

DESIGN AND CONTROL OF AUTOMATIC BOTTLES PACKAGING LINE WITH MODULAR MODELLING AND SIMULATIONS

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Paper deals with the development of automatic bottle packaging line using modelling and simulation with Arena Simulation software. The aim is to analyze the complex process of liquids processing, planning the filling and packaging line, implementing control with sensors and acquiring results that will present the functionality of the line. The model developed includes interconnected modules that represent the necessary processing machines: filling machine, capping machine, labelling machine and other units like supply reservoir, depalletizer, conveyors, palletizer, and storage as part of the main line. As part of the process control, sensors are included in the main units to monitor, control, and optimize the movement of bottles. Results will be acquired for the number of processed bottles at the end of the line and the number of pallets completed in order to analyze the performance and efficiency of the line. For the modelling and simulation of this line was used the Packaging Panel of the software.

Keywords: Packaging line, Modular Modeling, Beverages, Bottle Processing, Simulations, Process Control, Performance Analysis

1. Introduction

Companies that produce beverages have developed packaging lines in their factories that consists of a series of processing steps, depending on the type of beverages produced and type of bottles. Beverages produced and processed can be water, juices, beer, energy drinks and some types of milk products like yoghurt. The recent advancements of this process goes towards automatization, robotization, computer control, sensor control, and simulation using specialized software as an initial part of design and planning. A model developed in the software is a schematic and modular representation of the packaging line, which comprises of main constituent components, and also includes the flow and direction of the products, connects the components or modules, and identifies the interaction between them. The model needs to have defined the main operations of the process that represents the behavior of the packaging line. It should give the

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results of the Key Performance Indicators (KPI), identifies the problems, gives the options for various testing's and corrections, enables the analysis for improvement, control, redesign and optimize the packaging line [1], [2]. In this paper, we will use the methodology of modeling and simulations of one type of the beverages processing and packaging line and analyze the design, functionality and performance. The line is mounted in a local company in Kosovo.

Objective of this research is to emphasize the importance of creating the model of the packaging line prior to its implementation, so that bottle-packaging companies have a view how their processing line will look, how it will work, what is the performance, the ways it can be improved and analyze feasibility.

The software we used is Arena Simulation [3], with its Packaging Panel [4] (Fig.1). Modules are building elements that can be configured, programmed and regulated in the model [5]. An entity is the product or package, moving in the process. The Packaging Panel (Fig.1) contains a collection of modules or objects specially designed to perform high-speed simulations of production systems, processing lines, logistic systems, internal transportation, material handling, etc. [6]. Each module defines the logic, process, properties, data, animation, and/or statistics collection for a particular element in a model.

