs less frequently and is therefore less dominant in production parameters. In a "produce to demand" environment, short production runs are executed of every variant, mainly to keep inventory low. Frequent changeover of the production lines is necessary then, but this may contribute significantly to production losses, both time losses and material losses.

For liquid packing lines, it is difficult to control the machines in such a way that the production run is exactly ended at the desired amount of produced items. This may lead either to partly finished pallets causing extra storage and handling cost or to scrap cost. These effects will increase in the case of "produce to demand".

For a new liquid product variant in a "produce to demand" environment, which requires additional machines on the production line, the following research questions need to be addressed:

- What will be the impact of the new machines on the existing production line?
- How can the changeover losses be minimized ?
- How can the material flows be controlled in the end of a production run?

This paper will discuss the results of a project concerning a production line of cleaning liquid, that has to be modified to enable the production of a new variant. Simulation is used to answer the questions above. First, the case will be introduced. Then the simulation environment will be discussed, followed by the experiments and results and finally the conclusions will be drawn

CASE DESCRIPTION

The products concerned are bottles filled with a cleaning liquid. The bottles are filled, labeled and packed at the packing floor, from logistical point of view the most interesting part of the plant.

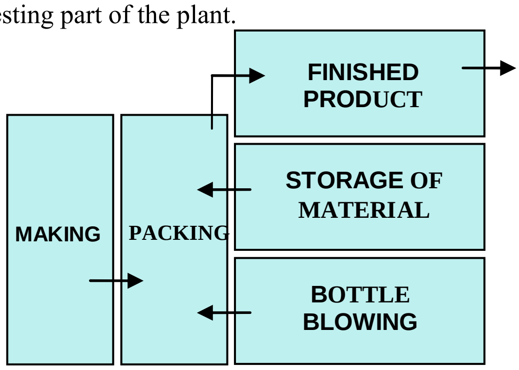

Figure 1: Schematic drawing of the plant

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The packing floor is fed by the liquids making department, the bottle blowing department and the packing material storage department . This is shown in Figure 1.

On the packing floor, several packing lines process material. The general lay-out of a production line is shown in Figure 2.

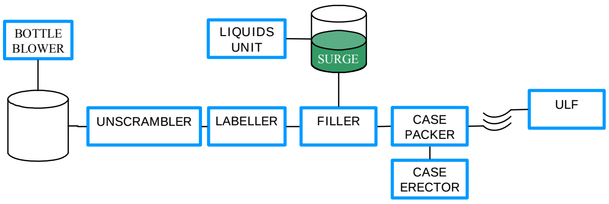

Figure 2: Schematic drawing of production line

ULF stands for Unit Load Former (palletizer). After the bottles are produced, the unscrambler aligns them on a conveyor. After the unscrambler, the bottles are labeled, filled and put in a case. The cases are palletized. The machines are connected by conveyors. The conveyors are short and therefore their buffer function is limited. Their primary goal is transport between the machines, not decoupling the machines. The filler machine (also capper) is regarded the bottleneck machine in this production line. Machine rates upstream and downstream of the filler increase stepwise.

Due to different causes machines will fail now and then, interrupting the flow of material. When a machine is down it will take some time to restart it and different failure modes will cause different downtimes. To describe the machine start/stop behavior, the following two expressions are used:

MTBF = Mean Time Between Failures
= Total Uptime / Number of Failures

MTTR = Mean Time To Repair
= Total Downtime / Number of Failures

To describe the performance of the production line, the concept of availability is used. For a period of undisturbed production, without planned downtime, the availability is defined as follows (Smith, 1981):

Availability = Uptime / Total Time

When the bottleneck machine of a production line has a constant rate, the availability for a period without planned downtime can also be defined as follows:

Availability = Actual Production / Potential Production

If different product variants are to be produced on the same line, and so the line has to be modified between variants: a changeover. The changeover losses can be divided in two categories. The first concerns a loss of time: during a changeover there is no production possible. The second loss concerns material. At the end of a production run there is always material (bottles, labels, caps, liquid, cases, pallets) on the line that has to be scrapped or stored. The storage of partly filled pallets increases costs.

