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Study of Operation Process, Production Planning and Forecasting of *Voglyplast Co.*

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Chania, 2018

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Abstract

The increasing competition in business environment, as well as the challenging financial situation in Greece, require an effective and efficient production planning in any company in order to overcome the obstacles and remain competitive. This thesis is conducted at Voglyplast Co., which is a manufacturing company that produces PET preforms, bottles and jars. The main sections of the thesis are the modelling and the simulation of certain scenarios of the production process and the demand forecasting for 2018.

Initially, the Petri Net formalism is used for modelling the production process of fifteen best-selling products, which are divided into three categories according to the characteristics of their production. Then, the simulation of alternative scenarios of the production process takes place and the results that are obtained indicate the potential improvement of the production capacity.

The demand of the following year is based on the past observations of each product. Four different forecasting models are implemented, but the most reliable and accurate with respect to the error measurements is finally chosen.

Finally, in the conclusion, recommendations for the improvement of the operation process are presented and future potential extensions of the present thesis are proposed.

To my grandparents,

Nina and Captain John

Acknowledgments

I would like to express my deep thankfulness to my supervisor George Tsinarakis for his constant help, guidance and support for my Thesis, and also for his motivation and encouragement throughout the elaboration of this study.

I would like to thank Voglyplast Co. and particularly the CEO, the director, the production manager and the employees for providing an opportunity to perform my Thesis at their facilities, as well as confidential information and advice.

I would also like to express my deepest gratitude to my family for their unconditional love and support all these years. Without them, I would neither be the person I am today nor I would have achieved my goals.

Last but not least, I owe my deep thankfulness to my friends for believing in me, enlightening my life and sharing all these unforgettable moments with me.

Special thanks to every single one for triggering my mind with their euphonious sounds that help me shape my life path.

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Chapter 1

1 Introduction

1.1 Motivation and Background

Nowadays, the highest exploitation of the resources and the capabilities of the production are inevitable and crucial for the development and the survival of the companies, in a modern business environment, where the competition is high and the pressure for reducing time and cost of production is very intense. These circumstances make necessary the development of the production planning, which has been proved vital for maintaining the competitiveness and the efficiency of a company. The study of problems related to industrial and production systems is a popular subject of analysis in the scientific community, since even a slight development or upgrade can lead to great benefits. The great range of applications in the production systems, as well as the fact that many problems cannot be solved analytically due to their complexity are two important factors that contribute to the popularity of the field of production systems and operation processes.

Production planning of operation process takes place in a manufacturing company and ensures that the levels of raw and other necessary materials and products, human resources and production capacity are satisfactory and they can provide the production of the final product on schedule. An effective planning and forecasting procedure result in great profits for a company, regarding to the sufficient utilization of the previous resources. Nevertheless, the element of uncertainty that is present in every aspect of the global market and economy, including the operation of a business, does limit the elaboration of an effective and realistic study. For improving the production planning, mathematical forecasting models for the future demand, in combination with simulation tools were developed and applied.

Additionally, the field of packaging and especially plastics, that constantly grows, in combination with the operation process in a manufacturing company with heavy machinery was a determinant factor for the elaboration of this case study.

1.2 Objective of Thesis

This thesis presents the study of a manufacturing company of PET products in Evia, Greece. First of all, the production and operation process, the time delays, the flow of raw materials and products within the production and the ways of interaction were recorded. Then, the production line of each product (preforms, bottles, jars) was modelled using Petri Nets and the models obtained were verified through simulation of fundamental scenarios with respect to all the limitations (physical, technological, financial).

Thus, the operation process was approached as a combination of many parameters that take specific values and features which interact with each other.

The demand forecasting in terms of four-month periods for the next year, for each product, was conducted with the application of appropriate mathematical models. Then, the most effective and accurate forecasting method was finally selected in cooperation with the executive members of the industry.

1.3 Solution Methodology

The fundamental tool that was used in this thesis for modelling and study of the production systems is timed Petri Nets (PNs) and their arc extensions. PNs combine a simple graphical environment, which increases the capability of understanding and state controlling of the system that is analyzed, with a complete mathematical framework that simplifies the use of the models, with respect to the qualitative and quantitative analysis of the represented systems. Moreover, the models that are implemented with PNs are more compact in comparison with others that are created with different modelling tools, such as finite-state automata. Note that PNs include a complete collection of analysis tools and in combination with other tools can satisfy more complicated needs. Finally, quantitative forecasting mathematical models are applied for every single product of each category that is produced in 2018, by exploiting the sales data of the last six years 2012-2017.

1.4 Contribution and Aim of Thesis

The idea of elaborating this case study came up after the realization that production process must be become more efficient, since the company is growing constantly, but the current analysis is based namely on the experience of the executive members. In cooperation with the managers and the employees, all the necessary information was gathered, so as to be the basis for the following study and planning of the operation process. Many data that were gathered are confidential and they are related to the suppliers, the customers, the dynamic of the system, the finances and the individual production processes.

The data that correspond to the placement, the interaction, the characteristics of the operation of machines, capacity of storages, in combination with the capacity of production, result in the creation of models that represent the operation process. The results of the simulation of these models, as well as the results of the demand forecasting for 2018 will make possible an improved production planning.

1.5 Outline of Thesis

This thesis report consists of six chapters,

Chapter 1 – **Introduction**, this chapter briefly describes the background of the case study which states the problem area, objective, solution methodology, the aims and the outline of thesis.

Chapter 2 – **Theoretical Background**, where the principles of Petri Nets (PNs) are introduced. The clarification of PNs seems to be necessary, since PNs are used in order to implement the models and simulate the production process. Moreover, this chapter describes the fundamental knowledge about modelling, simulation and forecasting, as they are analyzed in this thesis.

Chapter 3 – **Presentation of *Voglyplast Co.*** Initially, the company and its history were briefly described. Then, the departments of the company and the equipment are presented. The presentation of the products and the raw materials follows. In the next section, the production process including the flow charts, is analytically described.

Chapter 4 – **Modelling of the production process.** This chapter presents the modelling of the production process thoroughly. The process of modelling is analyzed, and the definition of each node, as well as the connection between them are presented. Then, alternative scenarios for the operation of the industry are created, based on realistic improvements on the production equipment that is used. Finally, the results obtained from the simulations are presented and evaluated.

Chapter 5 – **Forecasting.** This chapter presents the demand forecasting for 2018, using the data of the previous six years. The forecasting methods and the error measurements are analyzed thoroughly. Finally, the most accurate and effective forecasting technique is selected and the demand forecast is presented.

Chapter 6 – **Conclusion.** The conclusions drawn in this thesis are summarized in this chapter. Finally, the recommendations and the potential extensions of this thesis are introduced.

Chapter 2

2 Theoretical Background

2.1 Modelling

System modelling is a process that represents the actual available data of a system and aims at the reproduction of the physical system by simulating on a computer, applying mathematical models or researching in a laboratory. Moreover, it aims at an easier understanding, definition, visualization and quantification of the physical system. A model is a simplified representation of the system, which contains logic and/or mathematical correlations that describe the state, the entities, the characteristics, the sets, the events, the activities and the delays of the system. Alternatively, a model is defined as an algorithm or a set of equations connected to a set of data values (i.e. initial conditions and values) in order to represent the essential behavior of a system, a process or a phenomenon [1].

System modelling is the first step for studying the behavior of a system under different circumstances (different values of parameters or input functions). Additionally, a model can be used for the design or re-design of that system, for the development of a controller which ensures that the behavior of the system satisfies the defined limitations and requirements, for searching, verification and optimization of the system according to particular objective functions and for the qualitative and quantitative analysis of the system behavior as well. The major advantages of modelling are the study and the prediction of system behavior, as well as the efficiency under extreme operational circumstances, when study and prediction cannot be achieved (due to troublesome situation or high cost) or in case that the physical system is not available.

As stated in the first paragraph, models are simplified representations of the corresponding systems, since the representation of the set of characteristics, activities, processes and interactions between the components would result in as much complicated models as the physical systems. Consequently, that models would not be useful for further study and prediction of behavior of the system, since the current analysis tools would be useless. Additionally, this would require much time and resources because of its significant computational complexity. The real challenge of modelling is finding the necessary amount of principles, events and processes that complete the complexity of the system, which in combination with well-defined assumptions depict efficiently the behavior of the system. Moreover, the needs of modelling, analysis and control have a great impact on whether a system should be hybrid or not [1].

2.1.1 Modelling Process

Bandler and Grinder developed the process of modelling, which is summarized by the following steps [5]:

1. Identification of the components of model
2. Information collection of correlations, priorities, connections, ways of interaction and operation, requirements of mutual exclusive states and resource sharing
3. Modelling
4. Verification of model (in comparison with the actual system for a direct model verification)
5. Modification of model, if it is necessary, and definition of the initial conditions

These five steps do not correspond to a linear process, since each one feeds the following steps and gives a feedback to the previous ones. Thus, it is possible to have many repetitions of the algorithm, until the model takes the final form. Moreover, the final form of the model is revised every time that new data are gathered or when the behavior of the model differs significantly from the one of the real system.

Modeling of systems consists of two steps; the step of modelling and the simulation step. During the first one, structure and rules are defined, so as the states can be described sufficiently. After that, the analysis of the model by appropriate tools and its features are defined, so as to avoid results that worsen the application and the effectiveness. During the simulation step, the model is evaluated, in order to verify if its behavior corresponds to that of physical one. Finally, although there can be some changes, the fundamental structure is unchanged [1].

2.2 Petri Nets

2.2.1 Properties, Futures and Applications of Petri Nets

Petri Nets (PNs) were originally developed by Carl Adam Petri in 1962 and they correspond to a theoretical model of information flow. Considering the effort of finding simple and effective methods for describing and analyzing the flow of information and the system control, definitions, properties and features have been developed, as well as analysis tools and techniques which are related to PNs [4].

PNs are powerful graphical and mathematical modeling tools for systems defined as concurrent, parallel, distributed, asynchronous, non-deterministic or stochastic. The graphical representation has been proved crucial, for the reason that the models consist of a small amount of components, so, they form a modelling language, which can easily be comprehensible [4]. PNs, as a graphical tool, can be used as visual and communication technique similar to those of flow charts, block diagrams and networks. PNs are more appropriate for representing, in a natural way, logical interactions between the components and the activities of a system, than other representation techniques. In addition, Petri Nets implement the static and dynamic features of a physical system by combining the definition of the distributed state with a rule of state-transition. As a result, they are a very effective analysis tool for complicated systems, given the fact that they are computing tools that allow simulation as well. As a mathematical tool, PNs are applied to the determination of algebra formulas, conditional formulas and other mathematical models that define the system behavior [6]. Moreover, PNs are a powerful way of communication between theoreticians and practitioners, as theoreticians can make their models more realistic and practitioners can improve their models to be more methodical [7].

PNs, that are applied to certain systems which include discrete events, contain mutually exclusive tasks, mutual resources allocation in a system, restrictions about prerequisite conditions and sequence of events. Additionally, the most important application of PNs is presented on modelling, behavior analysis, performance evaluation, confirmation of structural properties, simulation, scheduling and real time control [7]. Petri nets are used to identify factors that limit the efficiency of a system, while they suggest modifications and improvements that correspond to the optimization of the system behavior [8]. Moreover, they can simulate the dynamic evolving and parallel processes and allow the hierarchical modelling.

The features of the scientific fields where PNs have been applied vary. Particularly, there is a great variety of application in the fields of computer engineering and information technology. For example, PNs are performed to solve problems related to computer science and informatics, such as modelling and analysis of communication protocols, distributed-software systems, distributed-database systems, compiler and operating systems, local-area networks, concurrent and parallel programs, data-flow computing systems, multiprocessor memory systems, fault-tolerant systems, asynchronous circuits and structures, office-information systems, programmable logic and VLSI arrays, telecommunication networks and digital filters [7].

Furthermore, PNs have been used for the modelling and the evaluation of the efficiency of multi-server queuing systems, modelling and analysis of production systems, supply chains, energy systems, chemical industries, industrial automation, traffic control systems, scheduling and control problems of railways, military control systems, positioning systems, robotic control, simulation of multiple drones and project management.

Nowadays, the application of Petri nets has grown to fields other than the traditional engineering. For instance, they are applied to analyze human behaviors under specific circumstances, decision making models, neural networks, medicine, biotechnology [9], modelling of biological processes, biochemistry and modelling of ecological systems and environmental topics [10].

2.2.2 Ordinary Petri Nets

Ordinary Petri Nets (OPNs) are the fundamental model for all the versions and extensions that were developed afterwards. The initial model does not include connections with respect to time, but it represents the sequences of transitions of discrete events and the logical connections and interactions between the components of the system. The sequence of the firing of the discrete events in a system that has been modelled with PNs, is enabled from the net structure and leads to non-determinism during its operation.

2.2.2.1 Components of Petri Nets

A Petri Net is an oriented graph that consists of two types of nodes; the places and the transitions. A set of tokens represented by dots, resides in places and travels along the arcs by the occurrence of transitions. Graphically, tokens are represented by black dots (•) and they do not appear independently on the net, as they interact with both types of nodes.

Places describe the conditions (states) and the number of tokens of the system (resources) and they are depicted by circles (◯). They are the passive components of the net and they can store materials (i.e. pieces in machines or buffers) or intangible values (i.e. information). Places illustrate the distributed information of a complicated system [11].

Transitions, which are depicted by bars or rectangles (■), represent events that may occur at the system and their occurrence (firing) changes the state of it. A transition illustrates an activity, a process, an event, a logical condition, a transmitter or a processor [12]. Transitions refer also to services and they are able to produce, transfer or modify tokens. Places and transitions constitute the static structure of a Petri net, whereas tokens define the dynamic state of a system.

Both types of nodes are connected through directed arcs, which connect a place to a transition or the reverse, whereas arcs cannot connect the same type of nodes. Arcs represent the physical connection, right of access, logical connection between places and transitions or need of resources. Additionally, they define the priority of enabled transitions or the order of them. Moreover, each arc corresponds to a positive integer number that shows the multiplicity of its weight. In case there is no number labeled on an arc, then the weight is considered as one. In Ordinary Petri Nets, each weight is equal to one [1].

Tokens are stored in the places of net, while they travel via arcs, and their flow is controlled by transitions which are fired whenever tokens are located at specific places. If a place contains a lot of tokens, then the number of tokens is labeled on them. Tokens in a place represent the availability of a resource, the state of a resource (i.e. if a machine is available or not), assumptions or signals for inputs and outputs. The weight of an arc corresponds to the number of tokens added at the input place (or places) or removed from places, with respect to the enabled transition [25].

2.2.2.2 Formal Definition of Ordinary Petri Nets

An OPN is an oriented graph that is determined by a set of five components: $\boldsymbol{PN = \{P, T, I, O, m_0\}}$, [1], [7]

where:

- $P = \{p_1, p_2, \ldots, p_{np}\}$ is a finite and not empty set of places
- $T = \{t_1, t_2, \ldots, t_{nt}\}$ is a finite and not empty set of transitions

The intersection of place and transition sets corresponds to the empty set ($P \cap T = \varnothing$), whereas the union of these sets defines the $\boldsymbol{V}$ set of net nodes $P \cup T = V$

- $I : (P \times T) \rightarrow N$ defines the table of input events that corresponds to the set of arcs with direction from places to transitions

- $O : (P \times T) \rightarrow N$ defines the table of output events that corresponds to the set of arcs with direction from transitions to places

The ***A*** set of arcs is determined by the equation: $A = I \cup O$ and is represented by the set of non-negative integer numbers.

- m_0: the initial marking (condition) of PN. It defines the initial allocation of tokens in the places of the net (the number of tokens in each place)

2.2.2.3 Transition Enabling and Firing

A transition can fire, only if the event takes place (the transition is enabled). In ordinary PNs, a transition is enabled when all the input places contain at least one token. Given that, $t_i \in T$ is enabled if $m(p_i)>0$, for every $p_i \in P$ there exists $I(p_i, t_i) = 1$. In general, a transition is enabled when all input places contain a number of tokens larger or equal to the number of the corresponding arc weight that connects the input place with the transition. As a transition fires, tokens of each input place are removed and tokens are added to each output place, according to the arc weight of each connection. The number of tokens that are removed from the input places is not always equal to the number of tokens added to the output places. This process is called also ''token game'' [7].

In some cases, even though a transition is enabled, it may not fire, for example when more than one transitions have one mutual input place that consists of only one token. This phenomenon usually takes place at a problem of resource allocation. Figure 1 shows the way that tokens are distributed in a simple PN, when a transition fires.

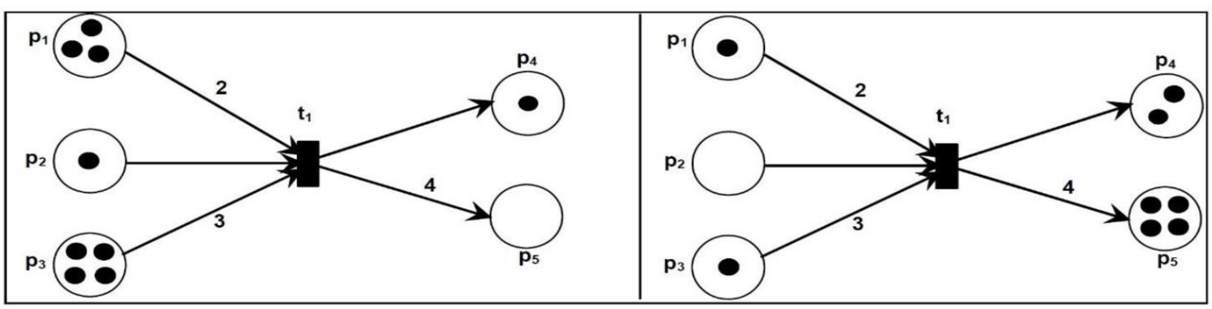


Figure 1. Example of PN: a) before, b) after the transition firing [1]

A transition without any input place is called a source transition, as it feeds the system with tokens and at the same time, it does not consume any existing token. For example, this phenomenon corresponds to events that cannot be controlled, such as breakdowns or arriving orders in a system. A transition without any output place is called a sink transition and consumes tokens, while it does not produce new ones. This phenomenon corresponds to a system that represents a situation of final products which are removed in order to be delivered to the customers [7].

2.2.2.4 Marking of Petri Nets

The state of a PN is described each time by its marking, which assigns a non-negative integer number of tokens to each place. Marking (*m*) of a PN is a vector with size equal to the number of places in the net. The initial marking determines the markings of the following firings. These markings are described as $\boldsymbol{m_i}$, where index $\boldsymbol{i}$ is a positive integer number that denotes the ascending order of the current firing. When a transition $\boldsymbol{t_j}$ of a PN is enabled and the marking of the current state is defined as m_i, the new marking obtained is determined by the following formula [1], [26]:

$$m_{i+1}(p_i) = m_i(p_j) + O(p_j, t_i) - I(p_j, t_i) \text{ , for } j = 1,2, \dots , n$$

Where:

n: quantity of places in the PN

Marking $\boldsymbol{m_{i+1}}$ is said to be reachable from the initial marking $\boldsymbol{m_i}$. The state transition from $\boldsymbol{m_i}$ to $\boldsymbol{m_{i+1}}$, due to the fact of the firing transition $\boldsymbol{t_j}$, is described as: $\boldsymbol{m_i} \xrightarrow{t_j} \boldsymbol{m_{i+1}}$

2.2.2.5 Fundamental Dynamic States Modeled by PN

The fundamental states that are presented during the modelling of a system, which contain discrete events, are sequentialism, concurrency, mutual exclusion and synchronization. Deadlocks and conflicts are two more ordinary states of a PN.

Sequentialism corresponds to a net that contains two transitions, where the output place of the first transition is the input place of the second one. As a consequence, the second transition cannot fire, unless the first one fires previously. Concurrency takes place when two transitions are enabled and they do no interact with each other, thus, they can fire simultaneously. Mutual exclusion is related to the existence of mutual resources in a system. It takes place when two transitions are enabled simultaneously, but they cannot fire due to the fact that they have the same input place that contains a single token. If one transition fires, then it does not allow the other transition to be enabled, because it contains at least one empty place. Mutual exclusion is a case of conflict, when the selection of the transition that will fire is based on different criteria, such as priorities or marking of the system [7]. Synchronization is presented when a transition consists of more than one input place. This transition will fire only when there are tokens in every input place. Typical example of synchronization is the assembly in a production system. Figure 2 presents the states that have been described.

Deadlock appears in a PN, when it reaches a state that none of the transitions cannot be enabled and fire. Consequently, that leads to the termination of the PN. It is an adverse situation that occurs due to wrong planning or design, so a redesign of a part of the system or model is necessary. On the other hand, there are some cases, such as the study of specific number of consumers in a system, where this is accepted [13].