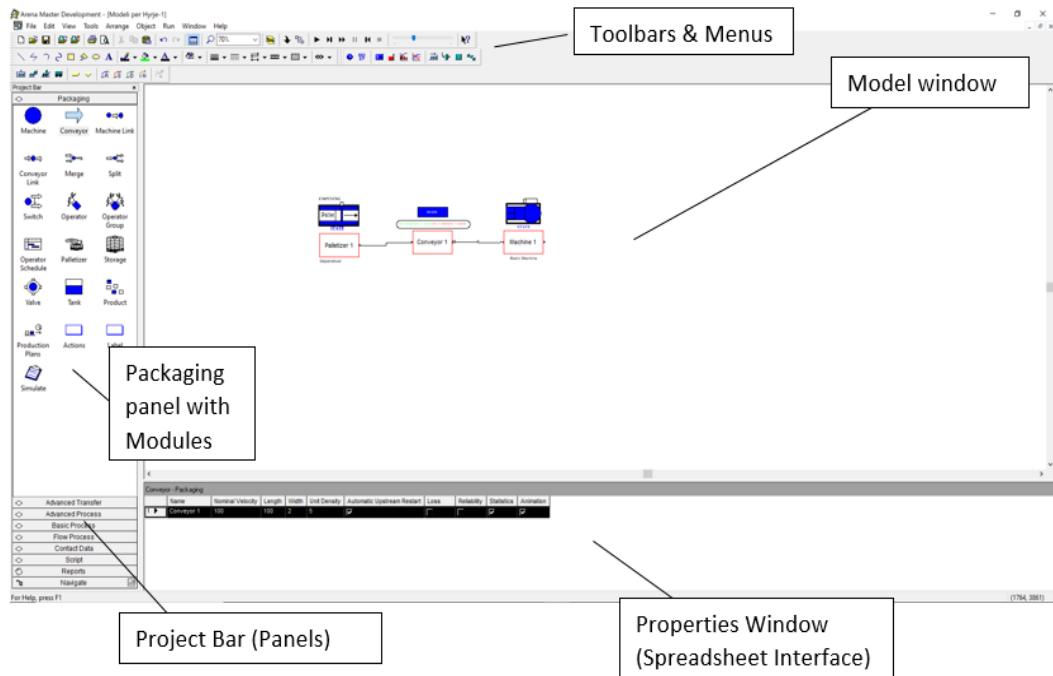


Fig.1. Arena Simulation software - User interface with an example of the model developed [4]

The Packaging line configuration consists of several steps with their units (Fig.2) [7], [8]:

- *Depalletizer* - The device that unwraps bottles and prepares them to enter the line. Unwrapping can be done by the operator or automated.
- *Belt Transporter* or *Conveyor* – The transportation device for carrying and transferring bottles from one unit to another. There can be more than one units.
- *Filling Process* – Generally consists of tank filled with beverages, valves, and filling machine that can have several filling heads. Usually, the rotating table is used to carry bottles during the filling. This is called rotary system.
- *Capping* – The process of sealing bottles with caps. Main device is *capping machine*, that can put a cap in more than one bottle at once.
- *Labeler* – Process that sticks labels on the bottle. Main device is *labeling machine*, that processes more than one bottle at once. There can be more than one labels stucked in the bottle. Also, printer can be used for labeling.
- *Paletizer* - The machine or device that wraps bottles in group, and prepares them for exiting the line, to the pallet.
- *Storage* – The facility used for storing the goods, in this case unwrapped (Entry Storage), or wrapped bottles (Exit Storage), and pallets.

In the Packaging line, there can be also washing and rinsing machines [9], [10]. For this case, we will neglect it, considering that bottles are entering clean.

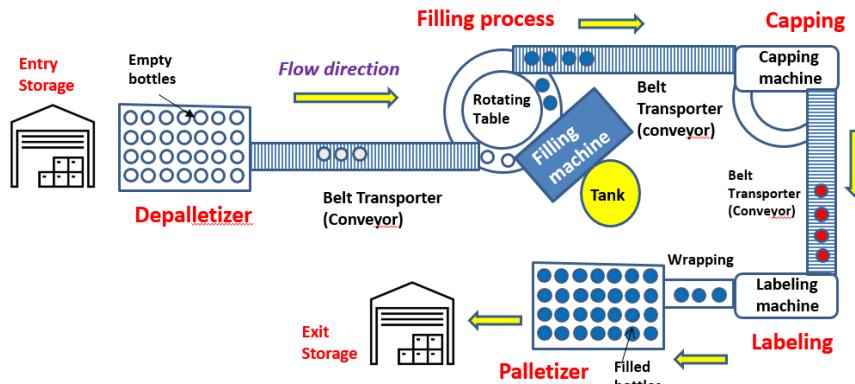


Fig.2. Packaging and processing line of beverage bottles

2. Literature Review

Literature review contains contributions and publications of authors regarding the modelling and simulation of bottle packaging and processing lines. Authors have given their contributions with models using Arena simulation, and other software, with various line configurations.

Authors G. Dereje et al. [1] developed a simulation model for the successful bottling and packaging line for returnable glass bottle Production line by using