In practice the system is not able to track every individual bottle on the line and therefore it is not possible to end the production run exactly at the desired production volume. If there is only a small amount of material left at the end of a run, it will be scrapped. If there is a lot of material left, it will be stored and reused at a later run of the same "stock keeping unit" (SKU). Given the trend towards 'Produce to Demand' and the accompanying increase in changeovers, there is a great need for improvement of this end of run procedure. One of the options is to (partly) automate the end of run procedure.

To answer the research questions, the following information is needed:
- The new line availability compared to the original
- Line availability as a function of filler MTBF
- Line availability as a function of filler MTTR
- Changeover losses as a function of number of operators
- Changeover losses as a function of average production run volume

MODELING

In the literature much work has been done on optimizing production control in the (semi) process industry (Günther and van Beek, 2003). When it comes down to adapting or extending a specific production environment, simulation appears to be a very powerful and flexible tool. Production in the (semi) process industry usually involves both continuous and discrete processes. Consequently simulation tools should be able to support both ways of production (Clark and Joglekar, 1992). Sierenberg and Wever (Sierenberg and Wever, 1982) simulated complete beer-bottling lines in a combined continuous-discrete model using the simulation language Prosim, one of the first advanced combined discrete-continuous simulation language (Prosim Web site 2006). This model was built to improve line productivity and used machine down time distributions derived form the real machines in the line. The simulation package used in this project is Extend (Extend web site 2006), a widely used tool within the company. The software package contains a wide variety of predefined blocks in libraries. The user can build its own model by selecting and connecting the appropriate blocks and providing the right control settings for the blocks. The program is easily linked to MS Excel for input and output files.

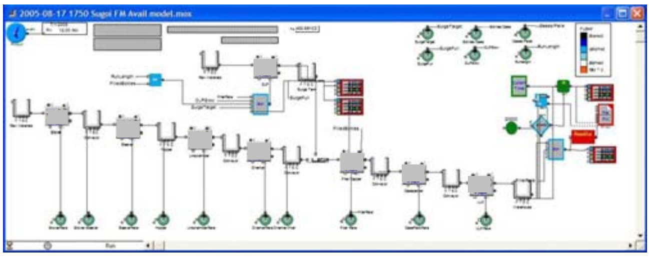

Figure 3: Impression of the Extend model

In the constructed model, a flow-based module is combined with an item-based module. The flow module represents the production line as displayed in Figure 2, and it communicates with the item-based changeover module. The changeover module is activated by signals from the production line, and then the changeover module indicates when the production line is ready to resume its activities.

The input for the model consists of:
- Machine Rates
- Machine Reliability Data
- Conveyor Lengths
- SKU Production Schedule
- Number of Operators
- Changeover Times per Machine

The reliability data of the machines consists of MTBF's and MTTR's. For the existing machines, real reliability data can easily obtained from the company's records. For a new machine, benchmarks with comparable machines combined with an expert opinion provide a good first indication. A sensitivity analysis for deviation of this indicated value was executed.

The production schedule includes the sequence and quantities of the different SKU's. Depending on the from/to SKU, the model detects which tasks have to be executed for each changeover and acts accordingly. The simulation runs are executed with a production schedule of one month. The number of operators available can be varied per changeover or can be varied over time to resemble lunch break and shift change.

The Production line module

In the production line module the machines are the active elements, and the bottles and the liquid are passive elements, processed by the machines. The conveyors in between machines and the hopper are modeled as ordinary FIFO queues. Every machine processes material, but is now and then interrupted because of a machine stop. Every machine has a downtime distribution and an uptime distribution, based on the given MTTR and MTBF.

For the bottle blower, the case erector and the CLP, the process is very much alike, as all three of these machines are modeled as machines with an infinite supply of material:

Process bottle blower, case-erector and CLP:
> **IF** downstream queue is NOT full,
> **THEN** process material at prescribed rate
> **ELSE** hold

All machine have fixed rates, except for the CLP. This rate is depending on the surge tank level:

CLP rate:
> **IF** surge tank level is < target
> **THEN** CLPspeed is highCLPspeed
> **ELSE** CLPspeed is lowCLPspeed

For the unscrambler, the labeller, the filler, the casepacker and the ULF, the processes are identical, however the CLP can only work when both upstream queues are not empty (liquid and bottles). And for the ULF the downstream queue will never be full, as the warehouse is assumed infinitely large.

