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SIMULATION OF ROBOTIZED FOOD PACKAGING LINES

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ABSTRACT

In robotized food packaging lines the performance depends on the number of products packed per time unit, product loss percentage and the percentage of completely filled packages. This paper presents a feasibility study to investigate a new packaging concept where the product and box conveyors are uncoupled by introducing buffer positions for boxes with each packaging robot. The new concept proves to be superior with respect to all performance aspects. Above that the concept enables immediate and full-speed startup from all situations.

INTRODUCTION

In modeling food packaging, productivity questions focus on minimizing both product loss and incomplete product boxes – besides the usual maximization of production and cost minimization [PMMI, 2002] [Tompkins et al., 1996]. In this paper a new concept for the configuration of an automated packaging line is investigated and compared to a common configuration (as shown in figure 1).

Figure 1. Chocolate packaging line

The new concept shows technological advantages beforehand, but the logistic consequences were still unclear. To investigate these consequences a simulation model has been developed.
In this paper the configuration and possibilities of the model are explained and the results of experiments will be described.
The model aims to support a comparative study of concepts and not to optimize the configuration and control. Therefore the robot control with respect to product and box selection is kept simple for both concepts.

MODELING OF FOOD PACKAGING

A packaging configuration typically consists of two conveyor systems and a material handling system with robots. One conveyor system is being used for the transportation of products (chocolate bars, hamburgers, bread etc.), the second conveyor system transports the boxes that should be filled with products. Figure 2 shows the primary functions of the material handling system with robots.

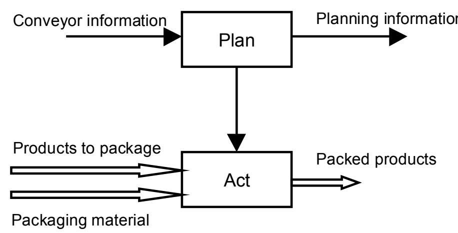

Figure 2. Packaging functions

Two function types are distinguished:

- Control ("Plan")
- Operate ("Act")

The Plan function receives data about the state of and on the conveyor systems. The data represent the image of the products and boxes on the conveyors, their speed etc. Based on this image a selection is made and tasks sent to the robot system. For this case it is not important whether the control is centralized or not.
When we zoom in to the control function, three subfunctions are distinguished (figure 3):

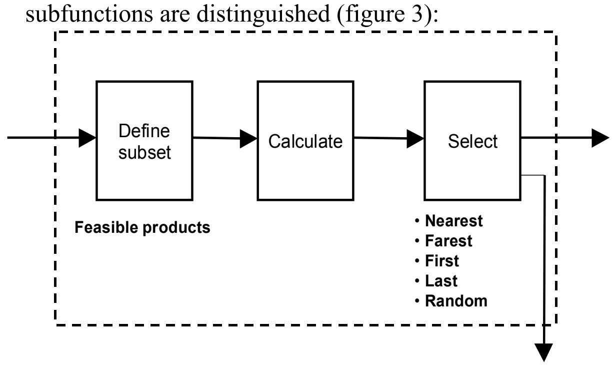

Figure 3. Plan functions

- Define a subset of products: determine the set of products, which can technically be reached by a robot.
- Calculate attributes of these products that will be used for the final selection (distance, speed etc.).
- Select the product that best suites the requirements.

If a robot has picked up a product, the same functions are required to select the best box to put the product in.
The quality of the planning depends on each of the subfunctions and the conveyor information received. The model takes a communication delay of 10 msec into account. It is possible to select different selection strategies. The current model selects the product (or box) that requires a minimal robot displacement in the direction of the conveyor.
The subfunctions of a robot are shown in figure 4. First a number of product cycles is being performed. The number depends on the number of "grippers" of a robot. Each cycle consists of three steps:

- wait for (the assignment of) a product
- move to the product
- pick up the product.

Next a packaging cycle is performed, consisting of waiting for (the assignment of) a box, move to the box and "drop" the product.

Asynchronous configuration

The new configuration for food packaging lines also consists of two conveyors, but now a buffer space is present between these conveyors. Buffers are positioned at the positions of the robots. The conveyors now move in the same direction.