Arena simulation software. The aim is to eliminate the bottlenecks in production line and to provide optimal performance by applying Effective Preventive Maintenance Strategy. Authors Said M. and Ismail N. [2] in their paper have developed a simulation model of the real production line layout and a new improved production line layout and analyzed the improvement of indicator values of new model compared to real model. The key performance indicators were evaluated using Arena software. Author Jorge V. Villar [7] in his project presents an automatic control software that controls a beer bottling plant using PLC and industrial control. The aim is to manage bottles flow along the production line as well as keeping stocked all the machines involved in the process of filling, labelling and capping. He also implemented SCADA control. Author Teklay Araya [8] in his thesis conducts a research of the bottling production line, efficiency losses, OEE analysis, improvement by using simulation modelling, collection of primary and secondary data from the case company through direct observations and check sheets. In addition, he implements tools such as OEE, Pareto chart, fish bone diagram, and Arena simulation in analysis and improvement process. A.H. Abdul Rasib et al. [9] in their paper present the production smoothness improvement through ARENA simulation application for the food industry. They research a real case study to construct simulation model in ARENA and analyze it through simulation. N. Basán et al. [10] developed a model of the packaging line by using the Discrete event simulation (DES) tools provided by the SIMIO simulation software to optimize the design and operation of a complex beer packaging system. A. N. A. Ahmad et al. [11] in their paper study the importance of conveyor layout to increase the production output based on simulation analysis using ARENA simulation software and to analyze work process by creating an overview of the movement of a process with more accurate and precise simulation results. A. Grassi et al. [12] in their paper present a developed theoretical model of a line with two machines and a buffer, which is a simplified version of a real packaging line from Tetra Pak company. The two-machine finite buffer problem is modeled as a continuous time, mixed state Markov process and then a simulation for the two-machine line is presented. Authors K. Vasudevan et al. [13] in their paper present the software selection methods, tools & techniques for the creation of a model for a high-speed bottle manufacturing line. Simulation models are used as three distinct case studies. and were built using Enterprise Dynamics® software. Author J. Kim [14] in his paper compares reusable to expendable packaging systems in a total cost analysis. ARENA software is used to calculate the number of reusable plastics containers and costs for three international supply chain routes. T. Al-Hawari et al. [15] in their paper present a simulation model built to analyze the performance of a pull type (Kanban) automated production system using Arena Simulation,

with conveyors and three stations: forming station, filling station and packaging station.

Authors achieved to emphasize the importance of prior planning with the help of modelling and simulations, and as a method for optimization of the packaging line. They also used software with hardware programming, like PLC.

There should be more studies in this topic, mainly in the implementation of sensors, improving line control, analyzing different bottle volumes, even canisters. It would be useful to investigate more packaging line configurations due to their specific features. In addition, latest software versions should be used, while they have new options that contributes to advanced analysis.

While there are not many studies published on this topic, this paper is important contribution. To mention few: calculating the final number of processed bottles and number of pallets as main performance parameters, planning the simulation scenario of bottles flow, analyzing bottles dropout, identification of bottlenecks, selection of machine properties, selection of conveyors velocity, results of pallets numbers. In addition, the model developed gives the opportunity for optimizing, working with various bottle volumes and further development of the line.

3. Model of the Packaging line

In the figure 3 is the model of the bottle packaging and processing developed in the software Arena. The line starts from the left and flows to the right, in one direction. The main parts of the model are modules with their symbols, connected with wiring. Other objects are numerical results, and textual explanations. Numerical results are in blue squares. Some symbols of objects, like machines or sensors change the color, depending on their operation.

Key parameters that will be considered for investigation are the number of final processed bottles, number of dropout bottles, number of finalized pallets, conveyors optimal velocity, performance of each processing unit. This will be done in the timeframe of 8 hours, as reference timeframe of one working shift.

The beverage processed and packed in bottles is water. Bottles to be filled and packaged have the diameter 6.5 cm and height 22 cm. The volume is 0.5 liters each. One case has 12 bottles. There are 40 cases in one layer of the standard wooden pallet with dimensions 121.9x101.6 cm [16]. This makes $40 \times 12 = 480$ bottles in one pallet layer. There are five layers in a pallet. In total, one pallet can carry $480 \times 5 = 2400$ bottles with volume of 0.5 liters.