Process unscrambler, labeller, filler, packer and ULF:
> **IF** downstream queue is NOT full,
> **AND** upstream queue is NOT empty
> **THEN** process material at prescribed rate
> **ELSE** hold

This describes the basic behavior of the production line module. The number of bottles with liquid 'flowing' through the line depends on the machine rates and the start-stop behavior of the machines

The Changeover Module

In this module, the operators are the active elements, and the machines are the passive elements. This part of the model is item based. Based on a signal from a machine, indicating that the target production for this SKU is achieved, the machine will stop and will be marked 'ready for changeover'. Next an operator will prepare the machine for the time needed for a changeover (can be zero), and the machine will be marked 'ready for production'. The (variable) pool of operators will work their way downstream from the bottle blower to the ULF. When all machines are marked 'ready for production', the production module will commence producing the next SKU. The influence of the number of operators on the changeover time is illustrated in Figure 4.

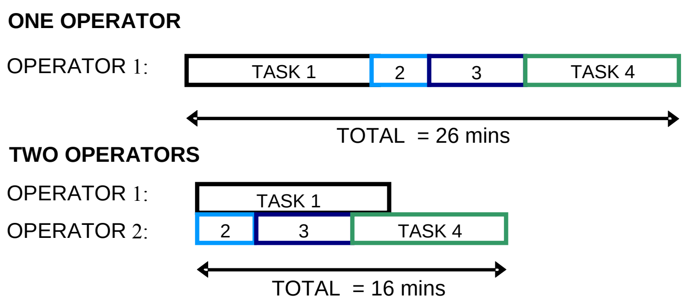

Figure 4: Operators influence on changeover time

The influence of the number of operators on the changeover is depending heavily on the tasks that have to be executed in a changeover, and thus on the 'From' and 'To' SKU. type of changeover. One of the tasks of the changeover model is that it detects the 'from' and 'to' SKU and then determines the tasks to be executed.

EXPERIMENTS AND RESULTS

For the new product variant, one of the additions to the production line is a new filler/capper machine. The system availability is lower with this machine then without it, since the machine process is quite complex. The influence of unexpected behavior of the machine on the system availability is determined. In Figures 5a and 5b, the results are displayed for filler behavior deviating from the expected. The numbers are indexed for confidentiality reasons.

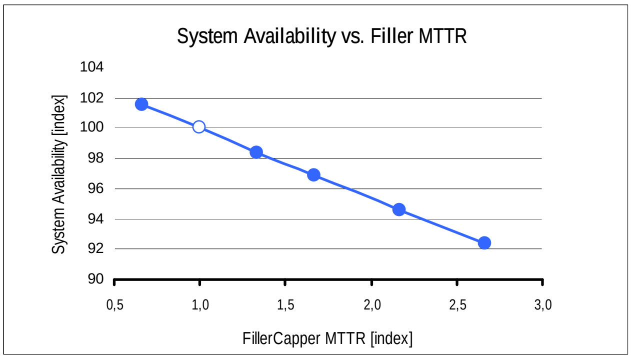

Figure 5a: System Availability vs. Filler MTTR

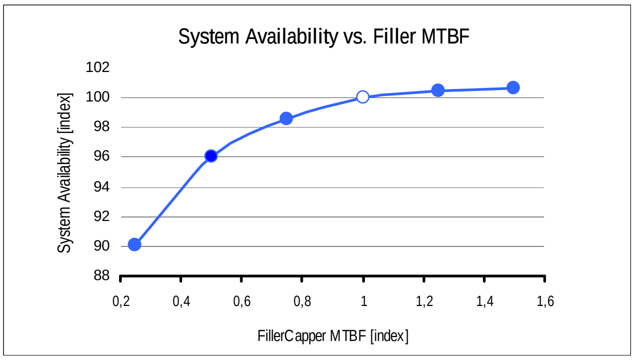

Figure 5b: System Availability vs. Filler MTBF

The open dots represent the expected situation, the closed dots represent what/if scenarios. As could be expected, influence of the filler behavior on system availability is quite significant, as it is the bottleneck machine. From the graphs we read that, from operational point of view, it is most efficient to first make sure the filler MTBF is high enough, before focusing on ways to decrease the filler MTTR.

The next question to answer regards the changeover time losses. Since in a "produce to demand" environment, the changeovers will occur more frequently, it is important to develop ways of reducing changeover losses. One option is increasing the number of operators that are executing the changeover. Figure 6 displays the relation between changeover losses and the number of operators.