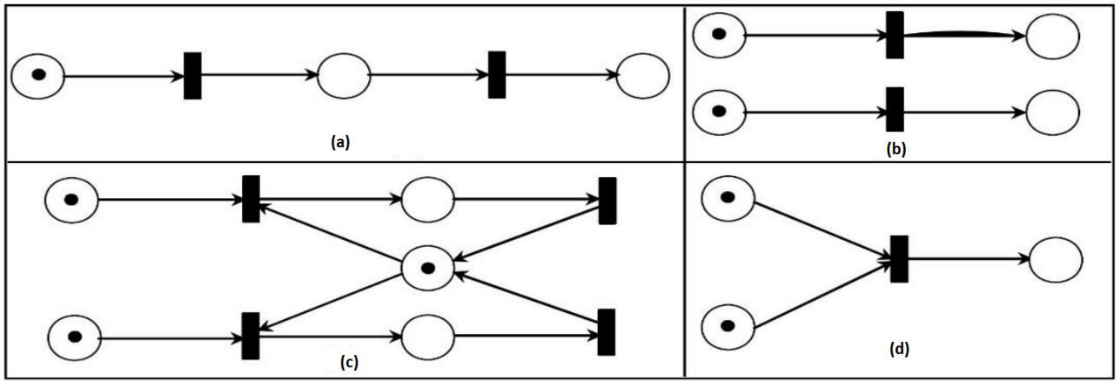


Figure 2. PNs representing a) sequentialism, b) concurrency, c) mutual exclusion, d) synchronization [1]

2.2.3 Petri Net Extensions

In this section, the PN extensions, which are applied to this study or other production systems, are presented. Particularly, the properties and the features of timed Petri Nets are defined and described, in addition to the extensions of arcs that can be used in combination with the initial model or its extensions.

2.2.3.1 Timed Petri Nets

Timed Petri Nets are implemented with respect to the quantitative analysis of the efficiency and the evaluation of reliability of the systems, as the time goes by. The introduction of time parameter in timed PNs is performed by the time delay of nodes. Even though time delays can be applied to both types of nodes, it is recommended to be applied either to places or transitions. In this case study, time delay is applied only to the transitions [14]. Consequently, these PNs are called ***t***-timed Petri nets. The time delay corresponds to duration of the moment when the transitions is enabled until it fires.

A timed Petri net is defined by the following six components:

$$TPN = \{P, T, I, O, m_0, D\}$$

The first five components are the same as those that were described at the Ordinary Petri Nets. Parameter $\boldsymbol{D}$ denotes a vector which consists of $\boldsymbol{m}$ components, represents the delays of transitions and is defined by a set of non-negative real numbers (0 , ∞). Delays may be consistent (deterministic PNs), random values, i.e. they follow exponential or uniform distribution (stochastic PNs) or they can even be formulas of places in the net.

The firing transition is completed by two successive events. Time between those two events may be zero, so the transition is direct, or it may be a non-zero value, so the transition is enabled with a delay that is called time delay. For better distinction, direct transitions are described by a black bar (■) and timed transitions are described by a white bar (▭). Tokens are removed from input places during the first event and are placed to output places during the second event [15], [16].

For example, fixing a machine, starts with the event of «start of fixing» (start of firing) and ends with the event of «end of fixing» (end of firing) [26].

Properties and analysis tools of timed Petri nets are the same to those of Ordinary Petri Nets. However, analyzing a timed PN as a corresponding ordinary one, will lead to wrong conclusions, because of the fact of not taking into account the time parameter.

2.2.3.2 Arc Extensions of Petri Nets

Usually, the set *A* that contains the arcs of a PN, is divided into two subsets; the subset of ordinary arcs and the subset of other types of arcs (extensions). Two of the most popular types are the activator arcs and the inhibitor arcs [17]-[20]. The main features are the following: their direction is only from a place to a transition, never reverse, and the tokens do not travel along them. Specifically, they are used in order to enable or block the firing of a transition, based on the existing tokens located to certain places.

- An activator arc with weight ***W*** and direction from a place p_i to a transition t_j, allows t_j to be enabled and fire, only if:
$$m(p_i) \geq W$$
- An inhibitor arc with weight ***W*** and direction from a place p_i to a transition t_j, allows t_j to be enabled and fire, only if:
$$m(p_i) < W$$

Normal arc is illustrated as simple arc (⟶), activator arc is depicted by a dashed line arc (⇢) and inhibitor arc is illustrated by an arc with a circle at the end of it (⊸).

It should be noted that in case a PN is k-bounded, activator and inhibitor arcs can be replaced by equivalent structures of ordinary PN [21]. As a consequence, the new model will be very complicated, since the replacement of an arc requires a complete structure of an ordinary PN. The arc extensions are very helpful to illustrate priorities and solve conflicts between the transitions.

2.2.3.3 Advantages of Petri Net Application

This section presents the major features of PNs and their advantages in comparison with other modelling techniques [11], [22]-[24]. PNs are a well-defined graphical and mathematical form of modelling, on the contrary to other techniques where only one of these properties is well-developed. Both of these features are essential, since the development process requires the use of graphical and algorithmic tools. The graphic environment has a great impact on a better comprehension, while the mathematical features help the determination of formulas and the simulation of the models that are performed. Simulation is the most important tool for evaluating the efficiency of PNs.

The fact that PNs represent effectively all the important features of discrete event systems with the interaction of their components, is responsible for the great response of the scientific community to the PN application. This interaction corresponds to the phenomenon of concurrency, synchronization, mutual exclusion, resources allocation, interaction between processes, randomness, deadlocks and conflicts.

More precisely, the elements of PNs (places, transitions, arcs) describe the structure of a system, while the tokens represent each time the dynamic state of this system.

There are many extensions to the initial model that improve the ways of its representation. These extensions allow more extended quantitative analysis of a system (timed PNs), representation of continuous or hybrid systems (continuous or hybrid PNs), more efficient representation of a system by connecting places with different types of tokens, where each type of token is related to different types of data (high-level PNs, i.e. colored PNs), representation of uncertain marking (abstract PNs), external controllers to effect the marking in net (controlled PNs), representation of conditional statement (PNs with arc extensions) and creation of a PN where a net corresponds to a token of another net (object-oriented PNs). Moreover, PNs are suitable for hierarchic system modelling, due to the fact that a place or a transition can be replaced from a subnet, so as to provide detailed description of some elements (hierarchic extensions to PNs).

The state transition of a PN is defined by the token flow in this net. In other words, a limited PN, with respect to the size, can represent a great amount of different states and initial features (m_0). This does not occur to other modelling techniques, such as finite-state machines or finite-state automata that represent a finite set of states (each state is represented by a node) and they are modified in response to the change of information of the initial states. In addition, finite-state automata have been proven to be insufficient for the description of parallel processes, whereas tokens in PNs can represent simultaneously the state of multiple components. That is, finite-state automata represent the state of the total system on a specific moment, while PNs describe the sates of each component independently. PNs are the most appropriate modelling tool for the representation of systems with repetition structures and flows. The use of verbal descriptions or mathematical formulas on finite-state machines makes the understanding of models more difficult for non-experts. On the contrary, the simple graphical representation of PNs that performs visualization of the state flow in a system and the detection of the interactions between the components, corresponds to a better comprehension from non-experts. Besides, the qualitative and quantitative analysis, which can be applied to systems that have been modelled with PNs obtain more essential results and their utilization can be combined with a great variety of tools and applications.

PNs show great advantages over Markov chains as well. The number of places and transitions increases linearly in PNs, while the number of states to corresponding Markov chains increases exponentially. Moreover, the use of fundamental subsets during the design of a PN allows the easier modification and extension, if it is necessary. In case of Markov chains, even the smallest modification of the system, requires the determination of all the states in the system. Note that Markov chain of a PN is created automatically with the application of reachability graph and can be used for further analysis of the system efficiency.

The fact that more techniques have been developed for the analysis of the properties (reachability graphs, coverability graphs) that correspond to a model is one more advantage. The most important is that a great variety of software programs for design, simulation and analysis has been developed. These software programs are applied to different categories of PNs and many of them are available online. The application of PNs, in combination with the reachability of fundamental subsystems, allows easier modification, upgrade and extension to parts of models that have been developed, without requiring the change of the whole model.

Petri nets allow the implementation of supervisory control strategies for the elimination of dangerous states from the system operation. There are two types of supervisory controls based on PNs; the mapping supervisor, where the control strategy is computed from a real time controller, as a feedback function of PNs marking and the compiled supervisor, where the control strategy is illustrated on the net structure.

2.3 Simulation

Simulation was firstly introduced at the field of scientific research as a study technique for the results obtained from the interaction with a phenomenon without interfering to the phenomenon itself. Simulation is performed in order to study and understand the fundamental principles of the operation of many natural, biological and social processes. Specifically, simulation is the imitation of system operation or process evolution through time by using a computer [27]. A System or a process determines the set of elements that evolve and interact according to rules, which are defined by mathematical or logical relations and correspond to the model of the system. If these relations are simple, then the solutions may be closed-form and model is solved analytically. However, when the systems are described by complicated models and large vector of states, the analytic solving is impossible. Numerical methods, such as simulation, and numerical analysis, are applied to these systems. Simulation is recommended for the development of a model on a software application, as well as for the set-up of an experiment that records the state of a system in successive moments, which illustrates in that way a potential evolution through time. The state defines the set of variables that hold the necessary information for the system description.

Simulation is applied to:

- Analysis and planning of production systems (industry)
- Stock control (industry, business)
- Analysis of traffic control systems (air traffic, road network)
- Analysis of customer service (banks, hospitals, telecommunications)
- Evaluation of decision making in uncertainty (investments, stock market, marketing)

Simulation evaluates the effectiveness and the efficiency of a system with the purpose of an optimum designing and planning, before it is even created. Moreover, it aims at a lower cost and at a faster and less dangerous representation of the reality in a computing environment.

2.4 Forecasting

Forecasting is the process of predicting a future value based on past and present data and trends. For an accurate forecasting procedure, the data that are used should be updated. The risk and the uncertainty are crucial for the forecast, so the degree of uncertainty should be noted.

The constant changes of business conditions, as a result of the international competition and the rapid changes of the technological advances have a great impact on companies for performing as much accurate forecasts as possible. Forecasting is essential for a company in order to plan the necessary resources and personnel, as well as the production process so as to meet on time the market demands. The accurate forecasts lead to an improved plan for using effectively the equipment, managing the human resources, reducing the delays and consequently the production costs, as well as taking advantage of the stock of raw materials and products [28]-[31]. Note that the application of any forecasting method will obtain results with variance of the reality, as there are many random factors that take place. The important feature of a forecasting method is to obtain as small variance as possible, thus the appropriate forecasting technique should be chosen carefully.

Forecasting is necessary for companies and has been proven to be one of the most essential functions of management, since companies operate in such a competitive environment. Moreover, not only forecasting does affect and support the decision making in business, but it also satisfies the information needs of the departments. Although a forecast does not eliminate the uncertainty of the modern environment (even if it is very accurate), it performs as a great information source for decision making in a company, since it eliminates as much as possible the element of uncertainty. Forecasting methods are based on either mathematical models by using historical data, or qualitative methods based on the experience of business executives, or even a combination of both of them. Some of the most popular methods are presented in the next sections, as well as their advantages and their limitations. Finally, these methods will be applied to the data of the past six years (2012-2017) for each product in order to forecast the demand of 2018.

The demand of preforms, bottles and jars is neither stable nor is distributed uniformly throughout the year. The demand of some products shows seasonality, especially during the summer and autumn when there is high demand of water and wine or olive oil, respectively. However, this phenomenon cannot be predicted accurately, as it is presented in random periods and it is related to market trend, to competitive conditions and to prices of raw material (PET resin) that is based on the stock market, since it is a product of petroleum.

2.4.1 The Basic Steps in a Forecasting Task

Forecasting involves the following five steps [41]:

- **Problem definition.** Usually, it is the most difficult and the most important step, due to the fact that the way of using the forecasts and the definition of the people involved should be clarified carefully.
- **Information gathering**. This step is divided into two subcategories: information related to statistics, such as numerical data and information related to accumulated specialist knowledge, such as judgment and experience of the people that are involved. Information needs to be collected before the beginning of forecasting process and at the same time, needs to be enlightening and defined clearly.
- **Preliminary (exploratory) analysis**. This step is related to the type of information that was obtained from the unprocessed information that has been already collected. Firstly, data are represented graphically and then statistical parameters are calculated (i.e. mean, minimum, maximum, linear trend, standard deviation). These parameters point out some secondary features of the time series, so as to obtain a complete interpretation of the data, as well as wrong standards, seasonality patterns, trends and outliers. This analysis results in a family of models, that is supposed to obtain satisfactory predictions.
- **Choosing and fitting models**. This step refers to the identification and the determination of parameters related to quantitative forecasting models that have already been chosen from the previous step. Every possible version of forecasting that has been proven to be appropriate is analyzed and gradually is excluded to a point that there is only one that dominates all the others.
- **Using and evaluating forecasting model**. The selected model is applied and the results that are obtained are recorded. If it is necessary or asked, some steps are repeated, so as the results to be

improved. The forecasting method can be properly evaluated only when the actual data of the forecasting period are available.

Once the forecasting is completed and the results are written down, the calculation of error follows. This is a required step in order to calculate the variation between the forecasting values and the actual data. The high reliability of the method is equivalent to the small variation, given the fact that it can calculate more accurate values, and vice versa. The criteria of evaluating the accuracy of methods are analyzed in section 5.2.

2.4.2 Forecasting Methods

Forecasting methods are divided into two main categories: qualitative and quantitative methods. Qualitative methods are subjective, they are based on estimations and specialists' opinion or judgments and include the aspect of bias. On the contrary, quantitative methods are based on mathematical modelling, they are unbiased and repetitive. These are divided into methods of analyzing time series, deterministic methods and methods of simulation. The basic principle of time series analysis is that the past observations can be used in order to forecast future values and corresponds to the analysis of parameters, such as trend and seasonality. The deterministic methods assume that the demand is related to external factors (macroeconomic). The difficult part is the fact that the variable that is forecasted is based on one or more external parameters that make the selection of the appropriate forecasting method harder. Deterministic models are complicated, since they analyze many parameters. Finally, the simulation method allows the introduction of assumptions and conditions related to the forecasting, as well as the application of a model that obtains the appropriate forecasting results.

2.4.2.1 Qualitative Methods

The qualitative forecasting methods are called also biased forecasting methods, because they are based on the experience and the subjective opinions of people inside and outside the company. These methods are usually used when there are not enough numerical data or the available time for the analytical time is not enough or when the forecasting is very long-term. For instance, the introduction of a new product or service does not correspond to experience in past observations. These are the cases where the use of qualitative methods is required, since there are not numerical data to be analyzed in quantitative methods.

Some of the most popular qualitative forecasting methods are described below [32]:

- **Grass Roots.** The forecasting is performed by using data that are provided by executives who are involved in the field of the object which is forecasted.
- **Market research**. This method is related to gathering information (i.e. interviews, questionnaires) in order to control the circumstances of the market. It is defined as a long-term method, namely for new products.
- **Panel consensus**. Free exchange of opinions (brainstorming) in a meeting from all levels of management, sellers and customers.
- **Historical analogy**. The object of forecasting is related to a similar one. This method is useful for the design of new products, where the forecasting is performed according to the data of a similar

product. It is considered that the sales patterns, which are associated with the previous product or service, can be transferred to the new product or service.

- **Delphi method.** A group of experts answers to a questionnaire and their identity is concealed, so everyone expresses himself freely. The answers are summed up and the questionnaire is given back to the entire group. This process continues until they reach to a consensus.

2.4.2.2 Quantitative Methods

Quantitative methods include numerical forecasting methods that are based on mathematical models. The way of their operation is very specific, unbiased and provides the opportunity of obtaining similar results under the same circumstances. The basic feature of these methods is that they use statistic results which are based on previous data. This category is performed for forecasting values of a following period of time, such as data of the following week, month, year. For example, the daily recording of the closing values of a specific stock for 5 years, provides complete statistic results for the values of this stock and they can be applied to a forecasting method in order to obtain the future values of this stock.

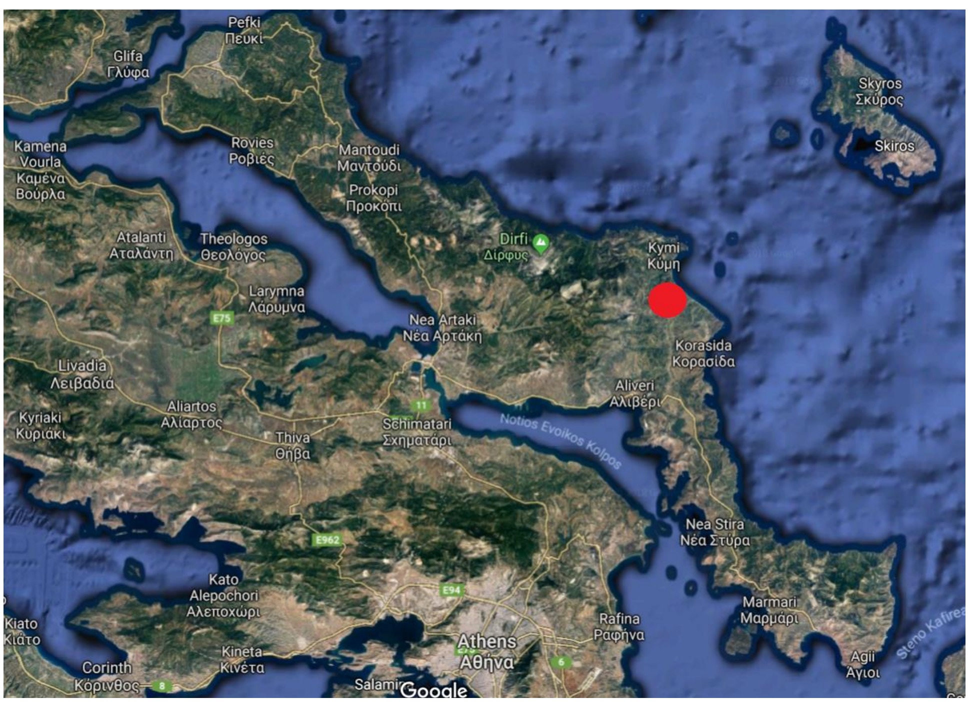
Some of the most popular quantitative forecasting methods of the three subcategories (time series analysis methods, deterministic methods, simulation methods) are presented below [41], [31]:

- **Naïve method.** It uses the actual value of last period as a forecast.
- **Simple Moving Average.** Average (mean) of ***n*** observations, where each one receives the same weight.
- **Weighted Moving Average.** Some observations (usually the most recent) receive greater weight than the older ones.
- **Double Moving Average.** Simple Moving Average is applied twice. It is performed when the observations show a linear trend.
- **Simple Exponential Smoothing (Brown's method).** This method is similar to weighted moving average. As the data get older, the weights declines exponentially.
- **Double Exponential Smoothing.** The smoothing of observations is applied twice. It is used when the observations show linear trend.
- **Holt Method (Trend-Corrected Exponential Smoothing).** It is an extension to Brown's method.
- **Holt-Winters Method (Triple Exponential Smoothing).** This method is an extension to Holt method and is defined as trend and seasonality corrected exponential smoothing. It is performed when the observations show linear trend and seasonality.
- **Regression Analysis.** This method is focused on the relationship between a dependent value and one or more independent values. Such technique is the least squares method.
- **Box-Jenkins.** It is a complicated statistic method that adapts the model to the Bezier time series.
- **Shinskin Time Series.** It is an effective time series analysis method related to seasonality, trend and randomness. It requires data of at least three years.

Chapter 3

3 Presentation and Production Process of *Voglyplast Co.*

3.1 Voglyplast Company



Voglyplast was founded in 2004 in Kimi, Evia and is a well-known manufacturing company of PET *(Polyethylene terephthalate)* preforms, bottles, jars and caps in Greece, with one of the most distinguished know-how. When the company was founded, there were only two machines; one injection moulding machine and one blowing machine. The product range was small and consisted of Φ48-196gr preform, 5lt and 10lt bottles. As the sales increased, the company started to produce more and more products and then new facilities were built. The equipment multiplied, as well as the variety of the products. When financial and economic crisis started to appear around 2010, the founders of the company came up with an alternative business plan in order to survive the competition, but mainly in order to survive the adverse circumstances for small-medium sized enterprises. Thus, since then, apart from being respectable, reliable and trustworthy suppliers to many companies all around Greece, they focus on exports as well, especially in USA. In addition, the company supplies producers that are located in Greece, but they export their products worldwide. Moreover, the company cooperates with manufacturers and suppliers worldwide, e.g. Europe, India, China. The goal of company is being always updated about new technologies, new trends and materials, in order to satisfy the customers by providing the best quality. That is why, they visit exhibitions very often around Europe, USA, Asia and they have already built an important networking. Nowadays, Voglyplast keep on launching new products and being competitive.

3.2 Plant Layout and Equipment

Voglyplast is an industry with heavy machinery. The production lines consist of injection molding machines and automatic blowing machines. This section presents the areas and the equipment of the plant. Figure 3 shows the layout of the machinery and Table 1 presents the machines that are shown in the machinery plan.