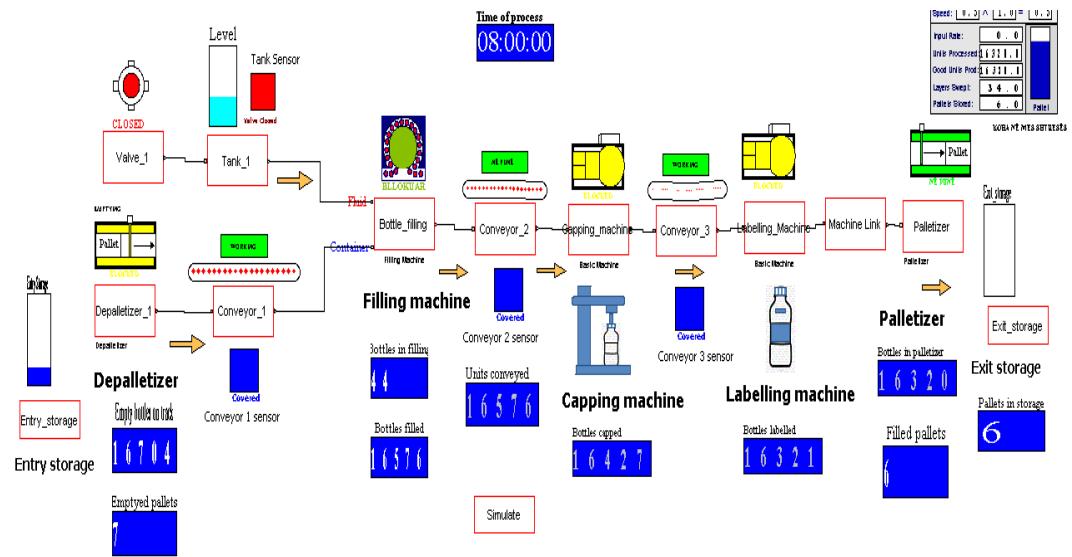


Fig.3. Model of the Packaging and Processing line of beverage bottles

Further, we will describe each unit of the processing line, as shown in Fig.3:

- The first module (unit) in the model is *Storage* (Entry Storage). It is a place where pallets with empty bottles are stored temporary and prepared for depalletizer. The planned number of pallets for this process is 30. The process will run until the number of 30 pallets with bottles is delivered, or the time of simulation is over. The capacity of storage is 150 pallets. The symbol is *Leveler*.
- *Depalletizer* is the second module. The control of the work is defined by the status of the depalletizer, which is visualized with 6 states with corresponding colors in the symbol: Idle, Working (green), Fast (green), Blocked (yellow), Failed (red), Changeover (light blue). In the entry, the speed of putting empty bottles from the depalletizer to the conveyor_1 is 0.5 layers/min (240 bottles/min). Time between layers is 1 min. Number of layer/pallet is 5. Time between pallets discharged is 3 min [17].
- Third module is *Conveyor_1*. This is the first conveyor in the line. Its dimensions are: length 800 cm, width 8 cm. Width is adjusted with bottles diameter 6.5 cm. In the conveyor can move one row of bottles. We adopt there is a 1 cm gap between bottles. In one meter length of conveyor can fit approx. 13 bottles. Velocity of conveyor is 15 m/min. The initial velocity is low, in order to avoid blockades to the next machine. Density is 165 bottles/m², 13 bottles * (100/6.5 cm) \approx 200 bottles. In the conveyor is activated sensor for control of bottles motion [17]. There are 3 conveyors in the model. To simplify the calculations, all 3 conveyors in the line have same dimensions and parameters. The work status of the conveyor is visualized with 7 states with corresponding

colors in the symbol: Idle, Working, Fast, Slow (dark green), Blocked, Failed, Stopped (light blue). Various units don't have the same working states.

a. Sensor in the conveyor is positioned at the 50 % length of the conveyor, and will detect and register the passing bottles. It has two states of work: Covered – when the bottle passes (blue color), Uncovered – when there is no bottle, or bottle moved over (red color) [4], [6], [13].

b. *Conveyor_2* and *Conveyor_3* have the same sensor, with same parameters as the *Conveyor_1*.

• *Valve* and *Tank*. These two modules goes together. Valve is used to open or close the flow of fluid from the tank, and to open the filling of the tank. Tank is the device where beverages are deposited and used to supply the filling machine. The control of the supply is regulated and controlled with sensor.

The valve has the fluid processing rate of 300 liters per minute. The tank has the capacity of 800 liters. Initial level to start delivering fluid is 50 liters.

The sensor will detect if the content of the fluid in the tank is to low or too high. If the level is lower than 8%, it will close the valve for filling machine supply. The tank needs to be filled with beverage from outside. If the level is higher than 95%, it will close the filling of the tank from the outside. Sensor in the tank has two states: Valve Closed (red color), Valve Open (green color).

• *Filling Machine* will fill incoming bottles from *conveyor_1*. It has two input Ports: fluid - coming from the tank, and container – empty bottles coming from the *conveyor_1*.

The output port of the filling machine will transfer the filled bottles to the *conveyor_2*. Parameters of the filling machine are 5 cycles per minute, 12 containers (bottles) per cycle. It has 12 filling heads [18]. Capacity is 80 bottles. The *filling machine* will fill 4 bottles at once in a round table and 20 bottles per minute. There is an important control parameter in the machine in case there are blockades from too many bottles. The machine is programmed to handle only 12 bottles at once. If there are more bottles waiting to enter in the machine, it will increase the Speed Factor of the machine by 30%. Similarly, if there are lower number of bottles incoming, the speed factor can be decreased.