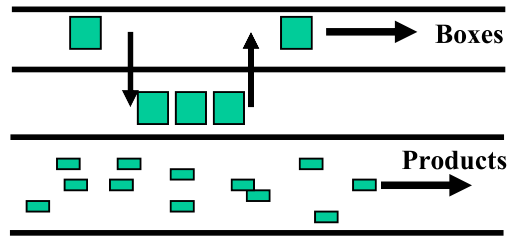

Figure 6. Asynchronous Configuration

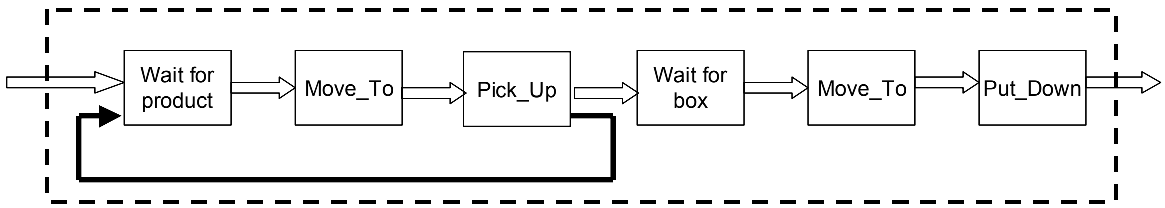

Figure 4. Robot functions

"Plan" and "Act" are strictly separated in the model in order to support physical parallel execution for future prototyping and to support straightforward experimentation with different control strategies.
The calculation of time to move to a product or a box takes both acceleration and deceleration, and the height of the products and boxes into account. Horizontal movements assume a simultaneous movement into X- and Y-direction.

ALTERNATIVE CONFIGURATIONS

Synchronous configuration

The usual configuration for food packaging lines consists of a product conveyor and an opposite moving box conveyor (figure 5).
The synchronous configuration requires an exact tuning between the product conveyor and box conveyor system. The supplied box capacity should match the supply of products exactly. Any difference between supply rates will result in empty boxes in case of product shortages or product loss in case of box shortages. For situations with a varying production rate this is a serious complication.

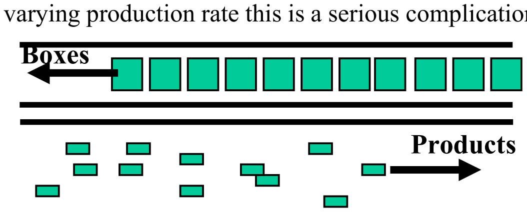

Figure 5. Synchronous Configuration

MODEL INPUT

The model input can be divided in 4 groups:

1. the product conveyor
2. the box conveyor
3. the product dimensions
4. the production characteristics
5. the robot (configuration) attributes

Input data on the product conveyor, box conveyor and product dimensions are shown in figure 7.
The input data of the box conveyor in the figure above concern the asynchronous configuration. The buffer size is not applicable for the synchronous situation.
Furthermore it is assumed for the synchronous situation that the speed of the box conveyor is set to a value that a box can be filled exactly

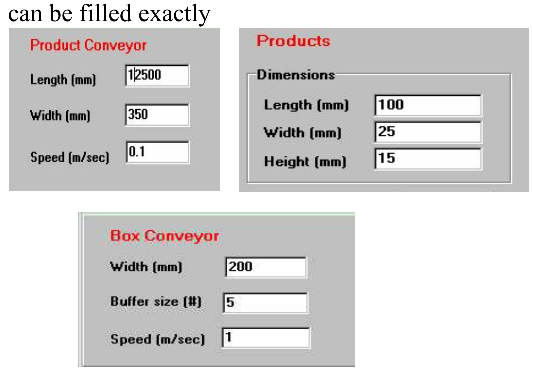

Figure 6. Physical dimensions

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after passing all the robots. Suppose C is the cycle time of a robot, the number of robots is
R, the number of products per box is N and the longitudinal reach of a robot is B, then the speed of the box conveyor should be:
(B x R) / (N x C).

The production characteristics are expressed in terms of production rate, production variance and number of products per box.

Arrival Rate (p/min)	300
Max. variance (%)	20
Products/Box	16
Rows	0

Figure 8. Production characteristics

The rows field is usually set to zero, which means that products can arrive at a random lateral position on the conveyor. There are situations however that products arrive in a perfect lines or rows, for example in bakeries. In these situations the variance is automatically set to zero.

Special attention is given to the generation of the correct production rate. According to figure 8 the production rate varies between 240 and 360 with an average of 300. To achieve this rate the generator in the model uses the maximum rate of 360. At arrival of a product it draws a uniformly distributed number x between 0 and 360. If x <= 300, the product is put on the belt, otherwise it is "thrown away".