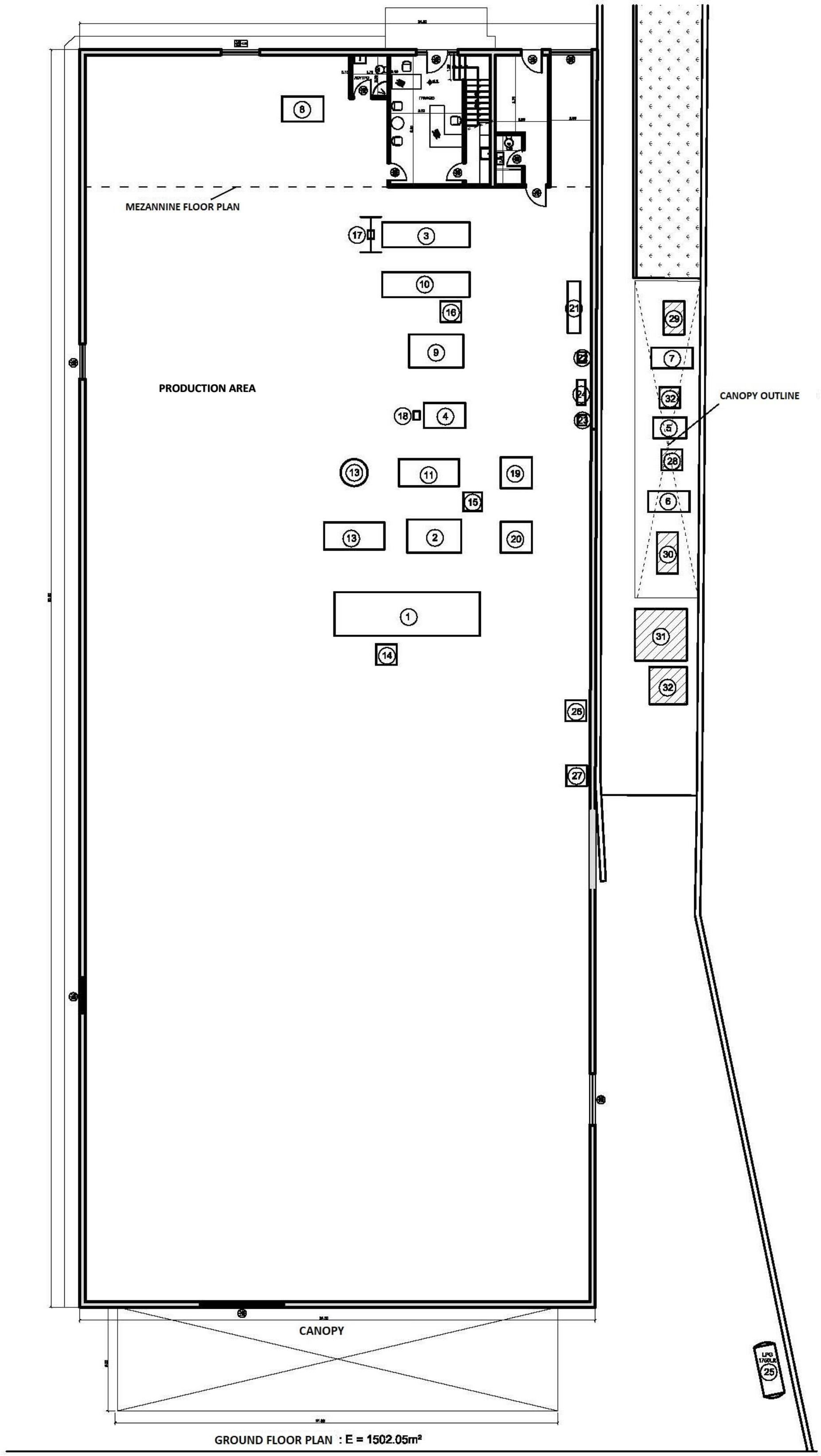


Figure 3. Layout of machinery

No.	Machinery
1	Injection moulding machine
2	Blowing machine
3	Injection moulding machine
4	Blowing machine
5	High pressure air compressor
6	Water chiller (cooling system)
7	Low pressure air compressor
8	Blowing machine
9	Blowing machine
10	Blowing machine
11	Wrapping machine (film)
12	Wrapping machine (film)
13	Packaging machine
14	Autoloader for preform
15	Autoloader for preform
16	Autoloader for preform
17	Electric chain hoist
18	Electric chain hoist
19	Autoloader
20	Autoloader
21	Lathe
22	Drill
23	Argon gas welding machine
24	Press machine
25	Liquid gas tank (LPG)
26	Milling machine
27	Milling machine
28	High pressure air compressor
29	High pressure air compressor
30	Water chiller (cooling system)
31	Water chiller (cooling system)
32	Air dryer
33	Dry cooler

Table 1. Machinery of Voglyplast Co.

3.2.1 Reception & Offices

The reception is next to the entrance of the building. There are three offices that are located at the ground and at the first floor.

3.2.2 Parking Area

There is a parking area in front of the building.

3.2.3 Storage & Dispatch Area

Storage is divided into two areas (Picture 1 and Picture 2); one for raw materials and preforms and the other one for the final products (bottles, jars, caps).

The dispatch area is located next to the storage, where gathering of the orders and shipping take place.

Picture 1. Storage of final products

(a) (b)

Picture 2. Storages of a) raw material, b) final products (palettes)

3.2.4 Lathe & Milling Machine

There is an area were a lathe and a milling machine are located. They are used for fixing and repairing many different parts and tools of the equipment. In addition to these machines, there is also a granulator machine which is used for breaking down and reduce the size of faulty products. This is an essential step for recycling.

3.2.5 Water Chiller & Air Compressors

Water chiller (cooling system) is used for cooling the mould in order the product to have a smooth finish and reduce the internal pressure. The are two types of air compressors; high and low pressure air compressors. Low pressure air compressors (approximately 10atm) are required for the operation of machines, while high pressure air compressors (approximately 30atm) are required for the blowing of bottles or jars in blowing machines.

Picture 3. Cooling system & Air compressors

3.2.6 Injection Moulding Machine

Picture 4. HAITIAN injection moulding machine

Injection moulding machine (i.e. like the one in Picture 4) manufactures plastic products by injection moulding process. Voglyplast produces preforms in two injection moulding machines.

The main components of those machines are the base, the injection unit and the clamping unit.

- **Base unit**

It is also known as ''bed'' and supports the frame for injection and clamping units. It is often made of heavyweight steel and must provide stability and accuracy.

- **Injection unit**

The function of injection unit is firstly to melt and homogenize the PET resin and then inject it to the mould. PET resin dries out of any moisture in the drying hopper, which feeds the granules in a barrel inside the injection unit. The barrel contains an Archimedes' screw, which heats and melts the resin, while it moves quickly and injects the molten plastic through a nozzle into the mould.

- **Clamping Unit**

The functions of the clamping unit are opening, closing and keeping the two platens of mould in perfect alignment. Note that the time of one repetition from the beginning of the opening to the end of the closing of the clamping unit is called cycle time. Also, the clamping unit ejects the plastic parts, once they have been hardened. The mould must be warm and closed, while the molten resin is being injected, so as to prevent hardening before the mould is full. The mould is divided into two platens; one fixed and one movable, which consist of a specific number of cavities with the preferable design of the final product. The molten granules flow into the cavities through a distribution channel. There is also a cooling system, which pumps cold water around the mould in order to reduce the heat and help the hot plastic to harden. Finally, the movable platen contains ejector pins, which eject the final hard plastic products on the exit conveyor belt that transfers them into a container, such as an octabin.

3.2.7 Blowing Machine

Picture 5. KENPLAS blowing machine

Blowing machine (i.e. like the one in Picture 5) produces hollow object, such as bottles or jars. The main components of these machines are a hopper, an oven with UV lamps for heating and a mould clamping unit with the preferable design of the final product. A hopper feeds the machine with preforms through an auto-loader feeder or a conveyor belt. The preforms get on rotating metallic rods and enter an oven, which heats them for making blowing process easier. Then, they enter into the moulding clamping unit, which closes and a stretching rod stretches the pre-heated preform. High pressure blowing follows, as air is inflated. The mould opens and the final blown product is discharged on the exit conveyor belt, which transfers the products into a container, such as an octabin or cardboard box.

3.3 Products of *Voglyplast Co.*

Voglyplast has a great product range. The products are divided into four big categories: preforms, bottles, jars, caps and the category of handles and nets. In addition to all these, there are customized products based on the customers' needs and their desirable unique design, thus, a new mould is manufactured especially for them.

3.3.1 PET or PETE (Raw material)

PET is the abbreviation for the chemical name of Polyethylene terephthalate, which is made of crude oil and natural gas and is formed in granules or resin packed in big heavy sacks. The main reason why PET is so excessively used as packaging material is that is light weight and strong, can have a clear transparent color like glass, retains carbonation and freshness, has high resistance and can be formed in very complicated shapes and designs. Moreover, PET is approved by Food and Drug Administration (FDA), as it is non-toxic and there is minimal migration from the material to the food/drink that is packaged with no harmful consequence to human health. Furthermore, PET is a fully recyclable material, that can be safely transformed again to recycled granules. On the contrary, if it is too contaminated, it is re-used as energy source. Table 2 shows the properties of PET [33]. PET resin (Pictures 6 and 7) is the raw material of all the products of Voglyplast Co.

Properties	
Chemical formula	$(C_{10}H_8O_4)_n$
Molar mass	variable
Density	1.38 g/cm^3 (20 °C) amorphous: 1.370 g/cm^3 single crystal: 1.455 g/cm^3
Melting point	> 250 °C (482 °F; 523 K) 260 °C
Boiling point	> 350 °C (662 °F; 623 K) (decomposes)
Solubility in water	practically insoluble
log P	0.9454
Thermal conductivity	0.15 to 0.24 W m^{-1} K^{-1}
Refractive index (nD)	1.57–1.58, 1.5750
Thermochemistry	
Heat capacity (C)	1.0 kJ/(kg·K)

Table 2. PET properties

Picture 6. PET resin [47]

Picture 7.PET resin (colored) [48]

3.3.2 Preforms

Preform (Picture 8) is a product of injection-molding process of PET resin, which is used for shaping the final product, such as a bottle or a jar, in a blowing machine. The raw material of preforms is PET thermoplastic polymer resin. The main characteristics of a preform are the following: neck type, neck size (diameter), weight and color.

Voglyplast manufactures preforms with neck diameter 63mm up to 110mm, type PCO (Plastic Closure Only) or Twist-off, which weight 30gr to 196gr, transparent, semi-transparent or opaque colored, such as green.

Picture 8. Preforms for bottles [49]

3.3.3 Bottles

Bottles (Picture 9) are produced in blowing machines out of PET preforms and are used for water, oil, alcoholic drinks, such as wine and distilled drinks, vinegar, beverages, juice, milk, pure alcohol or benzene, cosmetics, etc. The main characteristics of a bottle are the following: volume, neck size (diameter), neck type, weight, shape, such as round or square, color and design.

Voglyplast produces a great variety of bottles that range from miniatures of 30ml to large bottles of 10lt.

Picture 9. Bottles of Voglyplast Co.

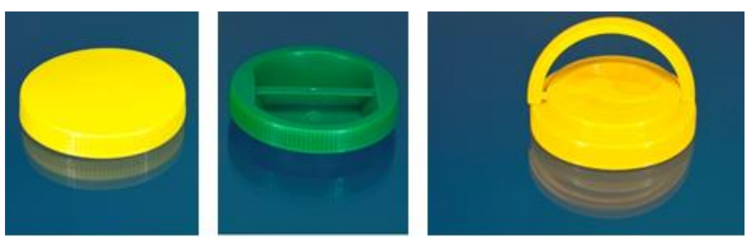
3.3.4 Jars

Jars are produced in blowing machines out of PET preforms and are suitable for olives, honey, jams, pickles, sauces, spreads, etc. The main characteristics of jars are the following: volume, neck size (diameter), neck type, weight, shape, such as round or square, color and design. Voglyplast produces a great variety of jars that range from 200ml to 5lt.

Picture 10. Jars of Voglyplast Co.

3.3.5 Caps

Caps (Picture 11) are produced in injection moulding machines out of Polypropylene. The main characteristics of caps are the following: size (diameter), type of screw and color. Voglyplast manufactures caps with diameter 110mm, with or without handle (internal or external).



Picture 11. Caps of Voglyplast Co.

3.3.6 Handles and Nets

Handles and Nets are produced in injection moulding machines out of Polypropylene. Handles are adjusted to the neck of large bottles, such as 3lt or 5lt, for carrying them easier as these types of bottles are heavy. In some cases, when jars are filled with specific product e.g. olives, pickles, a plastic round net is placed on top of them, in order to keep the product safe and avoid leaking, because of the upthrust.

Picture 12. Handle & Net of Voglyplast Co.

3.4 Statistics of PET (Polyethylene terephthalate) & Plastics

As far as the price of PET resin is concerned, the following figures present the pricing history of the last years. The price is estimated in Euro per kilo. Specifically, Figure 4 illustrates the average pricing of PET resin in Central Europe throughout the period 2008-2017. An important price drop in 2011-2015 is shown, while price has started to increase gradually since 2016. Additionally, Figure 5 presents the variation of average price of PET resin in 2017. There is a peak of 1.09 €/kg on September, followed by a trough of 1€/kg on October, when the high demand during summer is over [54].

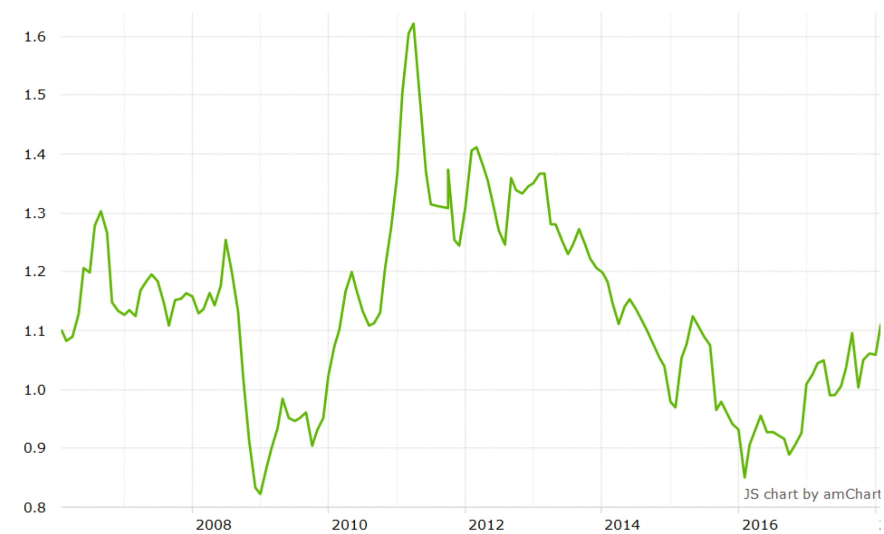


Figure 4. Pricing history of PET resin in Central Europe (2008-2017) [54]

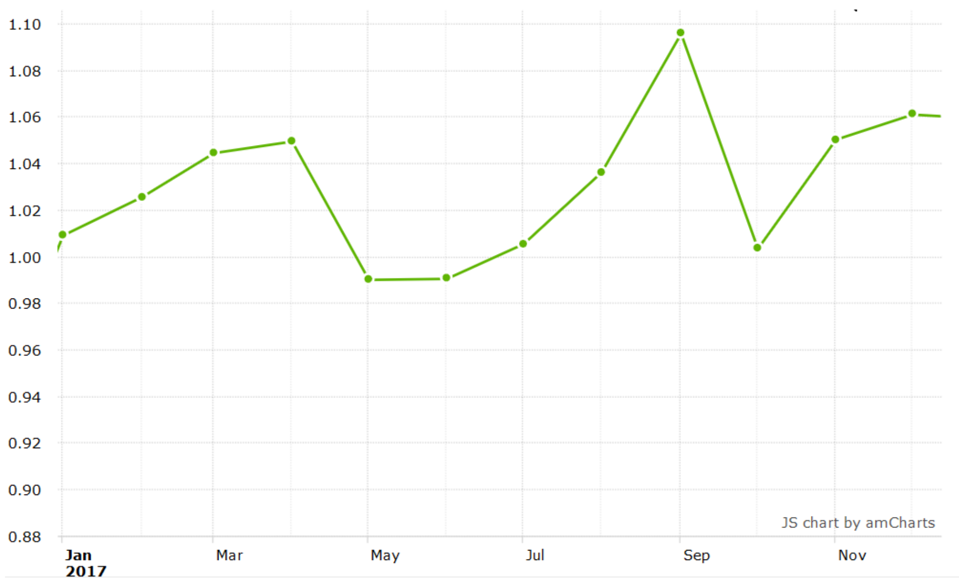


Figure 5. Variation of price of PET resin in 2017 (Central Europe) [54]

The demand of PET packaging is growing excessively as the years pass by, because of its wide applications. Asia-Pacific is the leader of consumption in the global market, while Europe and North America follow [35]. Figure 6 and Figure 7 present the consumption of PET worldwide. The bottled drinks held a share of 71% out of total PET consumption in 2016, particularly bottled water accounted for 26.3%, carbonated soft drinks accounted for 26.1% and other drinks held a share of 18.6%. Film and food followed with a share of 13.9% and 9.3%, whereas non-food applications share was 6%. The global PET consumption (including recycled PET) was 23.5 million tons in 2016 [34].

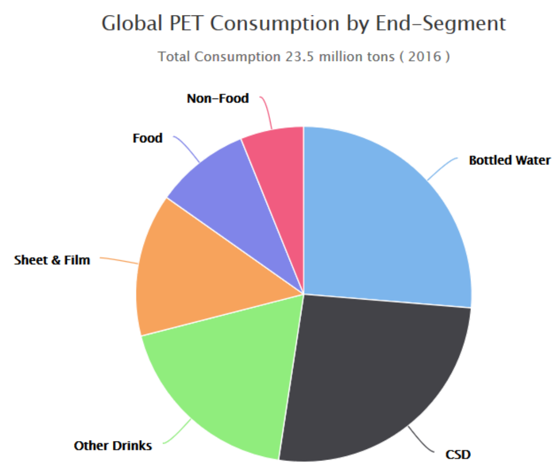


Figure 6. Global PET Consumption by End-Segment (2016) [34]

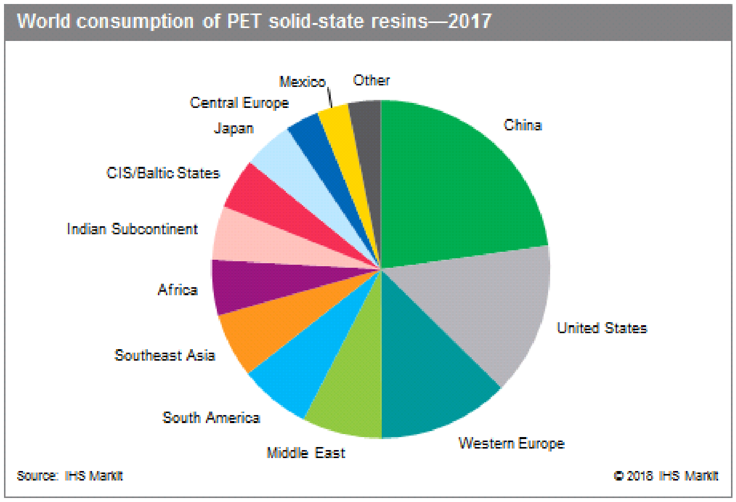


Figure 7. World consumption of PET solid-state resins (2017) [35]

According to European data for plastic industries, there are more than 800 companies that produce plastic packaging for food and beverages, such as bottles and jars, in Europe. In addition, for the period 2011-2013, the total plastics industry in Europe has produced about 57 Mt per year, on the contrary to Europe's demand that was about 46 Mt. Moreover, 1.45 million people work in approximately 62,000 companies (mainly small and medium sized) in the field of plastics. The European plastics industry creates a yearly turnover of more than 350 billion € [36].

The plastics industry worldwide has grown excessively the last 50 years. To illustrate this, for the period 2012-2017, demand for plastic products continuously increased by more than 3.7% per year. As a consequence, the total global plastic production was about 300 Mt in 2013. Figure 8 illustrates the global plastic production of the period 1950-2016 [37].

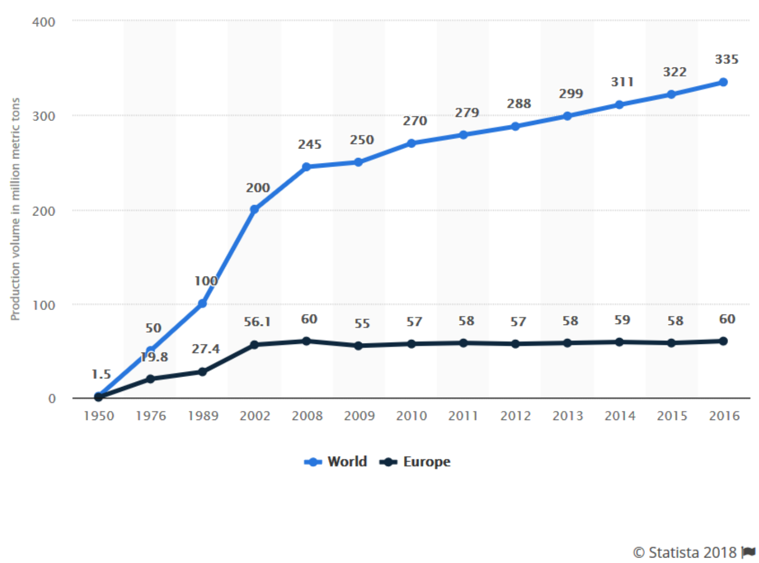


Figure 8. Global plastic production from 1950 to 2016 (in million metric tons) [37]

The PET resin production capacity worldwide was 30.3 million tons in 2017 (Figure 9). China is the leader in global PET resin production that had a share of 30.8% of the total production, while Asia (excluding China) had a share of 21% of the total production. North America accounted for 16.9% of the total PET resin production followed by Europe which had a share of 14.7%, Middle East (10.2%), South America (4.1%) and Africa (2.3%) [34].