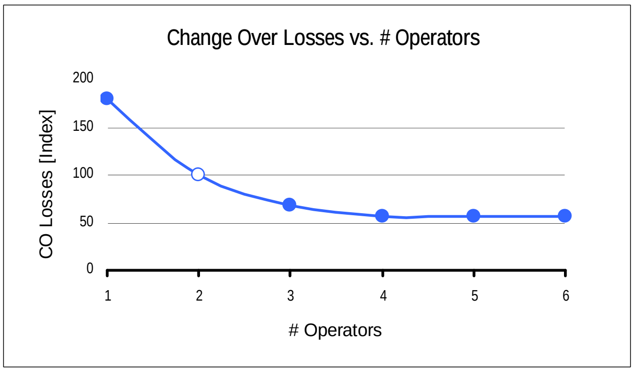

Figure 6: Changeover Losses vs. Number of Operators

The research clearly shows that adding extra operators does reduce changeover losses, until a certain limit. This limit Is governed by the longest individual task in a changeover. In this specific case, 4 operators would already deliver the minimal changeover loss.

The other aspect of "produce to demand", shorter run lengths, also influences the changeover losses, since in a certain period of production, more time will be consumed by changeover tasks.

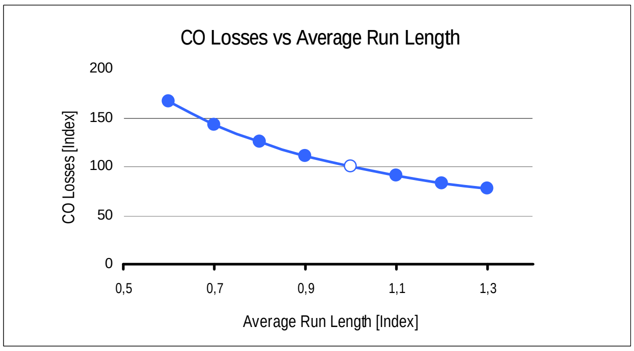

Figure 7: Changeover losses vs. Average Run Length

Figure 7 shows that the changeover time losses will increase faster than linear when the average run length decreases.

The next step is to find a way to minimize the material losses at a change over. Essential for ending the production run without material on the line and exactly the desired produced volume, is shutting down the machines at the correct point in time. Before the project started, shutting down machines was done by hand by the operator. There was a large risk of human errors, for example if operators are distracted on critical moments. As part of the project, the packing line PLC was extended to include automated shutdown of the unscrambler and the case-erector.

The decision to shut down a machine should be based on how many bottles (on spec) have passed that machine. The difficulty is that if x bottles have passed a machine, not necessarily x bottles will make it to the end of the line; at various points in the line scrap will occur at unpredictable rates. Therefore another approach is chosen. Starting point is a counter of the number of bottles that have made it to the end of the line. Whenever this counter, combined with the number of bottles on the line, adds up to the desired production volume, then the first upstream machine is shut down. The absolute margin of error (because of scrap) is much smaller this way because the margin is not derived from the total produced volume, but only from the number of bottles on the line.

The difficulty now is to assess the number of bottles on the line, since this is not a constant and it is also not measurable. With simulation it is possible to determine the average number of bottles on the line during constant production. The graph in figure 8 is constructed using simulation results

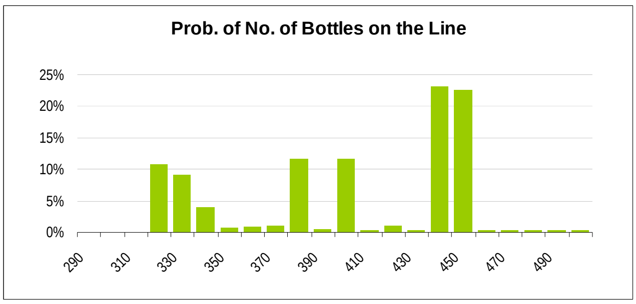

Figure 8: Probability of number of bottles on the line

The number of bottles on the line will vary between a minimum (all conveyors empty) and a maximum (all conveyors full). The variation is caused by the machine characteristics: when a machine fails, the upstream conveyors will fill up and the downstream conveyors will run empty. So the distribution of Figure 8 is governed by the machine reliability characteristics. The highest peak corresponds with normal operation, all other peaks are irregularities. The distribution is different for all lines, and for all bottle sizes.