The status of the work of the filling machine is also visualized with seven states with corresponding colors in the symbol: Idle, Working, Fast, Slow, Blocked, Failed and Stopped.

• *Capping Machine*, this machine will put a cap on the filled bottles that are coming from *conveyor_2*. It has one input port and one output port. Parameters of the capping machine are 20 cycles per minute, 4 units (bottles) per cycle. The capping machine will cap four bottles at once in a linear table. In total, it can cap 80 bottles per minute. Control is implemented in the *capping machine* in case

there are blockades from too many incoming bottles. If there is a blockage in the machine, it will increase the Speed Factor of the machine by 30% to process them.

- *Labelling Machine*, will put a label on the filled bottles that are coming from conveyor_3. It has one input port and one output port. Parameters of the labeling machine are 10 cycles per minute, 10 units (bottles) per cycle. The *labelling machine* can put a label in 100 bottles per minute.

- *Machine Link* links the labelling machine with the palletizer. It describes the bottles moving to the palletizer. It has no parameters.

- *Palletizer* is the device or machine that fills the pallets with filled bottles. The speed of transferring filled bottles from the labelling machine to the palletizer is 0.5 layers/min (240 bottles/min). Time between layers is 1 min. The number layer/pallet (layer per pallet) is 5. Time between pallets charged is 8 min.

- Last module is *Exit Storage* (Fig.3). It is a place where pallets with filled bottles are stored temporary. The initial number of pallets is 0. From this storage will be acquired important result, the number of pallets loaded with filled bottles. The capacity of the storage is 150 pallets. The symbol is *Leveler*.

4. Simulation of the model

After describing each module in the model, next step is preparing the simulation parameters. The simulation is planned for 8 hours. This is a basic measuring parameter for the daily performance. During the simulation run, results will be shown in the blue boxes around the modules. Above the model is placed the timing box, showing the process in hours, minutes and seconds (Fig.3).

5. Analysis and results

First, and most important result acquired is the number of bottles processed. Additionally, the number of pallets are acquired in the entry storage and exit storage. Based on the results of simulation, after 8 hours of work, number of empty bottles transferred from depalletizer to the conveyor_1 is 16704. Number of pallets emptied from depalletizer is 6, and the 7th pallet is in the process. Number of bottles filled in the filling machine is 16576. Number of bottles conveyed from conveyor_2 is 16576. Number of bottles capped in the capping machine is 16427. Number of bottles labelled in the labelling machine is 16321. Number of bottles transferred from palletizer to the exit storage is 16320. The efficiency of the line is $16320/8 = 2040$ bottles/hour. Number of full pallets in the exit Storage is 6, 14400 bottles in total. The 7th pallet didn't complete due to the time limitations. The number of bottles in the 7th pallet is $16320 - 14400 = 1920$.

Based on the results, the number of bottles processed at the start of the line is 16704 and at the end of the line is 16320. The dropout is $16704 - 16320 = 384$

bottles. This is a good result, compared to total number of bottles processed. There are no big blockades or bottlenecks in the line.

5.1. Impact of the velocity of conveyors

The first Key parameter to analyze is the conveyor's velocity and its impact on the processing of bottles. Some incremental values of this parameter will be tested in the model to view the results. Logically, the increase of the conveyor's velocity should speed up the process of transferring bottles from one unit to another. This can be implemented easily in practice. The problem that can occur are the bottlenecks and blockades due to high speed of transfer [11].

In the Table.1 are given 4 values of conveyors velocity, and number of bottles processed. These values will be the same in all three conveyors.

Table.1.
Number of processed bottles with various velocities of conveyors

| Conveyors velocity (m/min) | 12 | 15 | 18 | 20 | Increase in bottles (20 - 12 m/min) |
|--|-------|-------|-------|-------|-------------------------------------|
| Bottles from depalletizer | 16196 | 16704 | 17205 | 17423 | 1227 |
| Bottles in the capping machine | 15947 | 16427 | 16907 | 17224 | 1277 |
| Bottles from palletizer | 15840 | 16320 | 16800 | 17215 | 1375 |
| Dropout of processed bottles (Input->Output) | 356 | 384 | 405 | 208 | - |
| Pallets in exit storage | 6 | 6 | 7 | 7 | - |

Looking at the Table.1 vertically and Fig.4, with the increase of velocity the dropout of processed bottles does not decrease significantly. This compared with overall number of processed bottles. Highest dropout is 405, for the velocity 18 m/min, and lowest 208 for the velocity 20 m/min. Regarding the number of dropouts, the conveyor velocity 20 m/min is the best for this Processing line.