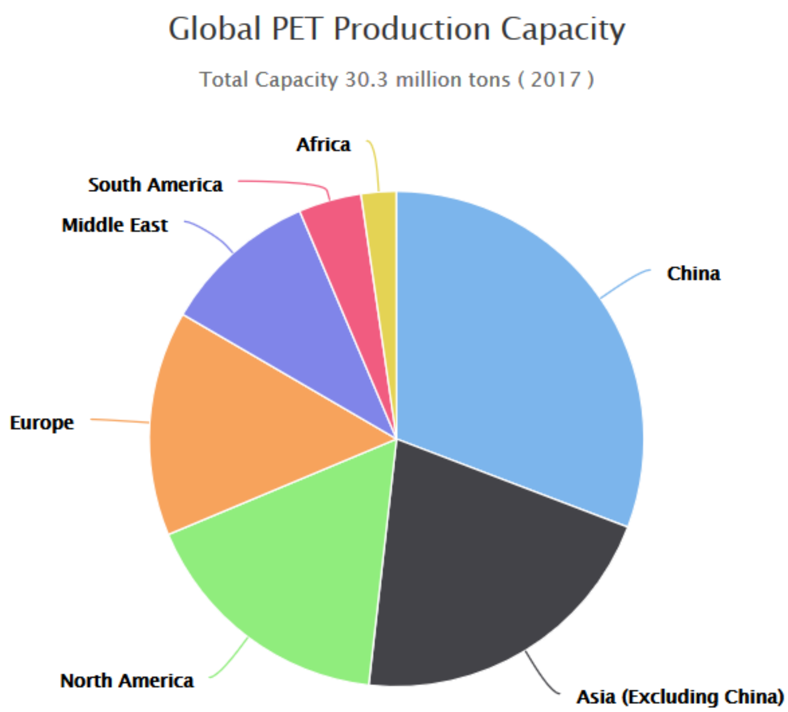


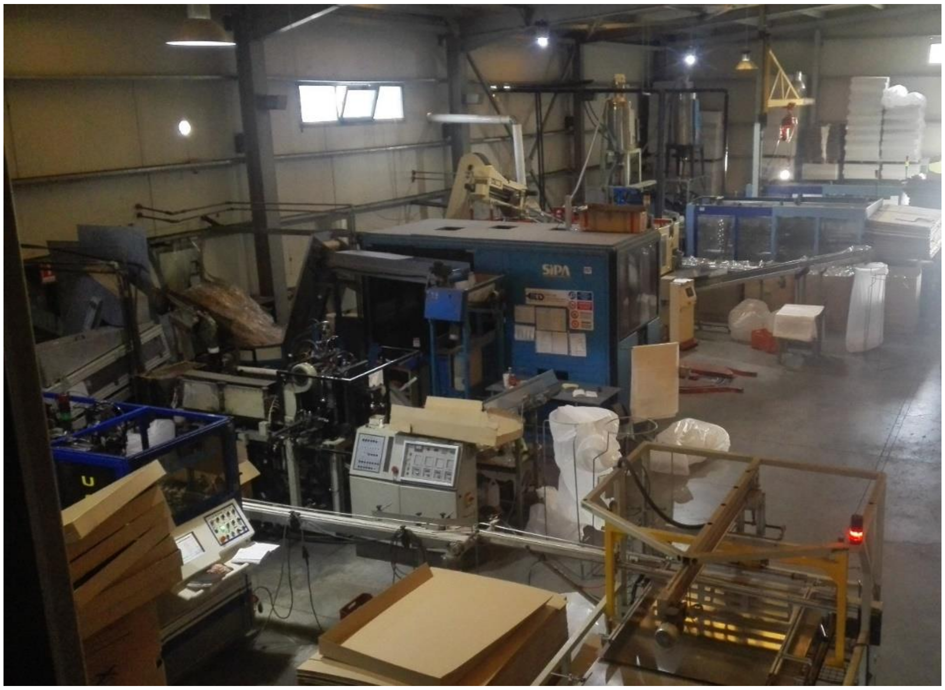
Figure 9. Global PET production capacity (2017) [34]

3.5 Production Process

3.5.1 Production Lines

The manufacturing plant of Voglyplast Co. has seven production lines, some of them are shown in Picture 13. They are divided into two sections: those with injection moulding machines and those with blowing machines. In particular,

- Two production lines of injection moulding machines that produce preforms of all sizes. Usually, the one produces small sized preforms and the other one manufactures larger preforms.
- One production line with an automatic blowing machine for jars.
- Four production lines that produce bottles in blowing machines.



Picture 13. Aspect of production lines

3.5.2 Products

As the product range of Voglyplast Co. is very wide, the whole analysis presented in this thesis is focused on certain best-selling products, which are divided into three categories related to the production process and the raw materials used for the production of each one. The categories are described below.

3.5.2.1 Category A

Category A consists only of preforms that are produced in injection moulding machines. The raw material of products of category A is PET resin.

PREFORM Φ48-195gr	
PREFORM Φ110-110gr	

	
PREFORM Φ110-140gr	
PREFORM Φ82-50 gr	
PREFORM Φ63-45gr	
PREFORM Φ 63-30gr	

Table 3. Products of Category A

3.5.2.2 Category B

Company produces the raw material, which is PET preform for the products (bottles and jars) of category B.

BOTTLE Φ48-3lt	
BOTTLE Φ48-5lt	
JAR Φ82-720ml	
JAR Φ110-1gal	
JAR Φ110-2lt (HONEY)	

JAR Φ110-2lt (SQUARE)	

Table 4. Products of Category B

3.5.2.3 Category C

Company buys PET preforms from external suppliers, as raw material for the bottles of category C.

BOTTLE-1,5lt (GRAPE)	
BOTTLE-1,5lt (ONE)	
BOTTLE-1lt (MILK)	

Table 5. Products of Category C

3.5.3 Flow Chart of Production Process

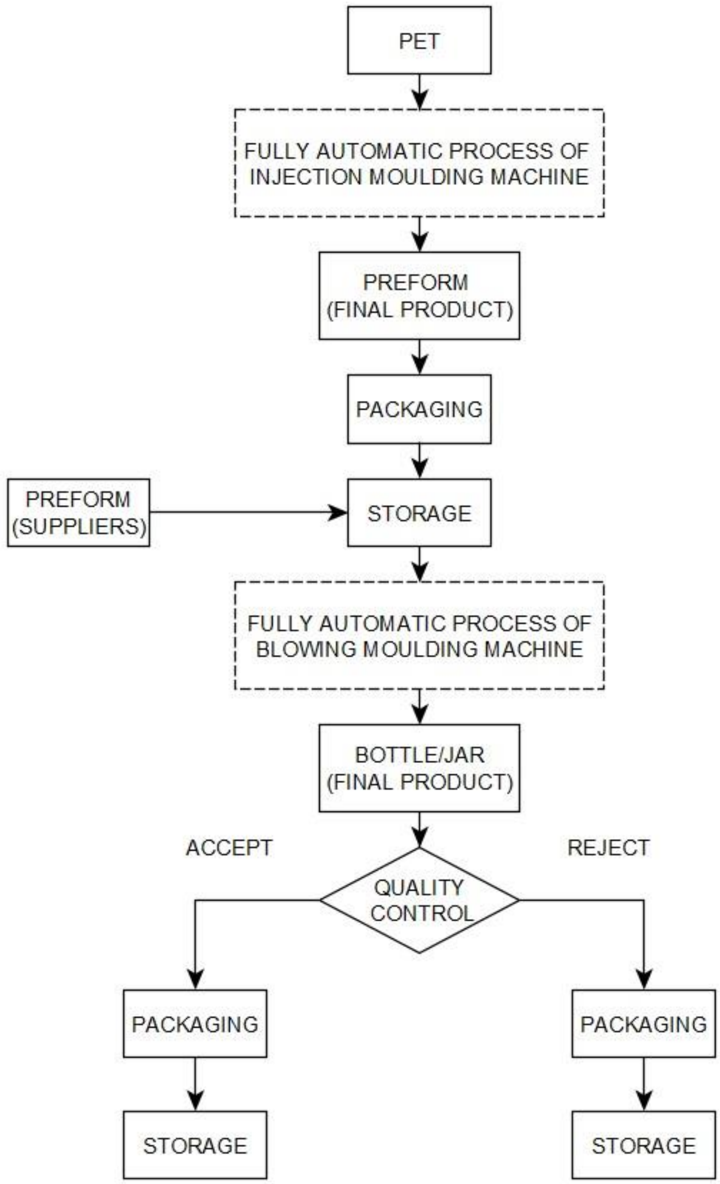


Figure 10. Flow chart of production process

The fully automatic process of injection and blowing moulding machines is analyzed in the flow charts of Figures 11 and 12.

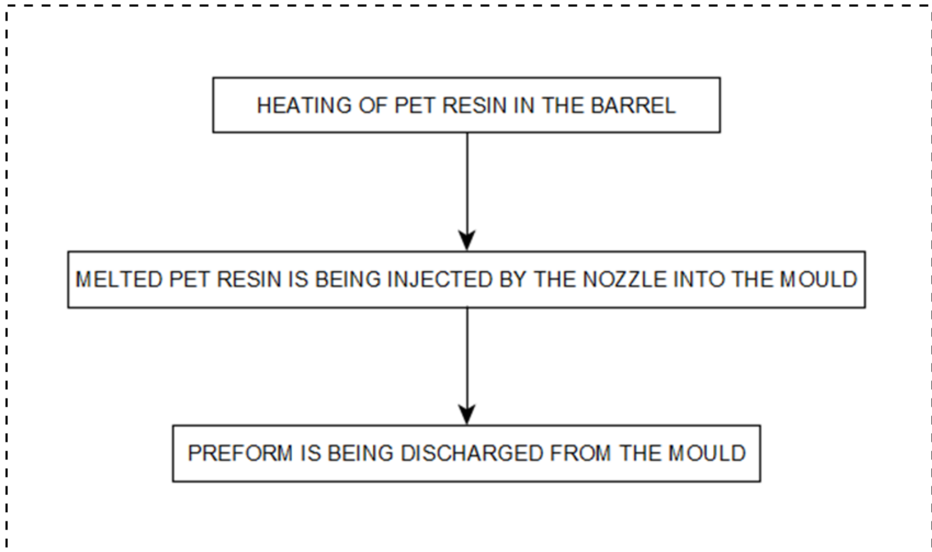


Figure 11. Flow chart of fully automatic process in injection moulding machine

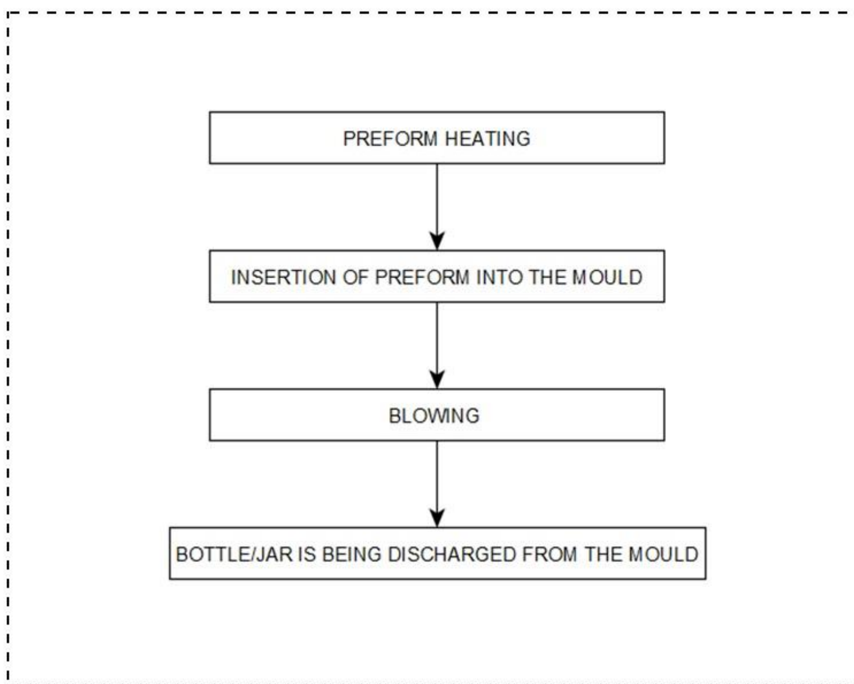


Figure 12. Flow chart of fully automatic process in blowing moulding machines

First of all, before any production process starts, production manager checks the production planning. According to the production plan followed, he checks the inventory of the products that need to be manufactured, the available raw materials, PET resin for manufacturing preforms and preforms for the production of bottles or jars. Then, he checks the available quantity of packaging materials that include palettes, cardboard palette caps and trays, bags and shrinking film. Eventually, the inspection of the machines takes place, so as to confirm that there is no breakdown and after that, the area all around the production line is being cleaned in order to avoid injuries, accidents or extra delays because of objects that are located at inappropriate places.

3.5.4 Production Process of Injection Moulding Machine

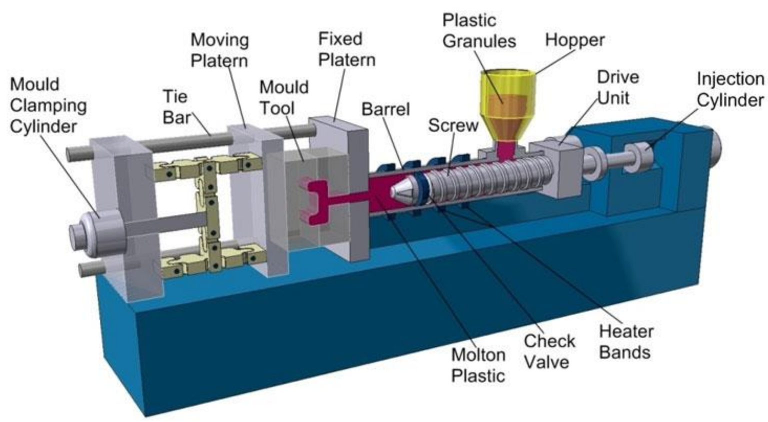


Figure 13. Components of injection moulding machine [50]

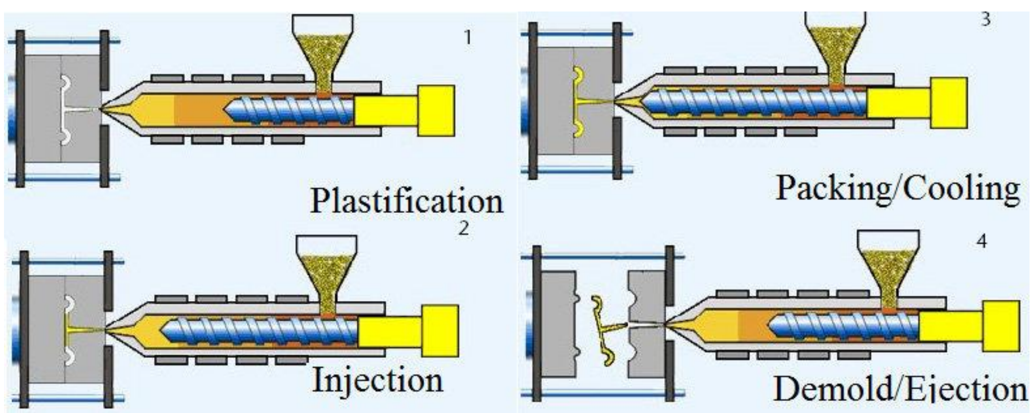


Figure 14. Automatic process of injection moulding machine [51]

The production line of injection moulding machine (Figure 13) contains an injection moulding machine, a drying hopper (Picture 14), conveyor belts (Picture 15), a structure for the PET resin sack and a temporary storage area where octabins are located before being transferred to the central storage. Both injection moulding machines are manufactured by HAITIAN Co. An employee is responsible for the whole process, namely in the beginning, during the set-up and every half an hour when the quality control takes place.

PET resin sack (Picture 16) is being transferred to the special structure at the production line. Every machine comes with a computer and a software, where the settings for the production of every type of preform are stored. Firstly, an employee checks the settings on the controller (Picture 17), makes any necessary changes (i.e. change of the temperature) and then the machine is turned on. This process is repeated in case of faulty preforms or a breakdown. The most important and necessary stage is the drying of PET resin in the drying hopper machine, which lasts four hours and is a necessary condition in order the production to begin. This stage is so important because PET material is hygroscopic, in other words, PET absorbs moisture from the atmosphere, which causes problems on the surface of a product, after the material exposed to melting temperature [53].

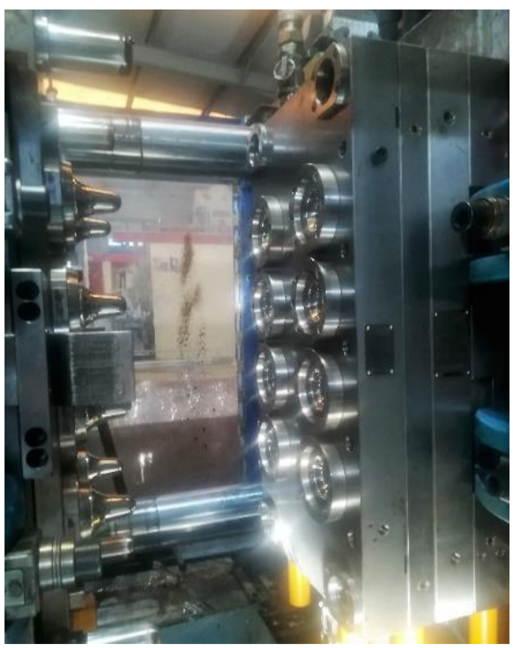
The next stage is the fully automatic process of the injection moulding machine (Figure 14). Each mould (Picture 18) consists of a number of cavities, thus in every cycle time preforms produced and discharged on the conveyor that transfers them directly in the octabin that is located at the packaging section (Picture 19). The final stage is the transferring of the octabin to the central storage.

Picture 14. Drying hopper machine

Picture 15. Conveyor belt

Picture 16. PET resin sack

Picture 17. Controller of injection moulding machine



Picture 18. Mould (with 8 cavities)

Picture 19. Packaging of preforms (with no delay)

3.5.5 Production Process of Blowing Machine

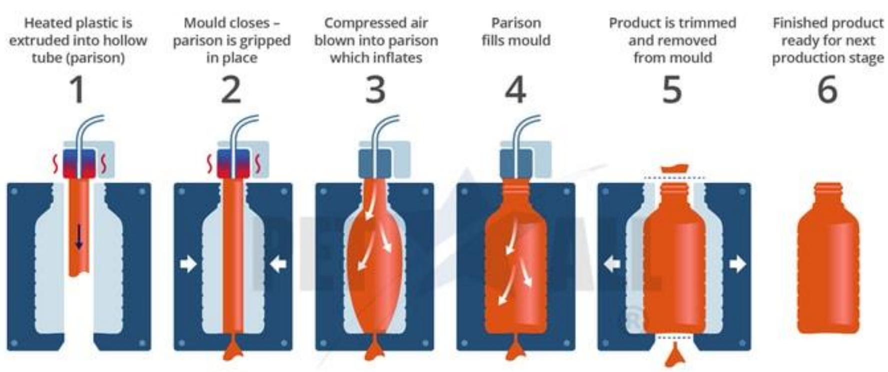


Figure 15. Blowing process [52]

The production line of blowing machine contains a blowing machine, a hopper with an autoloader machine for preforms (Picture 20) and a packaging area with a temporary storage. Blowing machines have been manufactured by different companies, such as KENPLAS, SIPA (Picture 21), UROLA, ETEKO. The whole operation requires an employee responsible for the packaging process and the quality control.

During the first stage, an octabin full of preforms is transferred from the central storage to the hopper, which loads them to the machine. Then, preforms get in the oven of the machine (Pictures 22 and 23), which contains UV lamps that heat them, making blowing, stretching and forming easier. The next stage is the blowing process (Figure 15) when the preform enters to the clamping unit of the mould and compressed air is being blown. The final product is being discharged to the conveyor belt (Picture 24), which transfers them to an octabin or to a special container at the packaging area.

During the whole process, an employee is packing the final products, according to the packaging type of each product code. Products are being packed to large plastic bags or palettes. Packaging of palettes needs also stretch wrapping with film at special stretch filming packaging machine. Finally, the final packed products are transferred to the central storage.

Picture 20. Hopper & Autoloader machine

Picture 21. SIPA blowing machine

Picture 22. Oven with UV lamps (in operation)

Picture 23. Oven with UV lamps

Picture 24. Conveyor belt that transfers the final product

3.5.6 Packaging

3.5.6.1 Packaging of Preforms

Preforms are packed in cardboard boxes (Picture 25) or octabins (Picture 26).

- Cardboard boxes are used for small-sized preforms. They are stacked on palettes covered with film.
- Octabin containers are light weight, but heavy-duty packaging. They are made of cardboard, they are multi-use, stackable and can be transported easily. Moreover, they are cost effective and eco-friendly.