If a certain number of bottles on the line is assumed (μ) there is a risk of undershooting this value. This means that the run will end with a partly finished pallet which has to be handled and stored. On the other hand, in case of overshoot of the estimate, there is a risk of scrap. If the distribution of bottles on the line is represented by a normal distribution, the balance between storage and scrap would look like Figure 9.

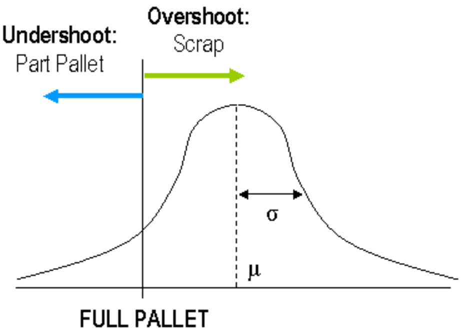

Figure 9: Relation between estimate, storage and scrap

The best way to assess the balance between storage and scrap is cost. With the automated shutdown system and the knowledge about the number of bottles on the line, it is possible to control the balance between scrap and storage. The only information missing is the optimal point.

To find the optimal balance between storage and scrap, a cost evaluation was performed. Figure 8 displays the results.

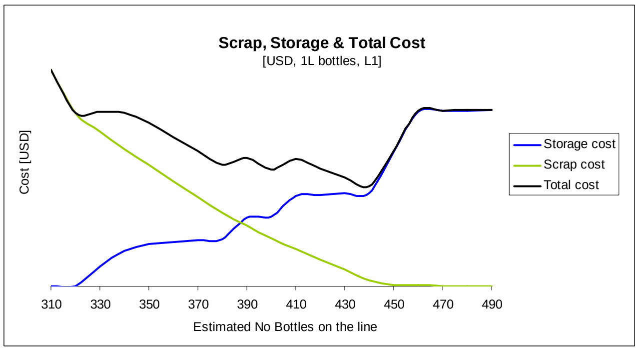

Figure 10: Cost evaluation of scrap and storage

The bumpy character of the storage cost line is caused by the distribution of bottles on the line. With this cost evaluation it is possible to set the estimate of number of bottles on the line to the point where the total of storage cost and scrap cost is minimized.

CONCLUSIONS

Simulation enabled an up front analysis of the effect of adding extra machines to an existing production line. Several what-if scenarios could be analyzed. The results strengthen management's earlier findings to focus first on increasing a machine's MTBF, before increasing the system productivity further by decreasing the MTTR.

In the simulation model, a flow-based module was successfully combined with an item-based module. They interacted via signals to simulate the production line (flow-based) and the changeover procedure (item-based).

With regard to the changeover losses, the following is noted. It makes sense that a more "produce to demand" oriented production environment incurs higher changeover losses. The experiments show that measures can be taken to reduce the changeover losses. However, it makes no sense to start reducing these losses without a holistic view. The costs of these measures should always be balanced against the advantages in other parts of the supply chain. Produce to demand also delivers significant advantages, which might easily overshadow an increase in changeover losses.

For the material synchronization, it is concluded that simulation is a powerful tool to statistically analyze a complex problem. Simulation provides the necessary input data for a significant improvement in material synchronization. The simulation results indicate that, at the same scrap level, a 70 % decrease in partly finished pallets is feasible. The findings of this study are used in de design of new production lines

REFERENCES

Clark M. Girish S, 1992. Simulation Software for Batch Engineering. In: Batch Processing Systems Engineering, Springer, ISBN 3-540-59201-6

Extend web site 2006: http://www.imaginethatinc.com

Gunther H.O, van Beek P, 2003. Advanced Planning and scheduling Solutions in Process Industry. Springer-Verlag Berlin Heidelberg New York, ISBN 3-540-00222-7, p.20

Prosim Web site 2006: http://www.prosimbv.nl

Smith Dr D.J, 1981. Reliability, maintainability and risk, practical methods for engineers, sixth edition. Butterworth Heinemann, ISBN 0-7506-5168-7

Sierenberg R.W, Wever P, J. (1982) Ucol: A New Bottling Line Simulation Model. International Journal of Modeling & Simulation, Vol.2, No.4, 1982