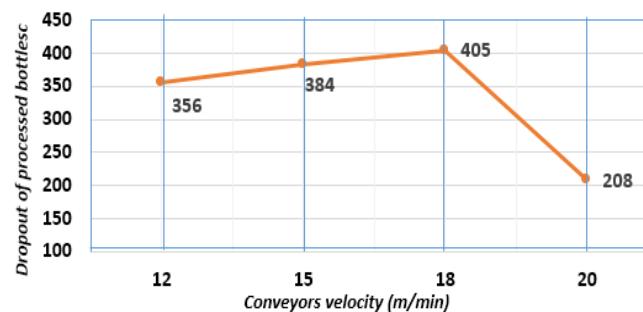


Fig.4. Dropout of processed bottles (Input->Output) based on Conveyors velocity

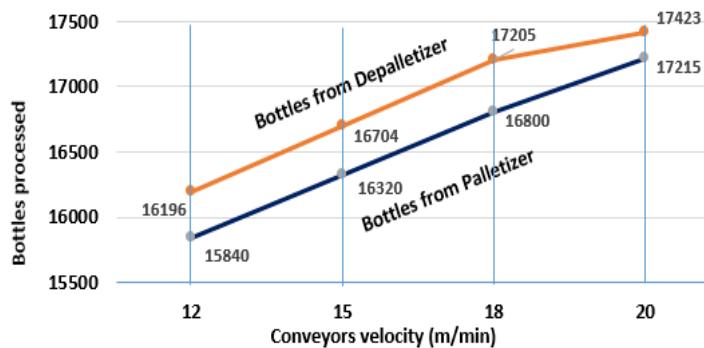


Fig.5. Number of processed bottles In the Input-Depalletizer and Output - Palletizer

In the Table.1 horizontally and Fig.5, are the number of processed bottles in the depalletizer, capping machine and palletizer, with the increase of conveyors velocity. Last column represents difference of bottles between velocities 20 m/min and 12 m/min. In the palletizer, as an output unit the difference is 1375 bottles in 8 hours, or 171 bottles/hour. This increase is 8.6%. It is not a significant increase of processed bottles, compared to the big increase of the velocity from 12 to 20 m/min, which is 66.6 %. In the last line of Table.1 is the number of output pallets in the *exit storage*. It is 6 for 12 and 15 m/min, and 7 for 18 and 20 m/min. Regarding the number of completed pallets, lower number of velocities leaves the 7th pallet incomplete, and higher number of velocities completes the 7th pallet.

Regarding the output pallets, the values of conveyor velocity should be optimized so that the pallets are completed, or the timing of the process should be exactly determined. Overall conclusion is that higher values of velocities does not increase significantly the number of processed bottles. The reason are the bottlenecks and blockades that occur in other units or machines.

5.2. Analyzing the parameters of the filling machine

Key parameters to analyze for the *filling machine* are two main features: cycles/minute and capacity. Initially, from Chapter 3, the values are 5 cycles/minute, 12 containers/cycle, capacity 80. Some incremental values will be investigated to view the results. The values for containers/cycle cannot be changed, while they are physical property of the machine. The number of heads is 12 and cannot be changed, unless we change the entire machine. Values of cycle/minute and capacity are interconnected. If we increase the first one we should increase the second one. The capacity should be equal or higher than cycles/min. Parameters of other units will not be changed from their initial values in Chapter 3. The results are presented in Table 2. There are 3 groups of parameters investigated. According to the manufacturer data [18], bigger numbers of those chosen are not practical for this type of machines.

Table.2.