Picture 25. Cardboard boxes

Picture 26. Octabins

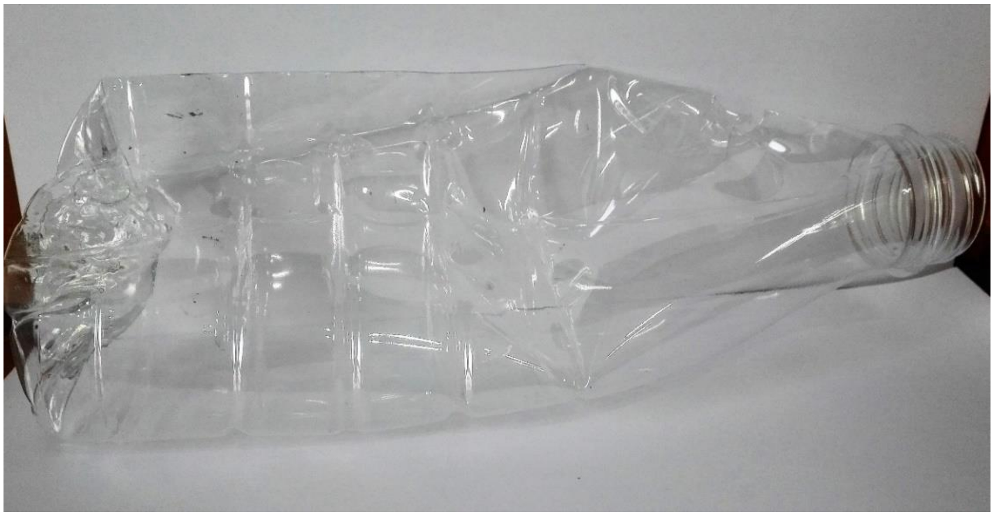
3.5.6.2 Packaging of Bottles and Jars

Bottles and jars are packed in large transparent plastic bags (Picture 27) or palettes (Picture 28).

- Plastic bags are large, transparent, oblong sized. Although that kind of packaging is faster and cheaper, it is not very safe, as the products can be damaged easily during the transportation, unless they are shipped very carefully (Picture 29).
- Palette packaging requires more time, especially when there is no automatic palletizing machine, but it has been proved as the safest solution. Products are stacked on levels up to a specific height. Each level is separated of one another with a cardboard tray, which works as protection as well. On top of the palette there is a cardboard cap, similarly to the bottom, where there is a cardboard base. Once the products are stacked, the palette is being transferred to the wrapping machine, where it is being covered with film.

Picture 27. Bags

Picture 28. Octabins & Palettes



Picture 29. Damaged bottle because of bag packaging

Chapter 4

4 Modelling of Production Process with Petri Nets and Simulation of Alternative Scenarios

4.1 Modelling of Alternative Parts of Production with Petri Nets

In this section, the modelling of the tasks of the complete operation process is presented. The production line consists of individual tasks that are described in section 3.5. For a more effective analysis, for each category, there is a fundamental model, which is adjusted to each product, based on the slight modification of parameters. Thus, in the end, there is one fundamental model for each product, similar to every model of that category. The modelling and then, the simulation were performed using VisualObjectNet++ software [39], which implements timed and continuous Petri Nets, a mathematical modelling language (section 2.2).

Initially, the model of the production process is implemented, where all the characteristics are defined, i.e. all the interactions among the elements of the system, the structure, the steps of the production line, the connections and the sequence between them, the quantities of raw materials, the proportion of raw materials and supervisor control structures that assure the sequence between the processes. Then, a mutual exclusion mechanism is applied in order to ensure the successive relation between certain tasks. Moreover, the model is completed by the addition of quantitative parameters that namely are referred to the delays of tasks that are not continuous, to the capacity of the places, to the size of batches and to the multiplicity of weights on arcs. Finally, for an effective and efficient study of the behavior of the production system in various circumstances, simulations of alternative scenarios have been performed, where the values of certain parameters have been modified. Specifically, these parameters are referred to the steps of the production, the equipment and the nature of certain quantitative parameters.

Modeling of random values of parameters is presented by the following function:

$$A = x + y * rnd(z)$$

Where:

- *x*: lower bound of A
- $x + y * rnd(z)$: upper bound of A
- $z \in \mathbb{Z}$
- *rnd(z)* returns integer values between [0, z]

In every case, *z* takes the maximum possible value. As a result, the random number generator (rnd) returns many different numbers. Thus, the more numbers the random number generator returns, the more realistic and unbiased the results are. For example, rnd(100) returns more unbiased results than rnd(10), as 100 is larger than 10 and it provides a larger set of numbers.

4.1.1 Modelling of the Production Process of Product Categories: A, B, C

The product categories are formed according to the production process followed for the production of each product which is based on the different production lines of the industry. Providing this, a single general and mutual modelling is not possible, as each product category is defined by a specific, totally different structure, that corresponds to each production line. However, there is a general model for each product category, that is modified for every single product, according to specific differences between them.

4.1.1.1 Modelling the Fully Automatic Production Process of Injection Moulding Machine & Blowing Machine

The fully automatic process that takes place in both injection and blowing moulding machine (sections: 3.5.4, 3.5.5) requires couple of steps that last a few seconds. This delay is very short compared to the delay of the other transitions (steps), so it can be considered as zero. The following two PN models illustrate the fully automatic process step by step. It should be noted that running these models will not affect the total simulation results. The fully automatic process is represented by just one transition at the fundamental models of the products.

4.1.1.1.1 Fully Automatic Process in Injection Moulding Machine

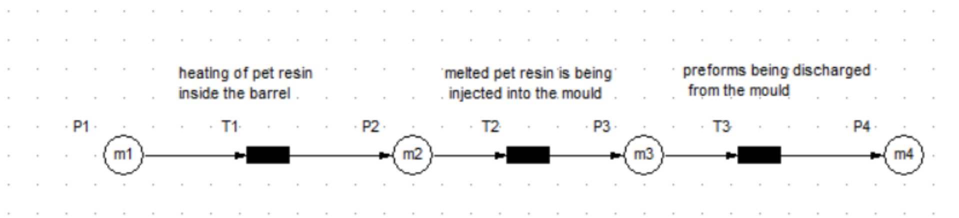


Figure 16. Fully automatic process of injection moulding machine

Each place is a buffer and each transition corresponds to each step that is described at the flow chart (section 3.5.3). Particularly, P1, P2, P3, P4 are buffers for tokens that are being transferred and represent the PET resin. Additionally, T1 represents the heating of PET resin inside the barrel, T2 describes the injection of melted PET resin into the mould and T3 represents the discharge of final products (preforms) from mould on the conveyor belt.

4.1.1.1.2 Fully Automatic Process in Blowing Machine

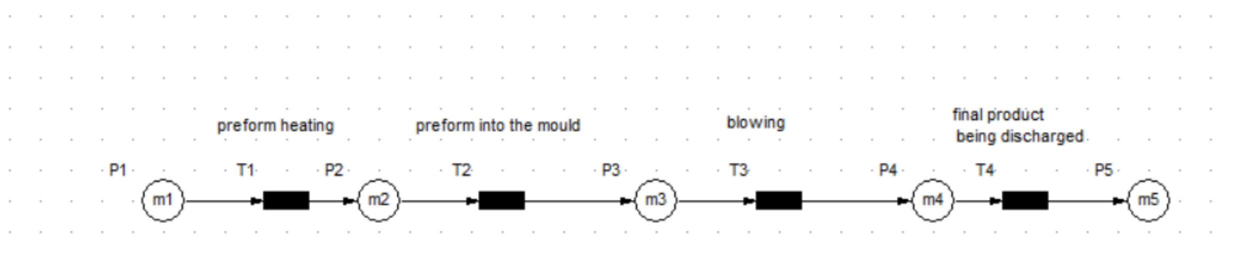


Figure 17. Fully automatic process of blowing machine

Similarly, each place is a buffer and each transition corresponds to each step that is described at the flow chart (section 3.5.3) Specifically, tokens (preforms and bottles or jars) travel by the arcs from places, that are described as buffers, where they stay until the next transitions is ready to fire, to transitions. Specifically, T1 represents the heating of preforms, T2 describes the step of preform entering the mould, T3 represents the blowing, where air is inflated by a metal rod into the preform and T4 describes the discharge of final product (bottle or jar) on the conveyor belt.

4.1.1.2 Modelling the Production Process of Product Category A

There are two types of fundamental models of category A according to the types of packaging and they are illustrated by the following figures.

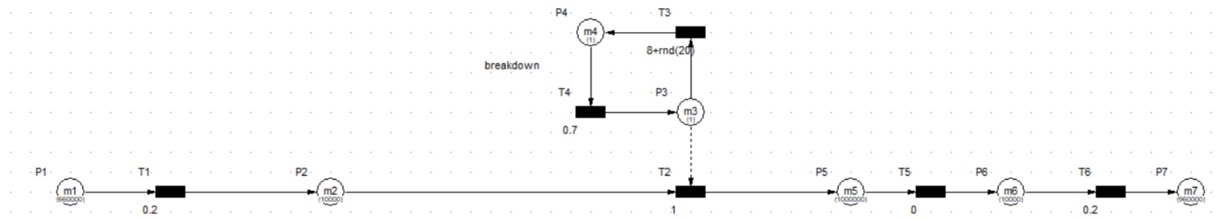


Figure 18. Fundamental model of product category A (packaging: octabin)

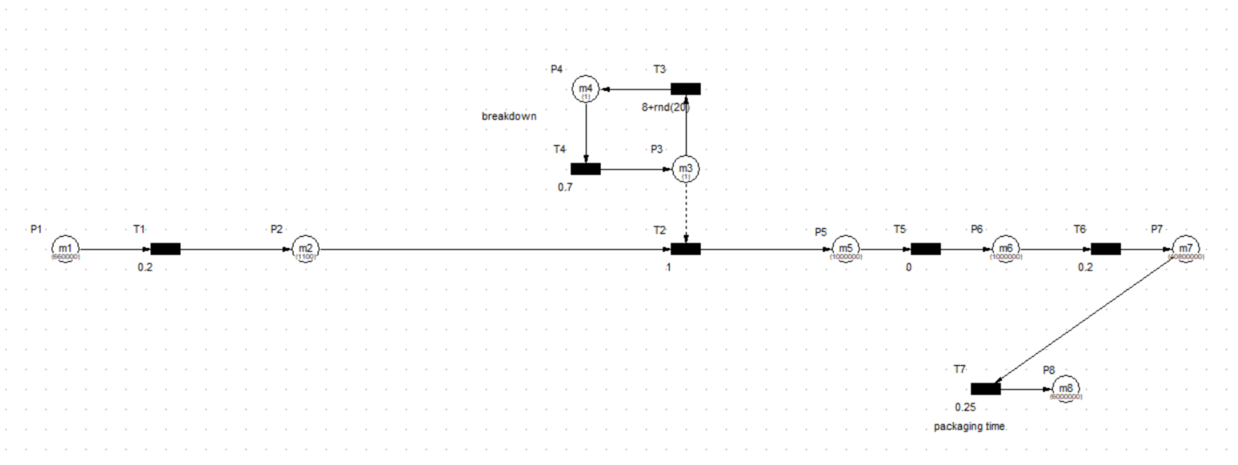


Figure 19. Fundamental model of product category A (packaging: cardboard box)

4.1.1.2.1 Definition of Each Step of Production Process

The following figures show each step of the production process.

- **Transfer of raw material to machine buffer**

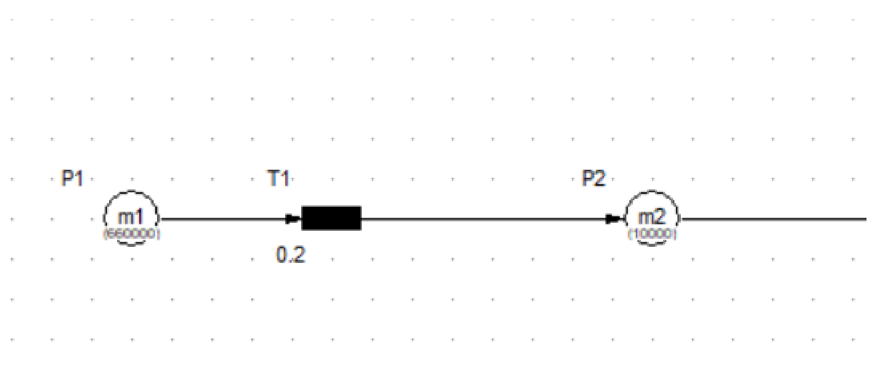


Figure 20. Transfer of raw material to machine buffer

Place P1 is the central buffer, where the raw material (PET resin sack) is stored. The capacity of P1 is 660,000kg which corresponds to 600 sacks of PET resin. PET resin is transferred to the storage of injection moulding machine (Transition T1).

- **Production of preforms**

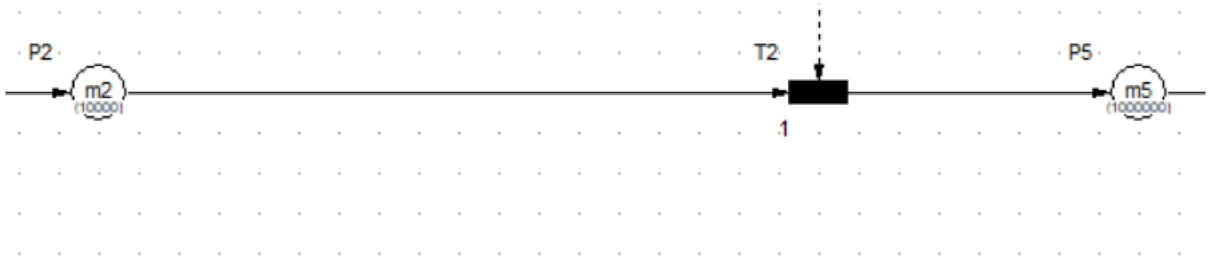


Figure 21. Production of preforms

T2 represents the fully automatic process of the injection moulding machine (which has been described in section 3.5.4). The weight of arc P2->T2 is the necessary quantity of PET resin that is needed for the production of preforms (pieces) per hour, depending on the hourly production of each product. For every start-up of the injection moulding machine, that usually takes place every Monday, PET resin needs to be dried in the drying hopper for approximately 4 hours. As the machine operates for at least 120 hours per week, this drying delay is considered as zero. Moreover, during this time, until the temperature reaches the required level, there is a small amount of faulty preforms (around 6kg), that is considered that holds zero value compared to the 1,100kg that are totally processed. After that period of time, there are no faulty preforms, unless there is a breakdown in the machine. An employee checks every 30 minutes the produced preforms, without stopping or delaying the process.

- **Breakdown**

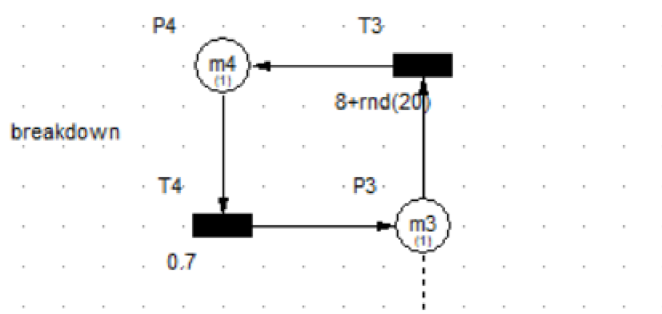


Figure 22. Breakdown

Transition T3 represents the time that breakdowns occur, whereas the delay of T4 is the duration of repair for each breakdown. The activator arc (dashed arc) of P3 to T2 shows that T2 cannot be fired, unless P3 is full. P3 is full only when there is no breakdown in the model. To simplify the modelling, we ended up to the assumption, after adjusting the statistical data, that there is one breakdown per day with a repair delay of 42 minutes. However, there are four or five breakdowns per year with a repair delay of 5-30 minutes, one or two breakdowns per year with a repair delay of two to three days and one breakdown per year with a repair delay of one to two weeks.

- **Packaging: Octabins**

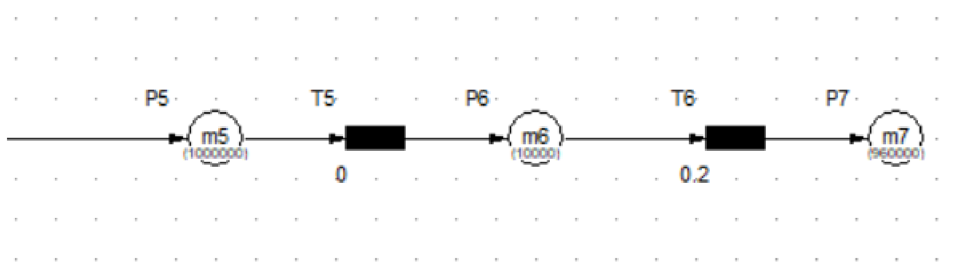


Figure 23. Packaging: Octabins

Transition T5 represents the packaging duration, which is zero because the preforms are transferred directly to the octabin via the conveyor belt, which requires no more steps in order to put them in packages. Finally, preforms are transferred to the central storage in batches.

- **Packaging: Cardboard boxes**

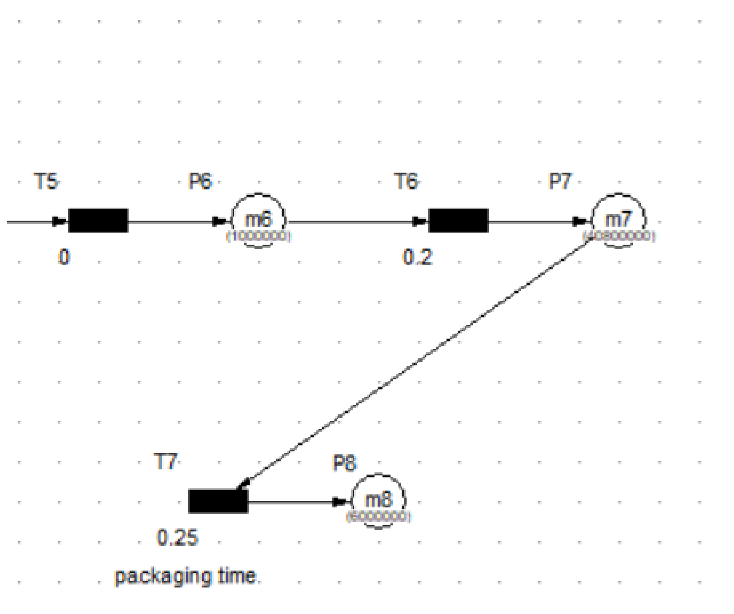


Figure 24. Packaging: Cardboard boxes

Some preforms are packed in cardboard boxes as well. In this case, there is one more transition T7 that shows the duration of packaging in cardboard boxes, after they have been transferred at the central storage.

4.1.1.2.2 Models of the Individual Products

The following figures present the different versions of every model of the individual products.