Finally the configuration and robot attributes are shown in figure 9. Robots may have more than one gripper. The model assumes that the number of products per box is an integer multiple of the number of grippers specified in order to prevent complications of picking up for example 2 products, while a box to be filled only has one empty position.

The pickup height is the distance the arm has to bridge if the gripper is positioned exactly above the product. After picking up the gripper rises 5 mm, before the robot starts the horizontal movement.
The put-down height is the vertical distance for putting down a product into a box. Effects of piling in the box are neglected. After putting down the same distance is traveled again before the robot is allowed to start a horizontal movement.

The simulation model has been developed in the discrete process simulation language TOMAS [Veeke, Ottjes, 2000]. TOMAS directly connects to the informal way of describing processes as it has been followed in this paper until now [Zeigler et al. 2000].

Robots	
Number	4
Relative distance (mm)	2500
Reach (mm)	1000
Number of grippers	1
X-Acceleration (mm/sec2)	30000
X-Deceleration (mm/sec2)	30000
Y-Acceleration (mm/sec2)	30000
Y-Deceleration (mm/sec2)	30000
Horizontal speed (mm/sec)	3000
Vertical speed down (mm/sec)	300
Vertical speed up (mm/sec)	300
PickUp Time (sec)	0.05
PutDown Time (sec)	0.05
PickUp Height (mm)	10
PutDown Height (mm)	50

Figure 9. Robot configuration attributes

TOMAS offers the usual verification support by debugging facilities. 2D Animation is being used for the verification of the control algorithm. The results of the plan functions are visualized by different colors of the products during the simulation (e.g. products within the physical reach of a robot are colored red).

EXPERIMENTS

The performance of the packaging system will be judged with 3 criteria:

- *the effectiveness of the system* is defined as the ratio between the produced number of full boxes per hour and the theoretically feasible number per hour based on the supply rate of products. Fr example if the supply rate is 300 products / minute and a box should contain 16 products, then a maximum of 300 * 60 / 16 = 1125 full boxes per hour can be produced. Incomplete boxes are considered production loss.
- *The percentage of product loss*; product loss means products reaching the endpoint of the conveyor without being picked up by a robot.
- *The utilization of a robot.* As a result of each experiment the average technical cycle time can be calculated; it is the time duration of one arm movement and one picking move. This duration is influenced by the position of the arriving products on the conveyor. The first robot receives the maximum supply and is able to realize a shorter cycle time than the last robot. This technical cycle time determines the maximum number of cycles per hour for a robot. The utilization is defined as the ratio between the real number of cycles and the calculated number.

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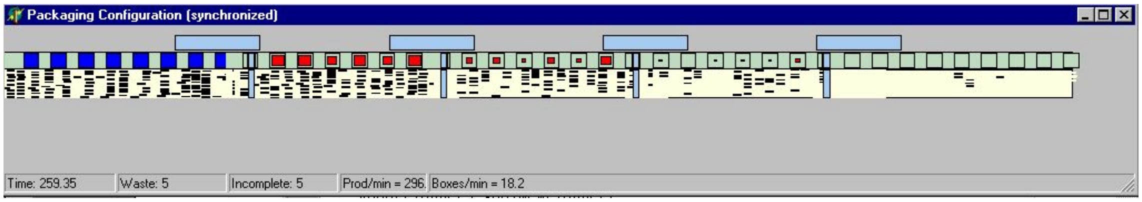


Fig. 10. Simulation of a synchronous configuration

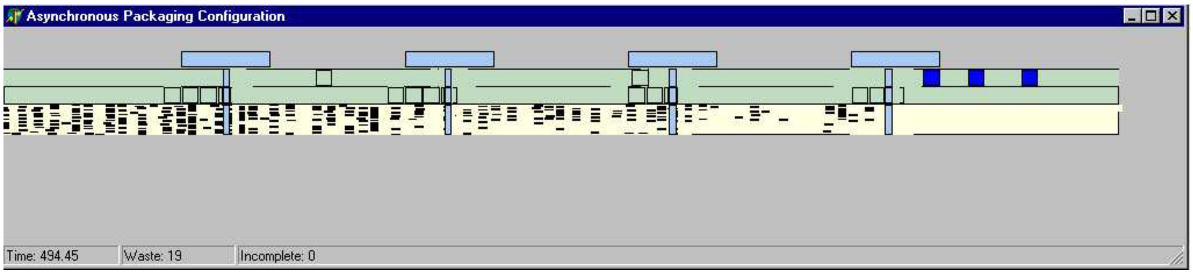


Fig. 11. Simulation of an asynchronous configuration

During a simulation run, the first 400 seconds are considered startup time of the system. After 400 seconds the registration of data for the performance criteria starts. Each simulation run covers a clock period of one hour. Comparison of results of 10 consecutive runs did not show significant deviations with the results of one hour.