Number of processed bottles with parameters of the filling machine

| <u>Cycles/minute</u> | <u>5</u> 80 | <u>7</u> 100 | <u>9</u> 120 | Increase in bottles (9;120 - 5;80) |
|--|-----------------------|------------------------|------------------------|---|
| Bottles from depalletizer | 16704 | 17593 | 18081 | 1377 |
| Bottles in the filling machine | 16576 | 17536 | 18016 | 1440 |
| Bottles in the capping machine | 16427 | 17387 | 17867 | 1440 |
| Bottles from palletizer | 16320 | 17280 | 17760 | 1440 |
| Dropout of processed bottles (Input->Output) | 384 | 313 | 321 | |
| Pallets in exit storage | 6 | 7 | 7 | |

Looking at the Table.2 vertically, with the increase of filling machine parameters the dropout of processed bottles is low, compared with overall number of processed bottles. The dropout number is similar, 340 in average, for all three parameters of cycles/minute and capacity. Increase in the parameters does not affect the dropout of bottle processing.

In the Table.2, looking horizontally, are the number of processed bottles in the depalletizer, filling machine, capping machine and palletizer based on the parameters in the filling machine. Last column represents difference of processed bottles between the first and third parameter. In the palletizer, the difference is 1440 bottles in 8 hours, or 180 bottles/hour. This increase is 8.8%. It is not a significant increase, compared to the big increase of cycle/minute, from 5 to 9, which is 80 %, and capacity, from 80 to 120, which is 50%.

In the last row in Table 2, the number of output pallets in the exit storage is 6, for the parameters 5;80, and 7 for the parameters 7;100 and 9;120. Regarding the number of completed pallets, lower number of parameters leaves the 7th pallet incomplete, and higher number of parameters completes the 7th pallet.

Higher values of parameters of the filling machine does not increase significantly the number of processed bottles. The reasons are the bottlenecks and blockades that occur in the filling machine itself and other machines and units. Important to mention for the impact of the filling machine is the increase in the bottles processed compared to the analysis in Chapter 5.1, for the conveyors. Highest values of parameters 9;120 increased the number on the palletizer to 17760. From Chapter 5.1, highest velocity of conveyors 20 m/min increased the number to 17215. It is an increase of 3.1% for the filling machine.

5.3. Analyzing the parameters of the Capping machine

Key parameter of the *capping machine* to analyze is *cycles/minute*. Initially, from Chapter 3, the values of two main parameters are 20 cycles/minute, 4 containers/cycle. The containers/cycle, which is related with the number of heads that is four, cannot be changed, while it is a physical property of the machine, unless we change the entire machine. There are three values of cycle/minute investigated. According to the manufacturer data [19], higher numbers are not practical nor constructed for this type of machine.

Parameters of other units will not be changed from their initial values in Chapter 3. The results are presented in Table 3.

Looking at the Table.3 vertically, with the increase of cycles/minute, the dropout of processed bottles is low, compared with overall number of processed bottles. The dropout number is highest for first value 20 cycles/minute, 384, and lowest for 26 cycles/minute, 94. Increase in the cycles/minute affects lower dropout of bottle processing. The value 26 cycles/minute gives the lowest dropout number 94, which is a good result.

Table.3.

Number of processed bottles for cycles/minute of capping machine

| Cycles/minute | 20 | 23 | 26 | Increase in bottles (26 - 20) |
|--|-------|-------|-------|-------------------------------|
| Bottles from depalletizer | 16704 | 16704 | 16800 | 96 |
| Bottles in the filling machine | 16576 | 16641 | 16800 | 224 |
| Bottles in the capping machine | 16427 | 16556 | 16748 | 428 |
| Bottles from palletizer | 16320 | 16532 | 16706 | 386 |
| Dropout of processed bottles (Input->Output) | 384 | 172 | 94 | |
| Pallets in exit storage | 6 | 6 | 6 | |

Looking at the Table.3 horizontally, the last column represents difference of processed bottles between first and third value cycles/minute. In the palletizer, as an output unit, the difference is 386 bottles in 8 hours. This is an increase of 2.3%. It is a small increase of processed bottles, compared to the big increase of cycles/minute (from 20 to 26), which is 30 %. The increase of processed bottles by increasing the cycles/minute which is 386 bottles is very small compared with the filling machine or conveyors.

Conclusion is that higher values of cycles/minute for capping machine does not increase the number of processed bottles. Capping machine contributes significantly for the bottlenecks or blockades. For this case, the increase in cycles/minute does not improve the efficiency of the capping machine and the line. The only solution is to choose machine with more capping heads.