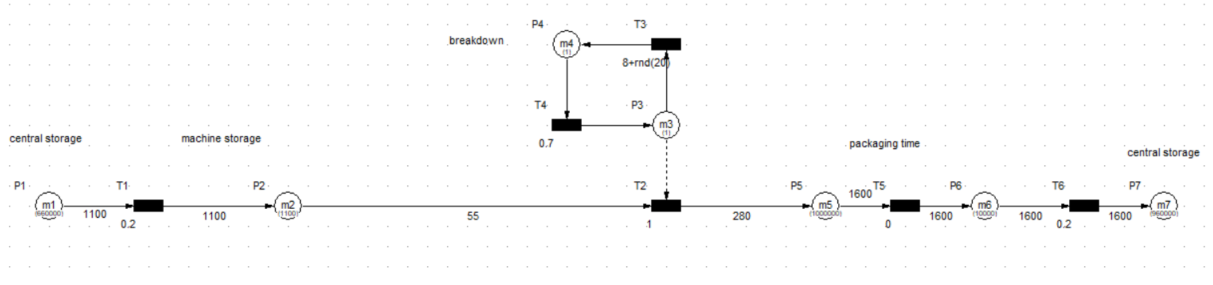


Figure 25. Model of preform Φ48-196gr

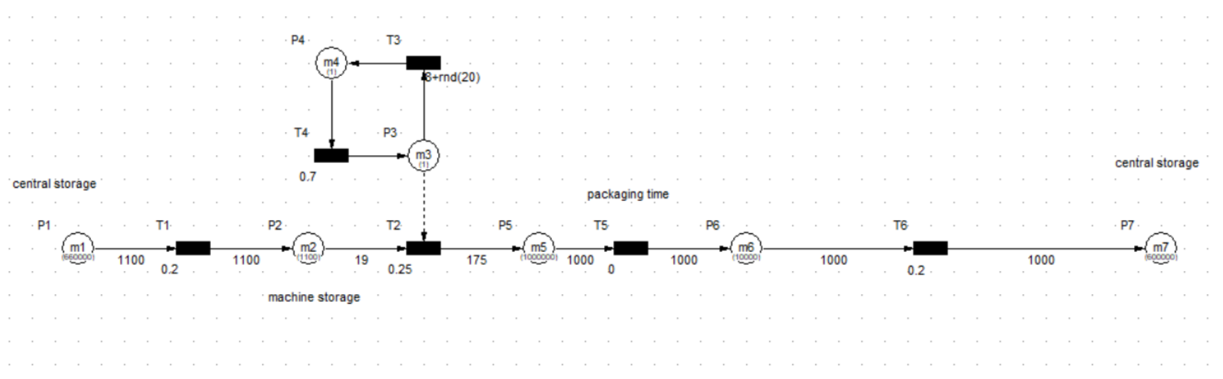


Figure 26. Model of preform Φ110-110gr

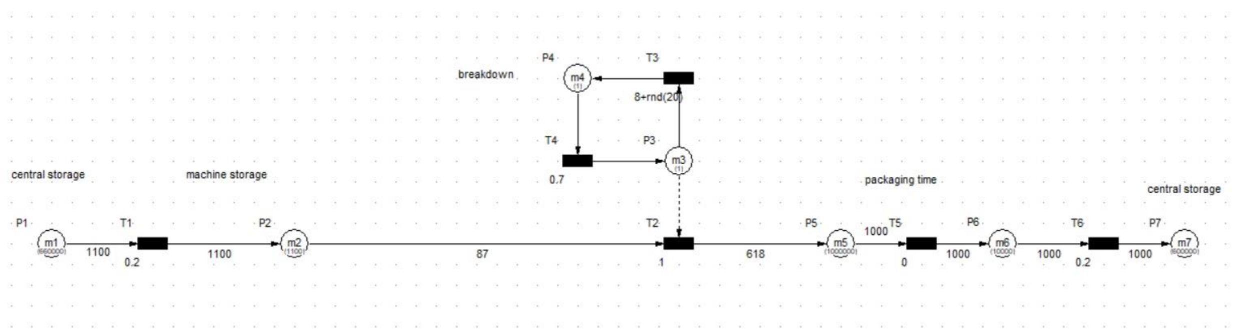


Figure 27. Model of preform Φ110-140gr (packaging: octabin)

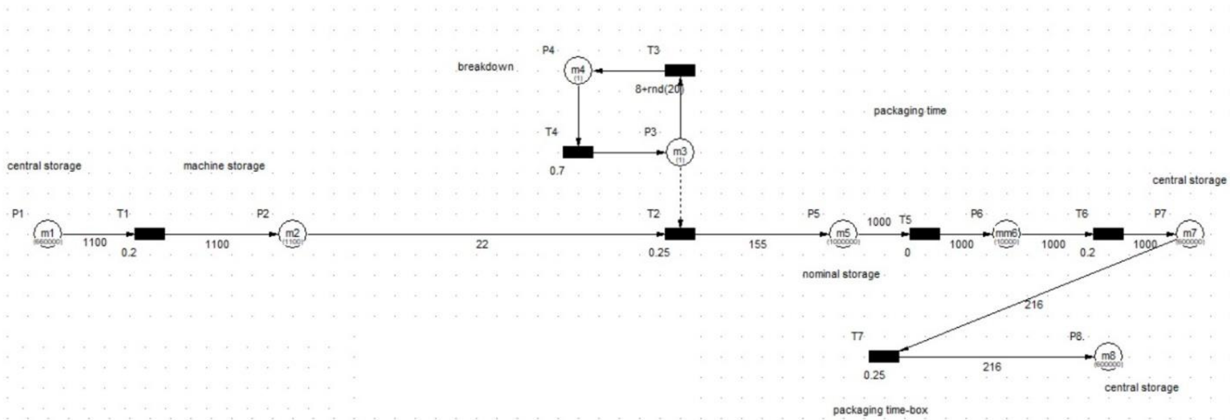


Figure 28. Model of preform Φ110-140gr (packaging: cardboard box)

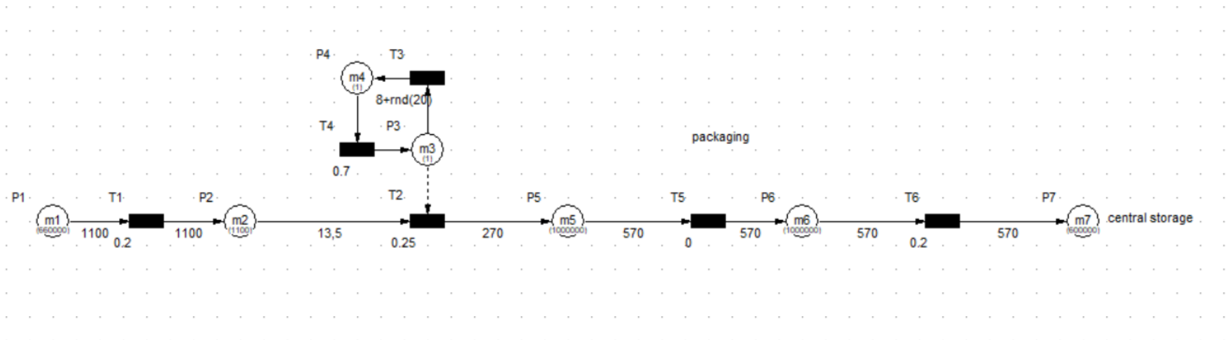


Figure 29. Model of preform Φ82-50gr

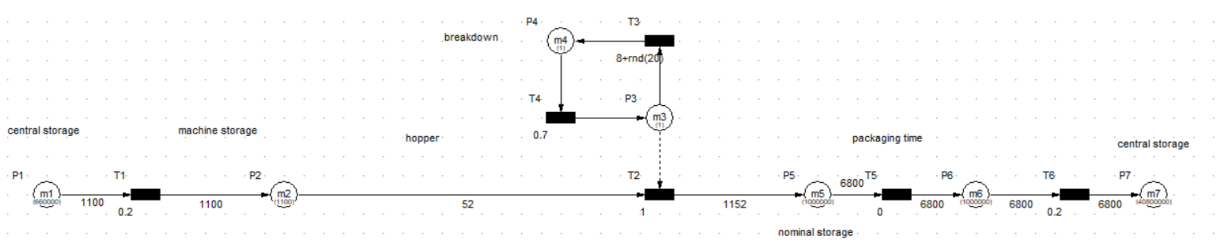


Figure 30. Model of preform Φ63-45gr (packaging: octabin)

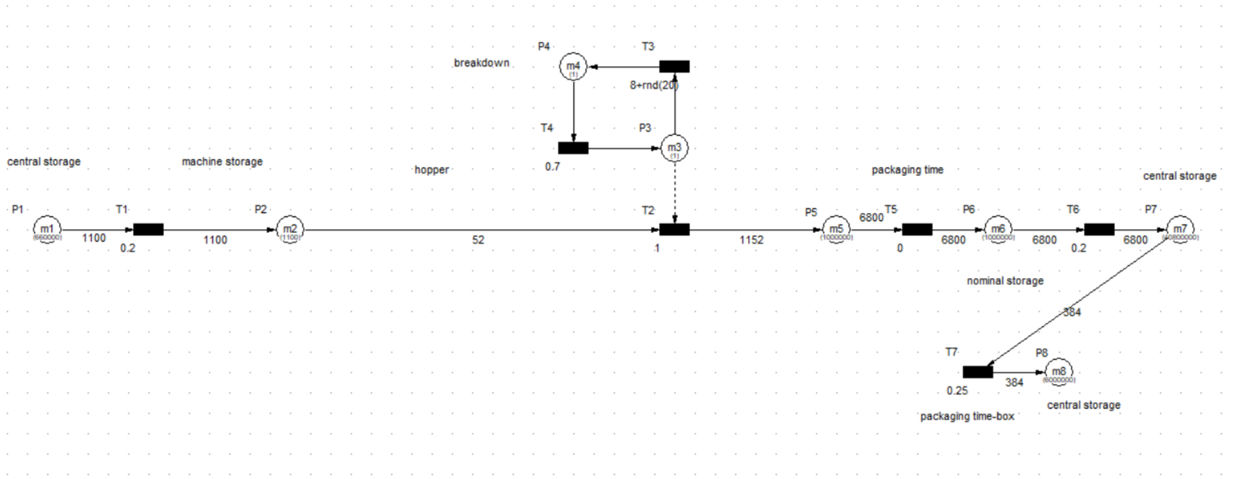


Figure 31. Model of preform Φ63-45gr (packaging: cardboard box)

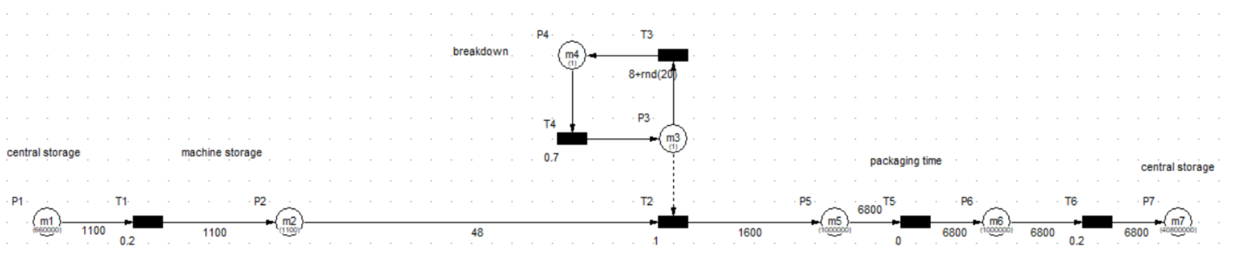


Figure 32. Model of preform Φ63-30gr (packaging: octabin)

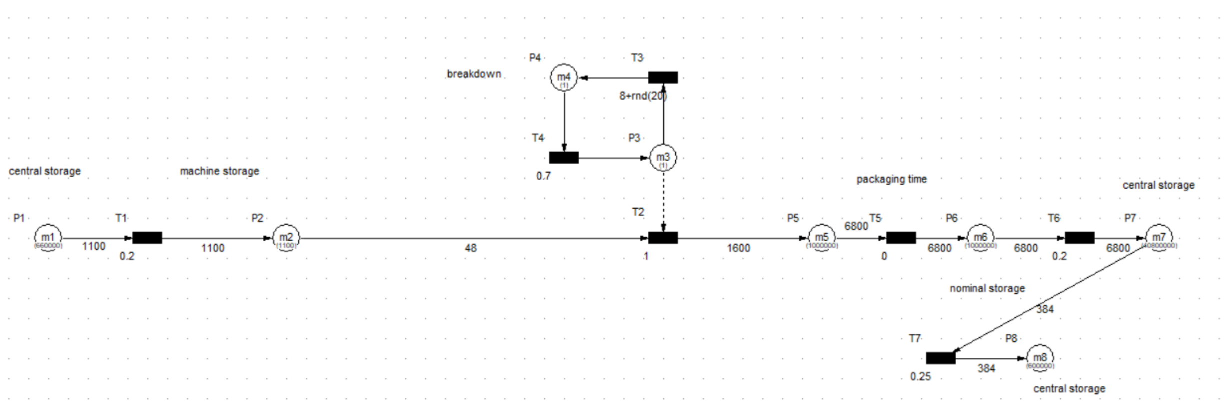


Figure 33. Model of preform Φ63-30gr (packaging: cardboard box)

Tables 6, 7 and 8 summarize the values of the places (the nodes where raw materials, in process-parts and products are placed), the transitions (the steps that are required in order materials or in process-parts to be transformed into a final product) and the arc weights (i.e. batches, random values for quality control) that complete the models of the individual products with Petri nets and explain the definition of each one.

Name	Definition	Preform Φ110-196gr	Preform Φ110-110gr	Preform Φ82-50gr	Preform Φ110-140gr	Preform Φ63-45gr	Preform Φ63-30gr
P1	Central buffer	660,000 kg	660,000 kg	660,000 kg	660,000 kg	660,000 kg	660,000 kg
P2	Hopper machine	3,300 kg	3,300 kg	3,300 kg	3,300 kg	3,300 kg	3,300 kg
P3	Control place for activation of breakdown	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
P4	Control place for activation of repair	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
P5	In-between nominal place	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs
P6	In-between nominal place	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs
P7	Inventory storage	960,000 pcs	600,000 pcs	600,000 pcs	600,000 pcs	4,080,000 pcs	4,080,000 pcs
P8	Inventory storage	-	-	-	1,620,000 pcs	4,080,000 pcs	4,080,000 pcs

Table 6. Places of each model: Definition & Capacity

Name	Definition	**Φ110 196gr**	**Φ110 110gr**	**Φ82 50gr**	**Φ110 140gr *Octabin***	**Φ110 140gr *Cardboard Box***	**Φ63 45gr *Octabin***	**Φ63 45gr *Cardboard***	**Φ63 30gr *Octabin***	**Φ63 30gr *Cardboard Box***
T1	Transfer of raw material to injection machine (h)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
T2	Production of preforms: Fully automatic process of injection machine (h)	1	1	1	1	1	1	1	1	1
T3	Time between breakdowns (h)	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]
T4	Repair (h)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
T5	Packaging (h)	0	0	0	0	0	0	0	0	0
T6	Transfer of palette to inventory storage (h)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
T7	Packaging of carton box (h)	-	-	-	-	0.25	-	0.25	-	0.25

Table 7. Transitions of each model: Definition & Delay

Name	**Connection**	**Preform Φ110 196gr**	**Preform Φ110 110gr**	**Preform Φ82 50gr**	**Preform Φ110 140gr *Octabin***	**Preform Φ110 140gr *Cardboard Box***	**Preform Φ63 45gr *Octabin***	**Preform Φ63 45gr *Cardboard Box***	**Preform Φ63 30gr *Octabin***	**Preform Φ63 30gr *Cardboard Box***
I1	P1→T1	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
O1	TI→P2	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100	1,100
I2	P2→T2	55	77	54	87	88	52	52	48	48

I3	P3→T2 *activator arc*	1	1	1	1	1	1	1	1	1
I4	P3→T3	1	1	1	1	1	1	1	1	1
O2	T3→P4	1	1	1	1	1	1	1	1	1
I5	P4→T4	1	1	1	1	1	1	1	1	1
O3	T4→P3	1	1	1	1	1	1	1	1	1
O4	T2→P5	280	697	1,080	618	620	1,152	1,152	1,600	1,600
I6	P5→T5	1,600	1,000	570	1,000	1,000	6,800	6,800	6,800	6,800
O5	T5→P6	1,600	1,000	570	1,000	1,000	6,800	6,800	6,800	6,800
I7	P6→T6	1,600	1,000	570	1,000	1,000	6,800	6,800	6,800	6,800
O6	T6→P7	1,600	1,000	570	1,000	1,000	6,800	6,800	6,800	6,800
I8	P7→T7	-	-	-	-	216	-	384	-	384
O7	T7→P8	-	-	-	-	216	-	384	-	384

Table 8. Arcs of each model: Connection & Weight

The inputs of the quantitative parameters of all the models of each individual product were defined by looking thoroughly the files, interviewing the employees and after checking real time observations. Most of the values are the most common ones.

4.1.1.2.3 Evaluation of Simulation Results

After the modelling with Petri Nets, the simulation of each model of the individual products follows. Table 9 summarize the results that were obtained after the simulation running for each product.

		Octabin Packaging			**Cardboard Packaging**		
Product	**INPUT *PET Resin (kg)***	**OUTPUT *Total (pcs)***	**OUTPUT *Packaging (pcs)***	**Production Time *(h)***	**OUTPUT *Total (pcs)***	**OUTPUT *(pcs)***	**Production Time *(h)***
Preform Φ48 95gr	1,100	5,460	4,800	20.62			
	2,200	10,990	9,600	42			
	550	2,730	1,600	10.2			
	1,100	9,975	9,000	15			

Preform Φ110 110gr	2,200	20,125	20,000	29			
	5,500	4,900	4,000	9			
Preform Φ110 140gr	1,100	7,750	7,000	13.5	7,750	6,912	14
	2,200	15,500	15,000	30.1	15,500	14,256	26
	550	3,875	3,000	7.4	3,875	2,808	6.2
Preform Φ63 45gr	1,100	24,192	20,400	23	24,192	20,352	23.5
	2,200	47,808	47,600	43	48,672	43,776	45
	550	12,096	6,800	10.5	12,096	6,528	10.8
Preform Φ63 30gr	1,100	36,400	34,000	24	36,400	27,264	24
	2,200	73,200	68,000	49	73,000	65,664	49.5
	550	18,000	13,600	11.2	17,600	13,440	13.2
Preform Φ82 50gr	1,100	20,760	20,520	20.1			
	2,200	42,390	42,180	42			
	550	10,530	10,260	11			

Table 9. Simulation results of the models of individual products (Category A)

Product	Fundamental Model *(pcs)*	Actual production *(pcs)*	Success Rate
Preform Φ48 195gr	2,170	2,288	94.56%
Preform Φ110 110gr	5,425	5,760	93.82%
Preform Φ110 140gr	4,710	4,800	99.79%
Preform Φ82 50 gr	8,370	8,640	96.77%
Preform Φ63 45gr	8,928	11,040	76.34%
Preform Φ63 30gr	12,400	12,800	96.77%

Table 10. Comparison between the output of the models of individual products (category A) and the actual production (8-hour shift)

In addition, Table 10 compares the actual production of preforms and the production values that obtained as outputs from simulations of the models of the individual products. The values show the production of pieces every 8 hours that correspond to one shift. The column of “Success Rate” defines the accuracy rate of the modelling that have been performed. Eventually, the success rate of more than 93% verifies that the models implemented manage to represent reality in a very satisfactory way, apart from the model of Preform Φ63-45gr.

4.1.1.3 Modelling the Production Process of Product Category B

The following figure presents the fundamental model of category B.

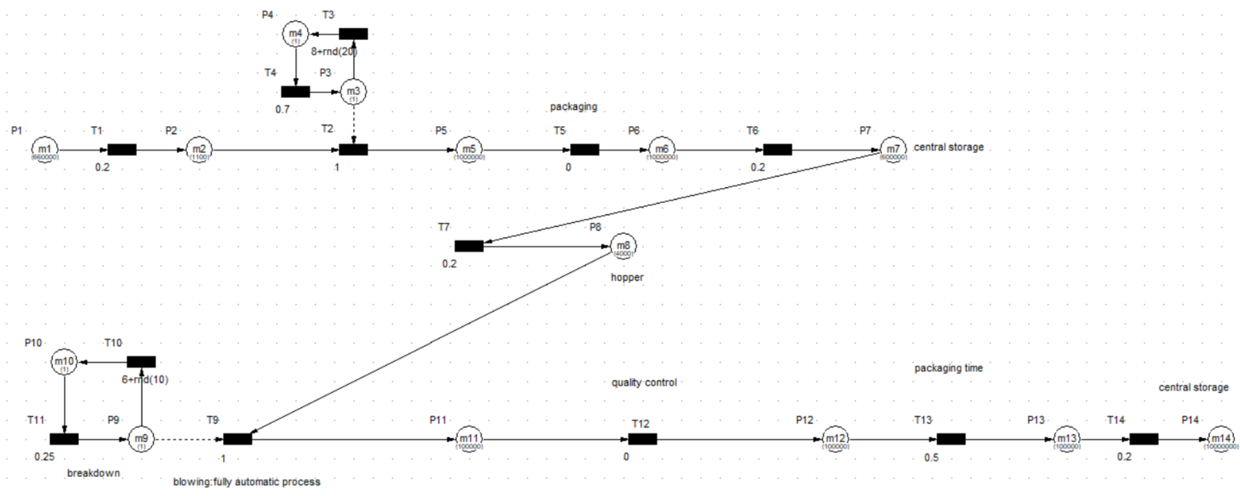


Figure 34. Fundamental model of category B

4.1.1.3.1 Definition of Each Step of the Production Process

The following figures present the definition of each step of the production process.

- **Transfer of raw material to injection moulding machine buffer**

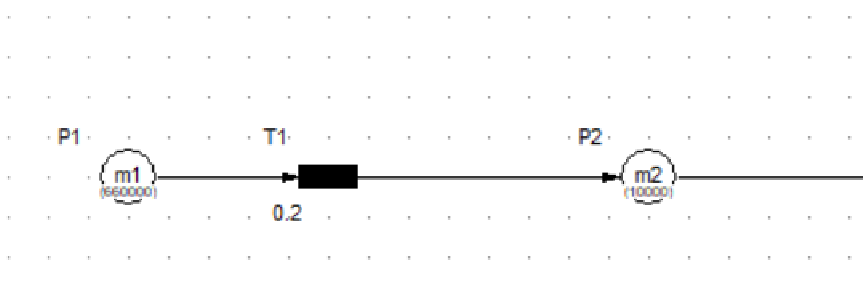


Figure 35. Transfer of raw material to injection moulding machine buffer

Place P1 is the central buffer, where the raw material (PET resin sack) is stored. The capacity of P1 is 660,000kg which corresponds to 600 sacks of PET resin. PET resin is transferred to the storage of injection moulding machine (Transition T1).

- **Production of preforms**

Figure 36. Production of preforms

T2 represents the fully automatic process of the injection moulding machine (which has been described in section 3.5.4). The weight of arc P2->T2 is the amount of PET resin that is necessary for the production of preforms (pieces) per hour, depending on the hourly production of each product. As it has already been described in the previous section, for every start-up of the injection moulding machine, that usually happens every Monday, PET resin needs to dry in the drying hopper for approximately 4 hours. As the machine operates for at least 120 hours per week, the drying delay is considered as zero. Moreover, during this time, until the temperature reaches the required level, there is a small amount of faulty preforms (around 6kg), that is considered that holds zero value compared to the 1,100kg that are totally processed. After that period of time, there are no faulty preforms, unless there is a breakdown in the machine. An employee checks every 30 minutes the produced preforms, without delaying or stopping the process.