In figure 10 a screen shot of the synchronous configuration is shown. The filling degree of a box is visualized by color and brush fill of the box's rectangle. At the bottom of the screen the current simulation time, the number of products lost so far and the number of incomplete boxes are shown, including the products and boxes production per minute.

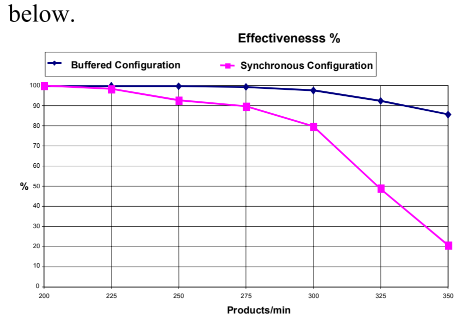
Figure 11 shows a screen shot of the buffered configuration simulation. In this concept each robot has a buffer conveyor line at its disposal to position the boxes to be filled. In this way the box conveyor and product conveyor are uncoupled. The advantage is clear: all boxes delivered will be completely filled by definition and the box supply can be controlled independent of the product supply rate. By filling the buffer with empty boxes before production there are no startup losses. Thus is even more important when production disturbances cannot be excluded. If a robot filled up a box, it signals the plan function to provide a new empty box. The filled box shifts to the end of the buffer and is inserted between the boxes passing on the box conveyor. At arrival, an empty box enters the buffer at the first (leftmost) buffer position and is shifted as far as possible to the right by the buffer conveyor. If the buffer size is n boxes then the loading position of the robot is buffer position n – 1. The first experiments already showed that the density of boxes at the box conveyor is very low. So one extra position after the loading position is enough to guarantee a box transport in time.

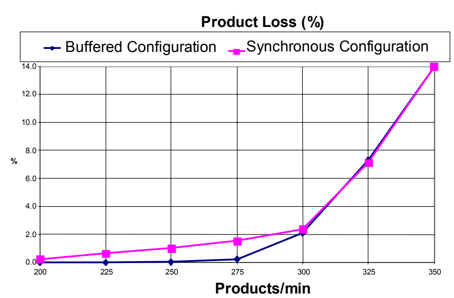
Two series of experiments have been performed:

- A series with 200, 225, 250, 275, 300, 325 and 350 products/min and 16 products/box
- A series with 275 products/min and 4, 8, 12, 16 and 20 products/box.

RESULTS

The effectiveness and product loss percentages are shown below.





The effectiveness of the synchronous configuration decreases strongly with an increasing product supply rate, because the increased number of partly filled boxes. The effectiveness of the buffer configuration is completely determined by the capacity of the robots. But even when

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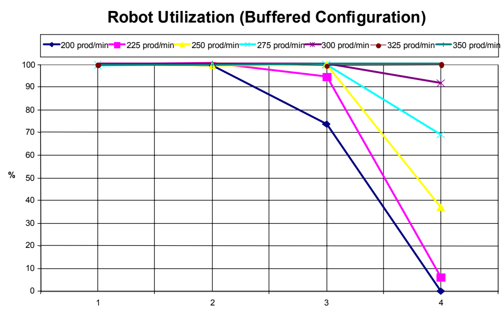
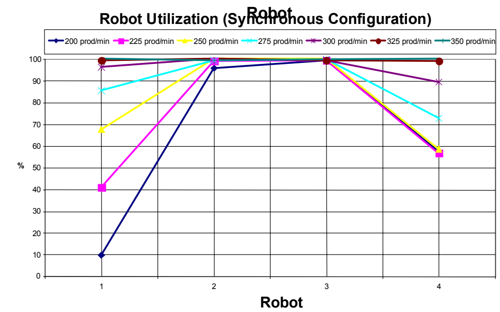
this capacity is insufficient the system still delivers only full boxes.
During the experiments the cycle time of a robot appeared to be about 0.8 sec. Therefore the maximum capacity with 4 robots is expected to be around 300 products / min. The variance of 20% causes irrevocable product losses at production rates of 250 products/min or more. This is shown by the product loss percentages. Below the capacity limit of 300 products / min the performance of the buffer configuration is superior to the synchronous configuration.