5.4. Analyzing the parameters of the labelling machine

Key parameter of the labeling machine to analyze is cycles/minute. Initially, from Chapter 3, the values of two main parameters are 10 cycles/minute, 10 containers/cycle. The containers/cycle, which is related with the number of heads which is 10, cannot be changed, while it is a physical property of the machine. The values of cycle/minute will be increased and investigated to view the results. There are 3 values of cycle/minute investigated. According to the manufacturer data [20], higher numbers of those chosen are not practical nor constructed for this type of machine. Parameters of other units are not changed from their initial values in Chapter 3. The results are presented in Table 4.

Looking at the Table.4 vertically, with the increase of cycles/minute the dropout of processed bottles does not decrease significantly, compared with overall number of processed bottles. The value 26 cycles/minute gives the lowest dropout number 69. This is the lowest dropout number in the analysis of the paper, which is a good result.

Table.4

Number of processed bottles for cycles/minute of Labelling machine

| <u>Cycles/minute</u> | <u>10</u> | <u>13</u> | <u>16</u> | Increase in bottles (16 - 10) |
|--|-----------|-----------|-----------|-------------------------------|
| Bottles from depalletizer | 16704 | 16800 | 17056 | 352 |
| Bottles in the filling machine | 16576 | 16800 | 17009 | 433 |
| Bottles in the labeling machine | 16427 | 16731 | 16801 | 374 |
| Bottles from palletizer | 16320 | 16731 | 16800 | 480 |
| Dropout of processed bottles (Input -> Output) | 384 | 69 | 256 | |
| Pallets in exit storage | 6 | 6 | 7 | |

Looking at the Table.4 horizontally, in the palletizer, in the last column, the difference is 480 bottles in 8 hours. This increase is 2.9%. It is a small increase of processed bottles, compared to the big increase of cycle/minute (from 10 to 16), which is 60 %. The increase of processed bottles by increasing the cycles/minute at the end of the line for 480 bottles is small for this machine, compared with the filling machine or conveyors.

In the last row in Table 4, the number of output pallets in the exit storage is 6, for 10 and 13 of cycle/minute, and the 7th pallet is complete for 16 cycle/min. For the value 16 cycles/minute the 7th pallet is completed.

Conclusion is that higher values of parameters of the labelling machine does not increase the number of processed bottles significantly. We can conclude that labelling machine contributes significantly for the bottlenecks or blockades, but less than capping machine. For this case, the increase in cycles/minute does not improve the efficiency of the labelling machine and the line. The solution is to choose machine with more labelling heads.

6. Conclusions

By creating a model and simulation of the bottle processing and packaging line, it is possible to design the system, plan the units of the line, plan the speed of bottles flow, analyze the results of important parameters, increase the performance and identify blockades and bottlenecks.

The objective of the study to model adequately the packaging line that can be analyzed and give good performance was achieved. Based on the results, the modelled line works well while the number of processed bottles did not decrease significantly from the entry to the exit, and there are no high bottlenecks. Other measured parameters give good results too, shown in graphs and tables. Also, the problems that could appear, like bottlenecks and bottles transfer issues were identified and suggested the measures to be taken.

For all three conveyors, nevertheless the velocity, which increased from 12 to 20 m/min, the number of processed bottles at the palletizer did not increase significantly. This means that intentions to increase the efficiency by testing various parameters might not always give great results. This is because the functionality and interconnection between units is not always predictable, nor it is easy to calculate. However, with many simulations and testing's it is possible to find the optimal values of the key parameters. The analysis of the filling machine shows that with the increase of work parameters cycles/minute and capacity the number of processed bottles does not increase a lot at the end of the line, but it is better compared to conveyors and other machines. The analysis of the capping machine and labelling machine is similar, with the increase of cycles/minute the number of processed bottles does not increase a lot at the end of the line. Due to the low increase of processed bottles, these two machines contributes more to the bottlenecks than the filling machine and conveyors.

Based on these analysis and conclusions, development of the Automatic Packaging Line is a complex process that requires prior deep analysis, planning and design. It requires the proper selection of conveyors, efficient machines, efficient depalletizer and palletizer, and some other auxiliary units; precise calculation of the key parameters, and highly important, the control of each unit to prevent the bottlenecks, blockades or slow motion of bottles. The complexity of analysis will increase if there are other bottle types with different volumes to be

processed. It would require more flexible machines and flexible conveyors with adjustable speeds and structure.

R E F E R E N C E S

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