- **Breakdown of injection moulding machine**

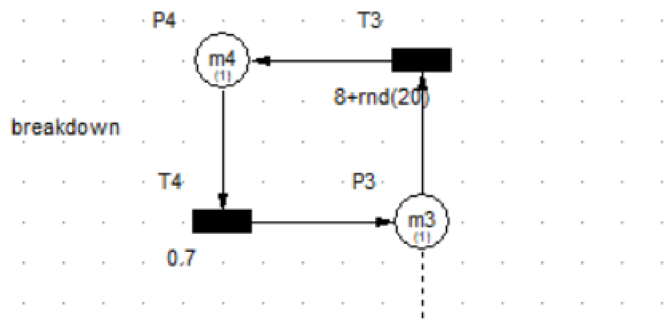


Figure 37. Breakdown of injection moulding machine

Transition T3 represents the time that breakdown occurs, whereas T4 is the duration of repair for each breakdown. The activator arc (dashed arc) of P3 to T2 shows that T2 cannot be fired, unless P3 is full. P3 is full only when there is no breakdown at the model. To simplify the modelling, we ended up to the assumption, after adjusting the statistical data, that there is one breakdown per day with a repair delay of 42 minutes. However, there are four or five breakdowns per year with a repair delay of 5-30 minutes, one or two breakdowns per year with a repair delay of two to three days and one breakdown per year with a repair delay of one to two weeks.

- **Packaging**

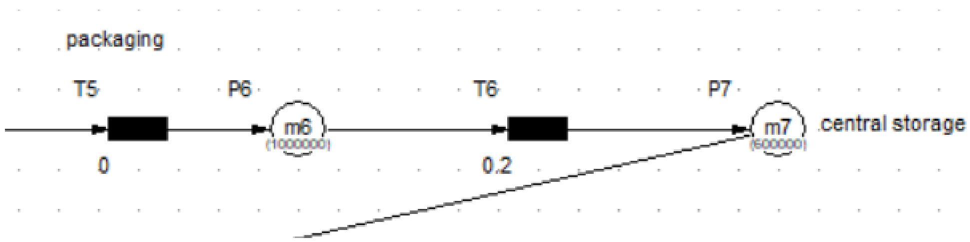


Figure 38. Packaging of preforms

Transition T5 represents the duration of packaging, which is zero because the preforms are transferred directly to the octabin via the conveyor belt, which requires no more steps in order to put them in packages. Finally, preforms are transferred to the central storage in batches.

- **Preforms are transferred to the hopper of blowing machine**

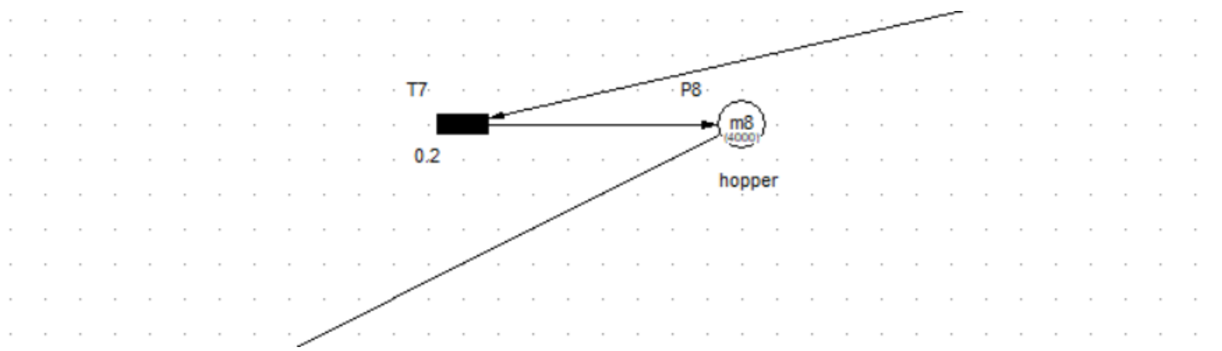


Figure 39. Transfer of preforms to the hopper of blowing machine

Octabins full of preforms are being transferred (T7) from the central storage to the hopper (P8) of blowing machine, with capacity 2000 pieces.

- **Breakdown of blowing machine**

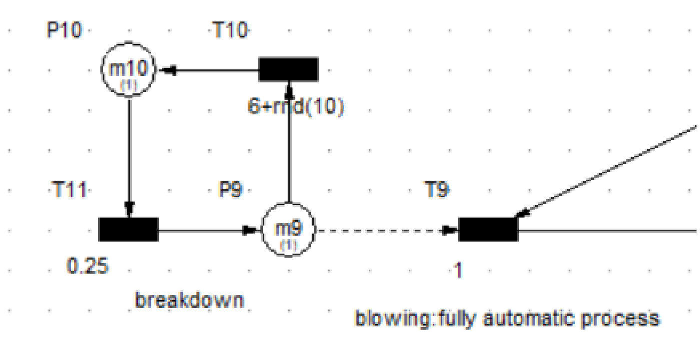


Figure 40. Breakdown of blowing machine

Transition T10 represents the time that breakdown occurs, whereas T11 is the duration of repair for each breakdown. The activator arc (dashed arc) of P9 to T9 shows that T9 cannot be fired, unless P9 is full. P9 is full only when there is no breakdown at the model. To simplify the modelling, we ended up to the assumption, after adjusting the statistical data, that there are two breakdowns per day and the repair delay is approximately 15 minutes, whereas usually there are one or two breakdowns per week with a repair delay of 5-30 minutes and two or three breakdowns per year with a repair delay of one or two days.

- **Production of final product: bottle/jar**

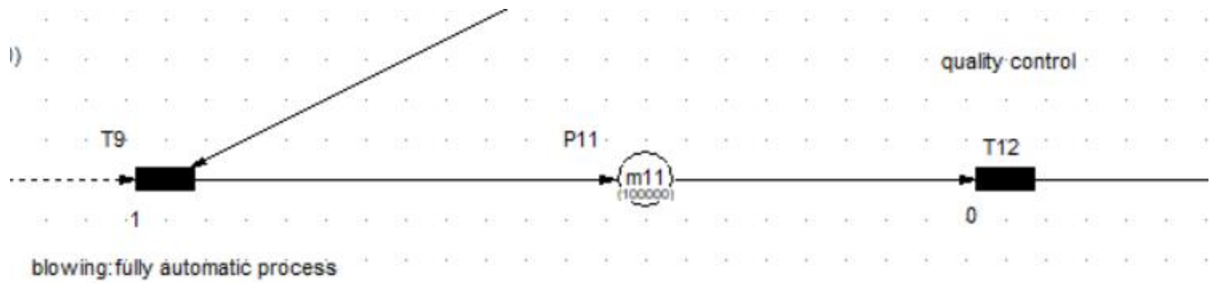


Figure 41. Production of final product: bottle/jar

Transition T9 represents the fully automatic process of blowing machine (that is described in section 3.5.5), where bottles or jars are being produced out of preforms. Place P9 is a nominal buffer, where the final products remain until the quality control takes place. The delay of quality control (T12) can be considered as zero, as there is an employee who checks the final products during the production without stopping or delaying the whole process. If there is a faulty product, it is simply removed. The weight of the arc that connects quality control (T12) and place (P12) is a random value that is based on statistics about the faulty products of each product code per hour.

- **Packaging**

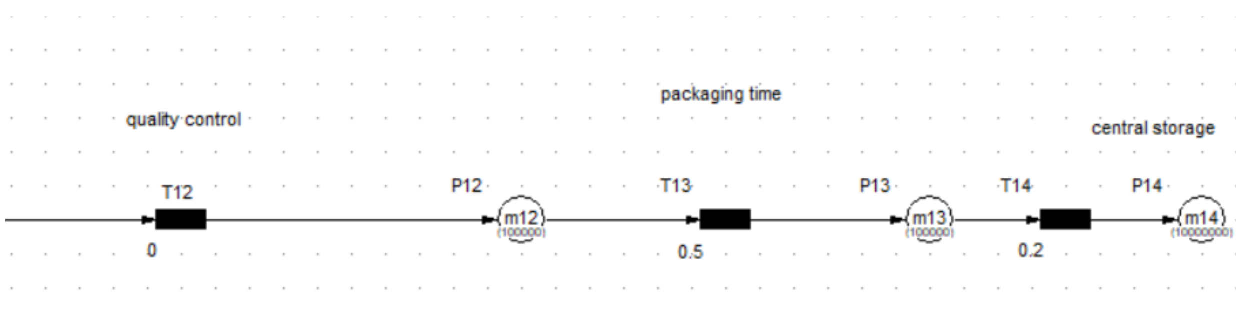


Figure 42. Packaging of category B

Transition T13 shows the packaging process, which consists of manual packaging of palettes, manual filling of bags, automatic palletizing and wrapping. Wrapping completes the stage of packaging process of a palette; during this process, an automatic wrapping machine covers the palette with film in order to protect the products and avoid any damage. Transition T14 represents the final transfer of palette/bag to the central buffer.

4.1.1.3.2 Models of Individual Products

The following figures present the different versions of the models of the individual products.

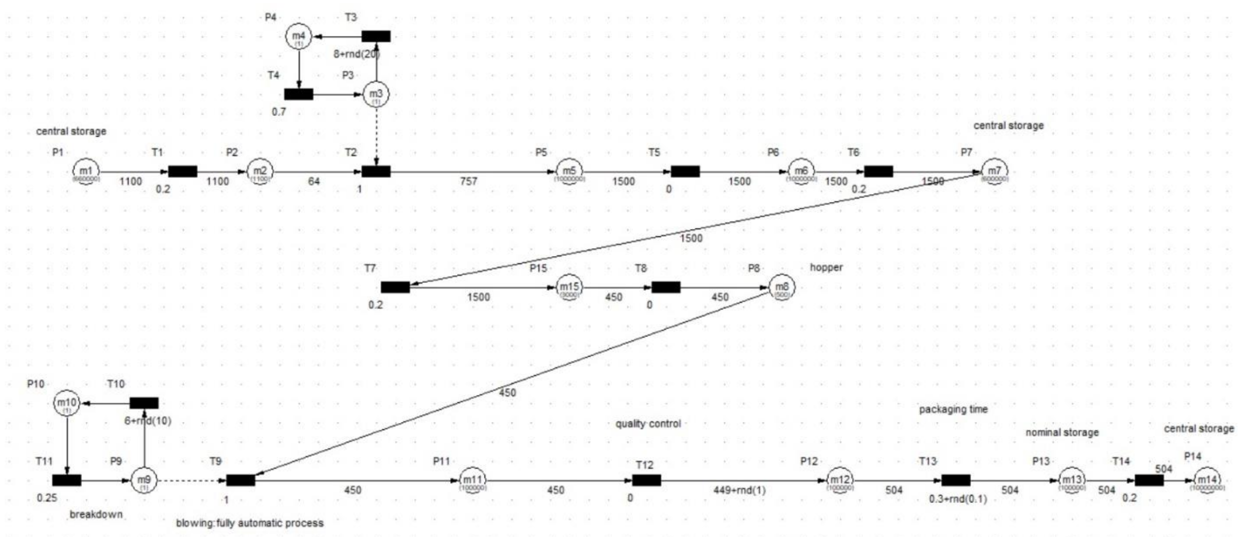


Figure 43. Model of Bottle – 3lt

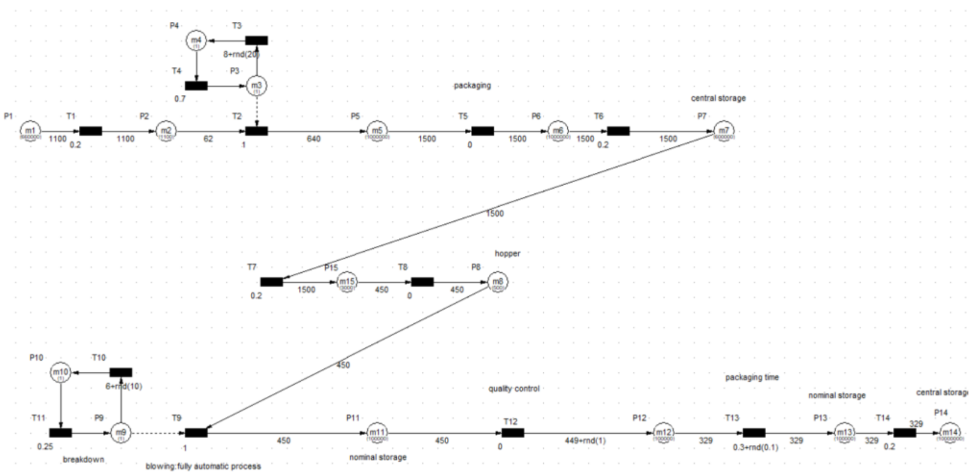


Figure 44. Model of Bottle-5lt (packaging: palette)

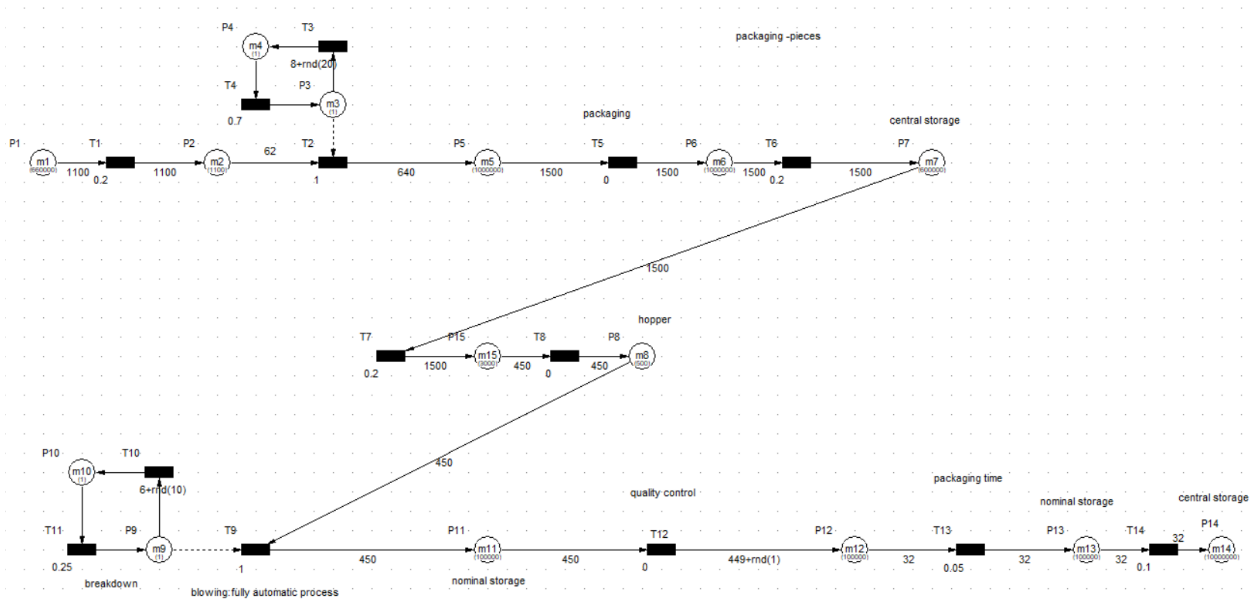


Figure 45. Model of Bottle-5lt (packaging: bag)

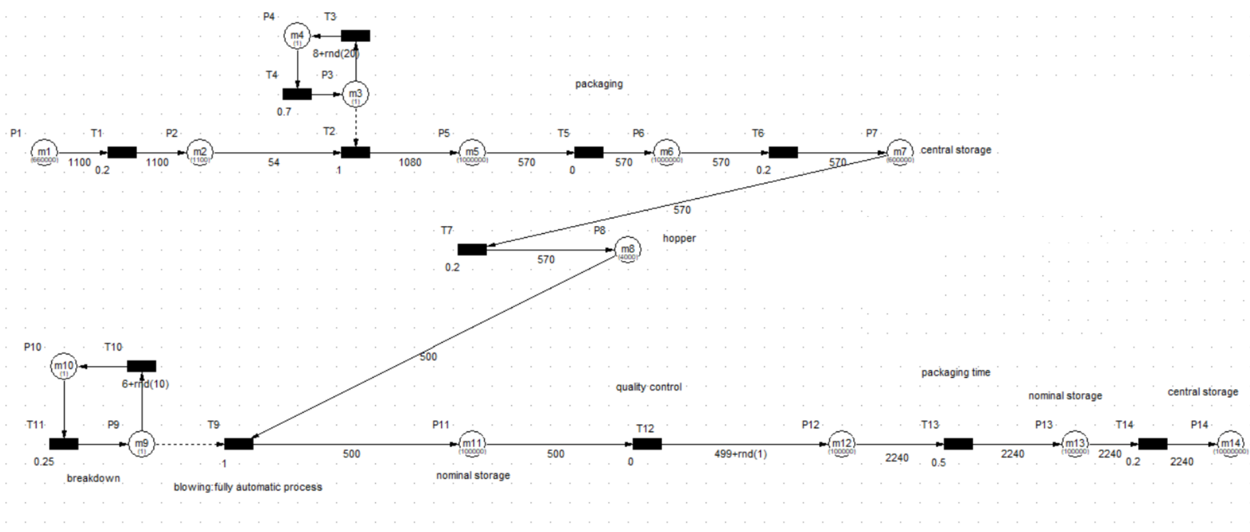


Figure 46. Model of Jar - 720ml

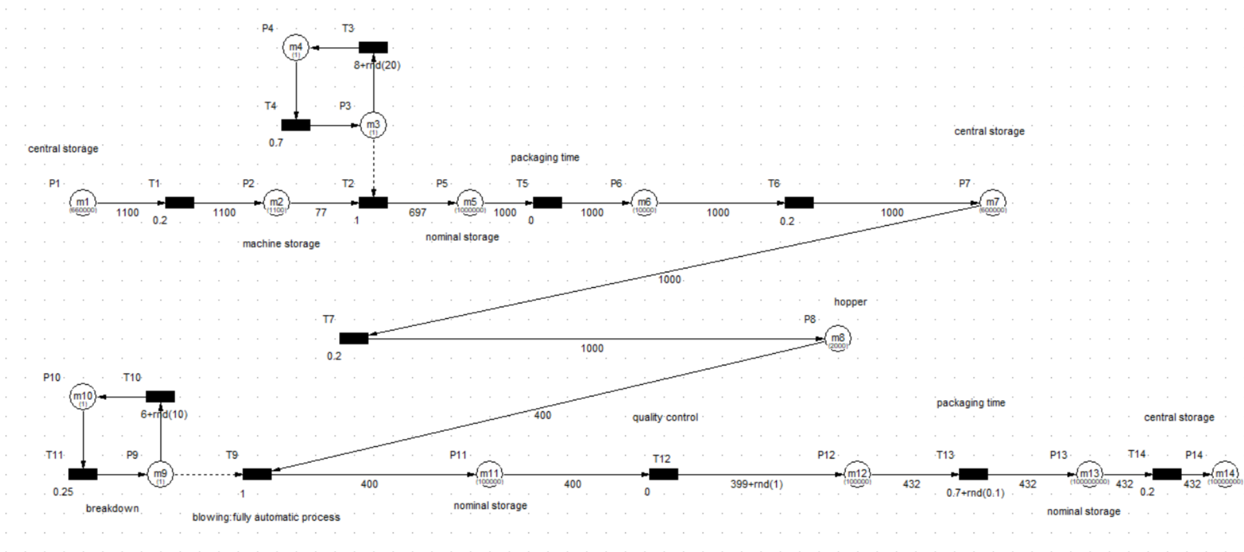


Figure 47. Model of Jar – 1gal

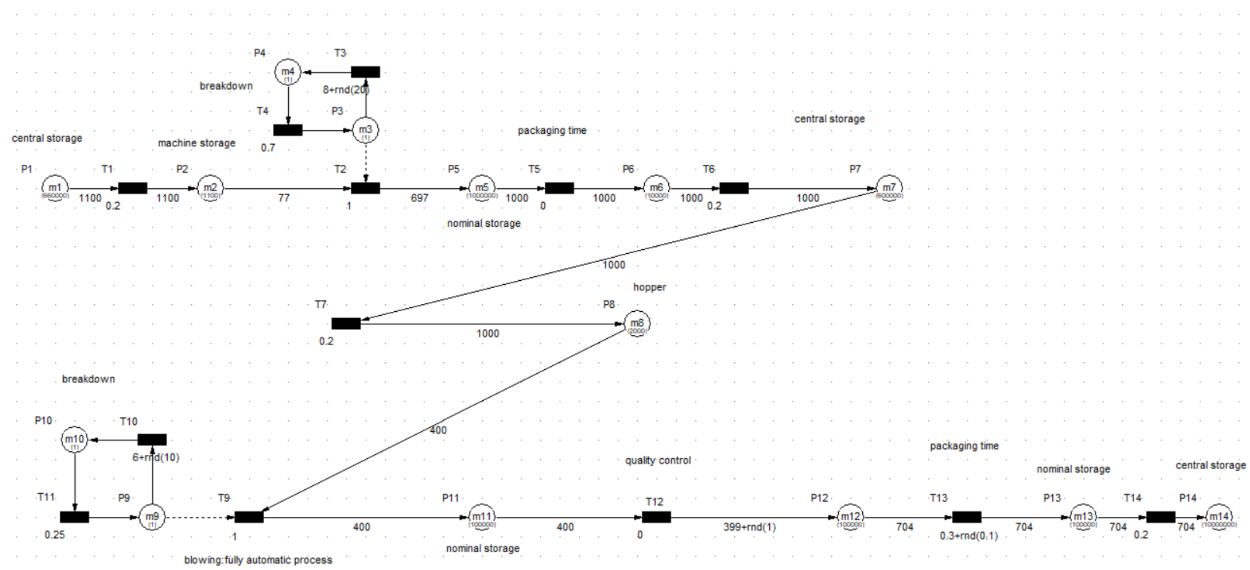


Figure 48. Model of Jar-2lt honey (packaging: palette)