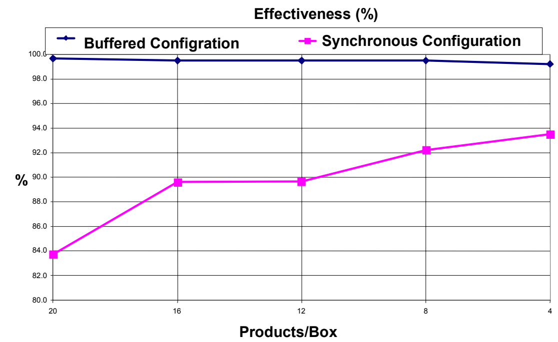
With respect to the criterion of robot utilization an effect appears, which is very interesting from an organizational point of view. With the buffer configuration all idle times concentrate at the last robot(s). This means that low production rates can be easily realized with less operational robots.

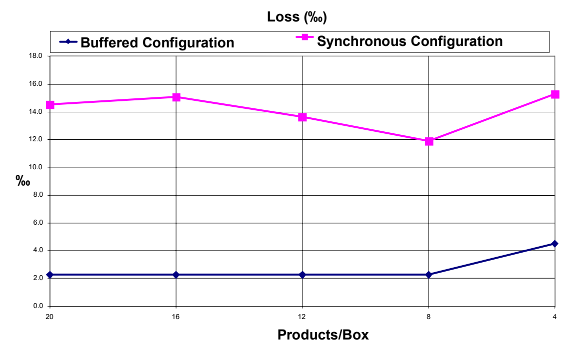




With the synchronous configuration idle times appear at both the first and the last robot. Apparently, the number of operational robots required cannot be controlled with different production rates. The system shows a "wave" effect in time. The first robot has no problems with the availability of products, but may have to wait for filling space in the boxes (they are mostly filled by the other robots). The last robots has always enough empty boxes at its disposal, but experiences increasing product shortages with lower production rates.

Finally the results with respect to the influence of box sizes are also in favor of the buffer configuration. The buffer configuration is hardly influenced by the box size. The effectiveness and product loss change slightly with 4 products per box. This can simply be solved by increasing the speed of the box conveyor or by increasing the buffer size with one position. It is also possible to make the control of the boxes flow more intelligent, but this is not the subject of this research.
With the synchronous configuration the effectiveness increases with decreasing box size but it still is significantly below the effectiveness of the buffer configuration. The minimum product loss percentage is reached at 8 products / box. Below this number the product loss increases again, because the density of the boxes on the box conveyor urges the system to increase the conveyor speed.





CONCLUSIONS

The buffer configuration has a number of logistical advantages compared with the synchronous configuration:

- The effectiveness, measured in number of filled boxes per hour, is structurally higher.
- By definition it is impossible to deliver incomplete boxes.
- Within its technological capacity limits the percentage of product loss is negligible. The maximum measured value was 2 ‰ with 16 products per box and 4 ‰ with 4 products per box.
- Overcapacity manifests itself at the last robot enabling real capacity control. This can significantly increase the efficiency of the configuration.
- The configuration has no start up problems. Also after a standstill caused by a disturbance the packaging line can start at full speed immediately. In the long term this will result into an increased effectiveness.
- The speed of both the box conveyor and the product conveyor can be controlled independently. Especially for small packages the advantages of this become evident. Besides this, the number of buffer positions automatically increases with smaller box sizes.
- The configuration can be extended further than the synchronized configuration. The introduction of an extra packaging line can be postponed, because the density of the box conveyor is low.

During the simulation it was shown that the box size in the synchronous configuration is quite important. The density of the boxes is so high that the only solution to provide enough boxes is speeding up the box conveyor; especially in situations where a small number of products per box is combined with a relative large product surface (e.g. hamburgers). The effect is however that the available time for the robots to fill a box decreases significantly. Contrary to the asynchronous configuration, which is hardly sensible for the number of products per box, the synchronous configuration has a predefined optimum number of products per box..

FUTURE RESEARCH

At this moment the configuration is being engineered and runs in prototype at some companies in the Netherlands. The logistic research now focuses on optimizing the control strategies for the Plan function. The configuration is one of the many production configurations that are subject of study in the Virtual Industrial System environment, which is currently being developed, based on the distributed simulation approach of TOMAS [Veeke and Ottjes, 2003].

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