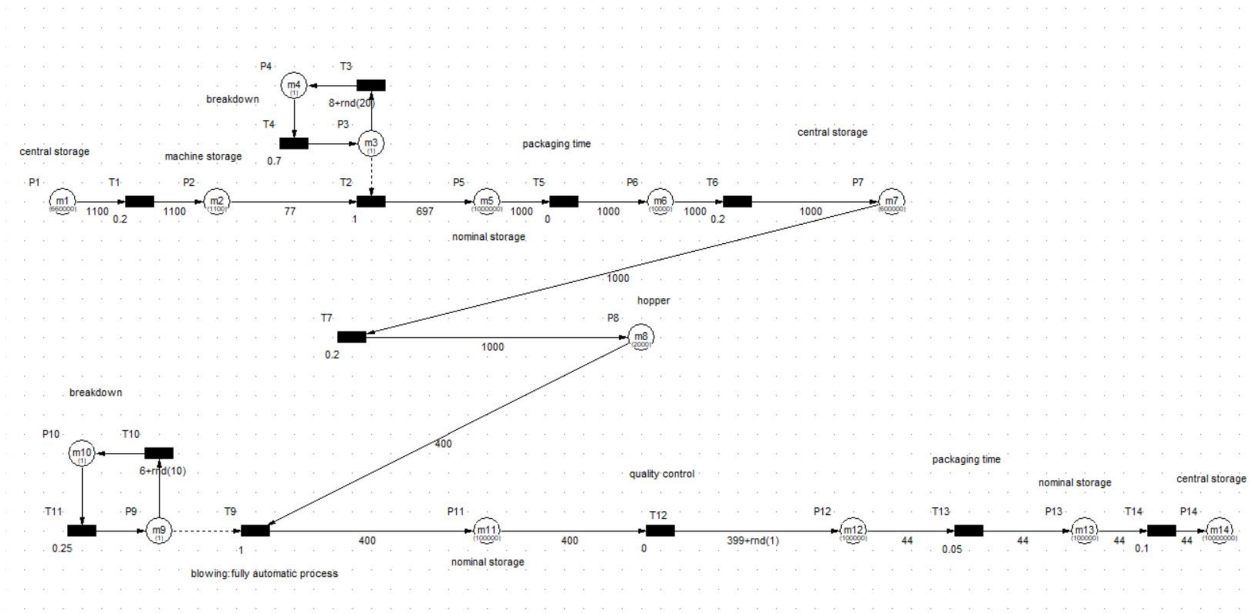


Figure 49. Model of Jar-2lt honey (packaging: bag)

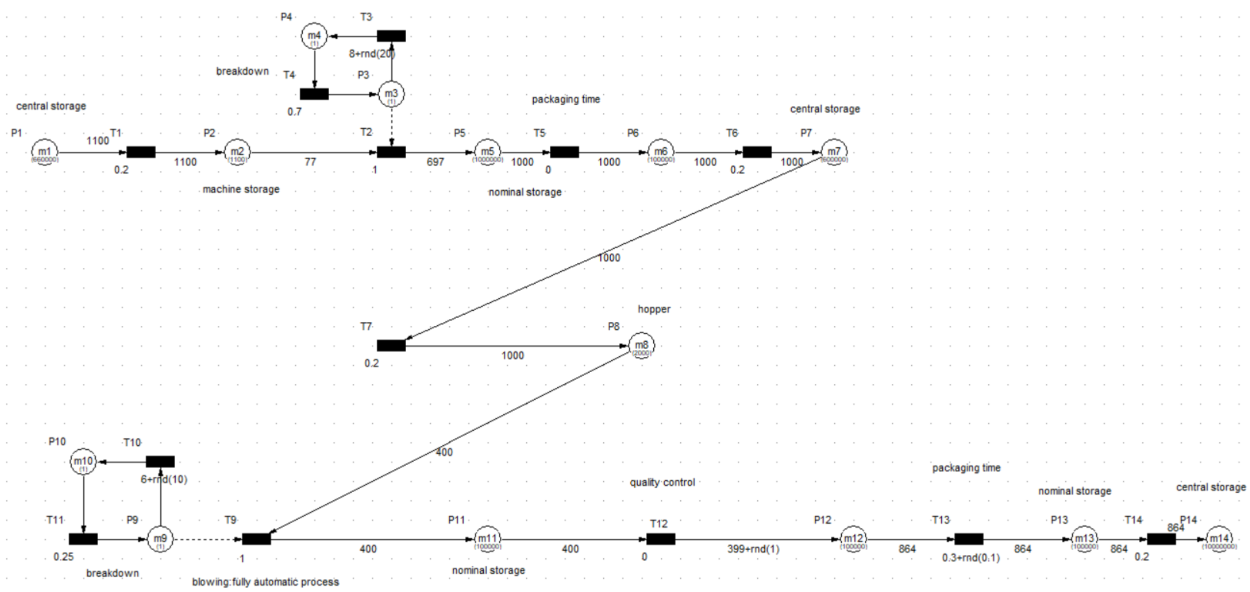


Figure 50. Model of Jar-2lt square

Tables 11-14 summarize the meaning and the capacity of the places (the nodes where raw material and products are placed), the transitions (the steps that are required in order materials or in-process products to be turned into a final product) and the arc weights (i.e. batches, random values for quality control) that complete the models of the individual products with Petri Nets and explain the definition of each component.

Name	Definition	Bottle 3lt	Bottle 5lt	Jar 720ml	Jar 1gal	Jar 2lt *Honey*	Jar 2lt *Square*
P1	Central buffer	660,000 kg	660,000 kg	660,000 kg	660,000 kg	660,000 kg	660,000 kg
P2	Hopper machine	3,300 kg	3,300 kg	3,300 kg	3,300 kg	3,300 kg	3,300 kg
P3	Control place for activation of breakdown	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
P4	Control place for activation of repair	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
P5	In-between nominal place	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs	1,000,000 pcs
P6	In-between nominal place	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs
P7	Inventory storage	600,000 pcs	600,000 pcs	600,000 pcs	600,000 pcs	600,000 pcs	600,000 pcs
P8	Hopper machine	500 pcs	500 pcs	4,000 pcs	2,000 pcs	2,000 pcs	2,000 pcs
P9	Control place for activation of breakdown	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
P10	Control place for activation of repair	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1	0 or 1
P11	In-between nominal place	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs

P12	In-between nominal place	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs
P13	Temporary buffer for bottles/jars	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs	100,000 pcs
P14	Inventory storage	10,000,000 pcs	10,000,000 pcs	10,000,000 pcs	10,000,000 pcs	10,000,000 pcs	10,000,000 pcs
P15	Temporary buffer for pallet of preforms	3,000 pcs	3,000 pcs	-	-	-	-

Table 11. Places of each model: Definition & Capacity

Name	**Definition**	**Bottle 3lt**	**Bottle 5lt *Pallet***	**Bottle 5lt *Bag***	**Jar 720ml**	**Jar 1gal**	**Jar 2lt Honey *Pallet***	**Jar 2lt Honey *Bag***	**Jar 2lt Square**
T1	Transfer of raw material to injection machine (h)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
T2	Production of preforms: Fully automatic process of injection machine (h)	1	1	1	1	1	1	1	1
T3	Time between breakdowns (h)	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]	[8,28]
T4	Repair (h)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
T5	Packaging (h)	0	0	0	0	0	0	0	0
T6	Transfer of palette to inventory storage (h)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
T7	Transfer of palette to	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

	blowing machine (h)								
T8	Dummy transition for activation of next operation (h)	0	0	0	-	-	-	-	-
T9	Production of bottles/jars: Fully automatic process of blowing machine (h)	1	1	1	1	1	1	1	1
T10	Time between breakdowns (h)	[6,16]	[6,16]	[6,16]	[6,16]	[6,16]	[6,16]	[6,16]	[6,16]
T11	Repair (h)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
T12	Quality control (h)	0	0	0	0	0	0	0	0
T13	Packaging (h)	[0.3,0.4]	[0.3,0.4]	0.05	0.5	[0.7,0.8]	[0.3,0.4]	0.05	[0.3,0.4]
T14	Transfer of palette/bag to inventory storage (h)	0.2	0.2	0.1	0.2	0.2	0.2	0.1	0.2

Table 12. Transitions of each model: Definition & Delay

Name	**Connection**	**Bottle 3lt Olive Oil**	**Bottle 5lt** ***Pallet***	**Bottle 5lt** ***Bag***
I1	P1→T1	1,100	1,100	1,100
O1	T1→P2	1,100	1,100	1,100
I2	P2→T2	64	62	62
I3	P3→T2 *activator arc*	1	1	1
I4	P3→T3	1	1	1
O2	T3→P4	1	1	1
I5	P4→T4	1	1	1
O3	T4→P3	1	1	1
O4	T2→P5	757	640	640
I6	P5→T5	1,500	1,500	1,500
O5	T5→P6	1,500	1,500	1,500
I7	P6→T6	1,500	1,500	1,500
O6	T6→P7	1,500	1,500	1,500

I8	P7→T7	1,500	1,500	1,500
O7	T7→P15	1,500	1,500	1,500
I9	P15→T8	450	450	450
O8	T8→P8	450	450	450
I10	P8→T9	450	450	450
I11	P9→T9 *activator arc*	1	1	1
I13	P9→T10	1	1	1
O9	T10→P10	1	1	1
I14	P10→T11	1	1	1
O10	T11→P9	1	1	1
O11	T9→P11	450	450	450
I15	P11→T12	450	450	450
O12	T12→P12	[449,450]	[449,450]	[449,450]
I16	P12→T13	504	329	32
O13	T13→P13	504	329	32
I17	P13→T14	504	329	32
O14	T14→P14	504	329	32

Table 13. Arcs of models: Connection & Weight

Name	Connection	Jar 720ml	Jar 1gal	Jar 2lt Honey *Pallet*	Jar 2lt Honey Bag	Jar 2lt Square
I1	P1→T1	1,100	1,100	1,100	1,100	1,100
O1	T1→P2	1,100	1,100	1,100	1,100	1,100
I2	P2→T2	54	77	77	77	77
I3	P3→T2 *activator arc*	1	1	1	1	1
I4	P3→T3	1	1	1	1	1
O2	T3→P4	1	1	1	1	1
I5	P4→T4	1	1	1	1	1
O3	T4→P3	1	1	1	1	1
O4	T2→P5	1,080	697	697	697	697
I6	P5→T5	570	1,000	1,000	1,000	1,000
O5	T5→P6	570	1,000	1,000	1,000	1,000
I7	P6→T6	570	1,000	1,000	1,000	1,000
O6	T6→P7	570	1,000	1,000	1,000	1,000
I8	P7→T7	570	1,000	1,000	1,000	1,000
O7	T7→P8	570	1,000	1,000	1,000	1,000
I9	P8→T9	500	400	400	400	400

I10	P9→T9 activator arc	1	1	1	1	1
I11	P9→T10	1	1	1	1	1
O8	T10→P10	1	1	1	1	1
I12	P10→T11	1	1	1	1	1
O9	T11→P9	1	1	1	1	1
O10	T9→P11	500	400	400	400	400
I13	P11→T12	500	400	400	400	400
O11	T12→P12	[449,450]	[399,400]	[399,400]	[399,400]	[399,400]
I14	P12→T13	2,240	432	704	44	864
O12	T13→P13	2,240	432	704	44	864
I15	P13→T14	2,240	432	704	44	864
O13	T14→P14	2,240	432	704	44	864

Table 14. Arcs of models: Connection & Weight

The initial values of the quantitative parameters were defined by looking thoroughly the files, interviewing the employees and checking real time observations. Most of the values are the most common ones.

4.1.1.3.3 Evaluation of Simulation Results

Table 15 summarizes the results that were obtained from the simulation running of every model of product category B.

			Palette Packaging				**Bag Packaging**			
Product	**INPUT *PET Resin (kg)***	**INPUT *Preforms (pcs)***	**OUTPUT *Total (pcs)***	**OUTPUT *(pcs)***	**Production Time *(h)***	**Packaging Time *(h)***	**OUTPUT *Total (pcs)***	**OUTPUT *(pcs)***	**Production Time *(h)***	**Packaging Time *(h)***
3lt	1,100	3,000	14,901	14,616	33.8	34.3				
	1,100	0	11,963	11,592	28.70	29.80				
	0	3,000	2,934	2,520	6.80	7.10				
5lt	1,100	0	10,384	10,199	26.0	27.6	10,384	7,168	26.6	36.0
	1,100	3,000	19,413	19,082	44.5	45.0	13,431	13,024	32.0	34.5
	0	3,000	2,605	2,303	6.8	7.9	2,934	2,688	7.0	9.5
1gal	1,100	0	8,944	8,640	25.3	25.4				
	1,100	5,000	14,000	13,824	36.7	38				

	0	5,000	4,974	4,752	12.8	13.3				
720ml	1,100	0	20,477	20,160	43	44.5				
	0	5,000	4,495	4,480	9.7	10				
	1,100	5,000	24,969	24,640	51.3	52.2				
2lt honey	1,100	0	8,786	8,448	25.2	25.2	8,988	8,756	25.5	26
	1,100	5,000	13,982	13,376	36.1	36.3	13,987	13,948	36.4	37
	0	5,000	569	4,224	13.2	13.3	4,994	4,752	13.1	13
2lt square	1,100	0	8,992	8,640	25.3	25.3				
	1,100	5,000	13,986	13,824	36.4	37.3				
	0	5,000	4,993	4,320	12.6	12.9				

Table 15. Simulation results of fundamental models (Category B)

Product	Fundamental Model *(pcs)*	Actual production *(pcs)*	Success Rate
Bottle - 3lt	3,501	3,558	98.37%
Bottle - 5lt	3,385	5,600	34.56%
Jar - 720ml	3,872	4,800	76.03%
Jar - 1gal	3,187	4,200	68.21%
Jar - 2lt (HONEY)	3,095	4,640	50.08%
Jar - 2lt SQUARE	3,095	4,640	50.08%

Table 16. Comparison between the output of fundamental models (category B) and the actual production (8-hour shift)

Table 16 compares the actual production of bottles or jars and the production values that obtained as outputs from simulations of the fundamental models. The values show the production of pieces every 8 hours that correspond to one shift. The column of “Success Rate” defines the accuracy rate of the modelling that have been performed. The modelling of the production process of some products provides inadequate results. The available data of the production of these models do not include the information that the preforms that are necessary for the production of these bottles or jars need to be produced in the injection machine first. In other words, the step of the production process in the injection machine has been skipped. Consequently, the total time of production is reduced on the available data. Alternatively, the quantity of production on an 8-hour shift is much higher than the one of the model, since there is no delay of the production line in the injection machine.

4.1.1.4 Modelling the Production Process of Product Category C

The following figure presents the fundamental model of category C.

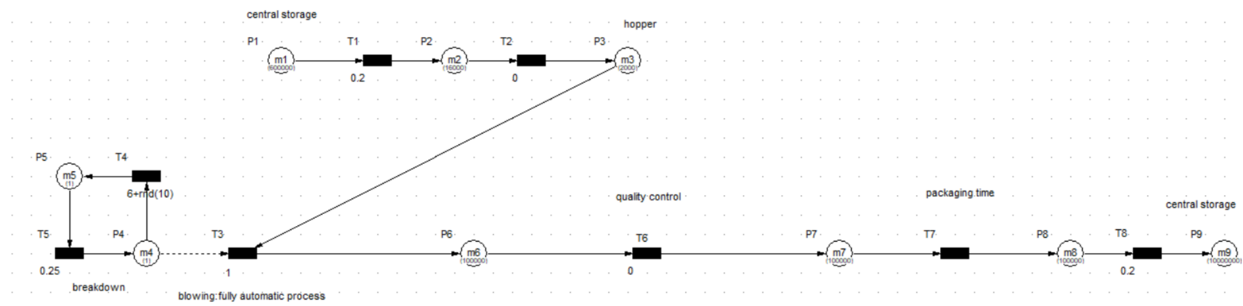


Figure 51. Fundamental model of category C

4.1.1.4.1 Definition of Each Step of the Production Process

The following sections present the definition of each step of the production process

- **Transfer of preforms to blowing machine buffer**

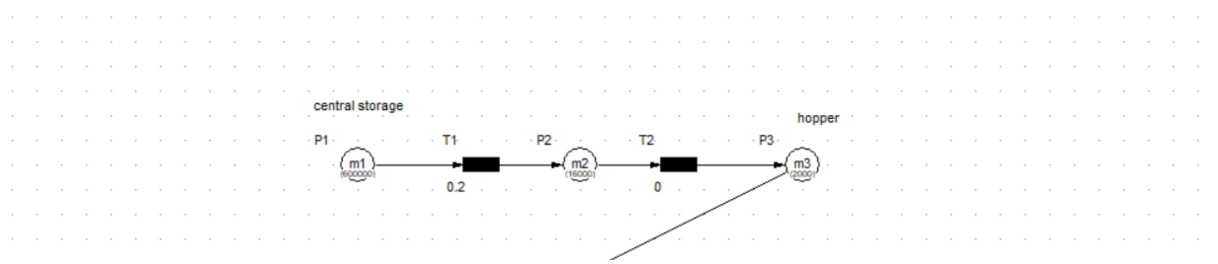


Figure 52. Transfer of preforms to blowing machine storage

Preforms are supplied in octabin packaging and stored in the central storage (P1), which then are transferred (T1) to the hopper of blowing machine (P3) in batches.

- **Breakdown of blowing machine**

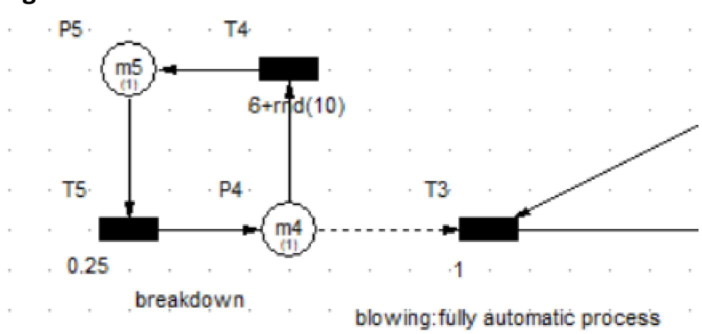


Figure 53. Breakdown of blowing machine

Transition T4 represents the time that breakdown occurs, whereas T5 is the delay of repair for each breakdown. The test arc (dashed arc) of P4 to T3 shows that T3 cannot be fired, unless P4 that is defined as control place for activation of breakdown, is full. P4 is full only when there is no breakdown at the model. To simplify the modelling, we ended up to the assumption, after adjusting the statistical data, that there are two breakdowns per day and the repair delay is approximately 15 minutes, whereas usually there are one or two breakdowns per week with a repair delay of 5-30 minutes and two or three breakdowns per year with a repair delay of one or two days.

- **Production of final bottle**

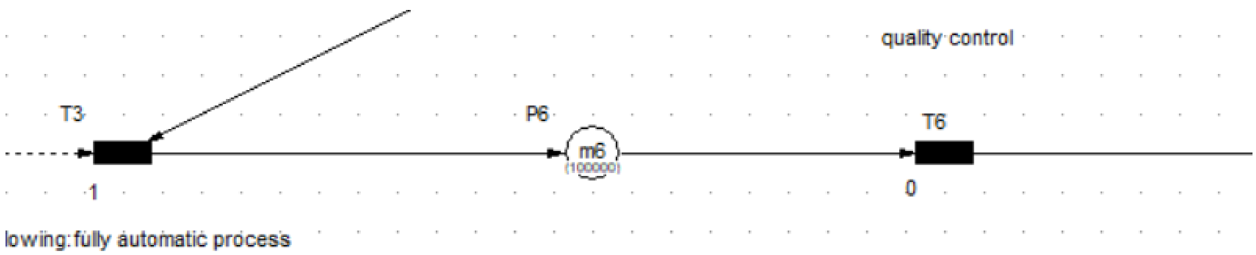


Figure 54. Production of final bottle

Transition T3 represents the fully automatic process of blowing machine (that is described in section 3.5.5), where bottles are produced out of preforms. Place P6 is a nominal buffer, where the final products remain until the quality control takes place. The delay of quality control (T6) is considered as zero, as there is an employee who checks the final products during the production without stopping or delaying the whole process. If there is a faulty product, it is simply removed. The weight of arc that connects quality control (T9) and place (P7) is a random value that is based on the study of the statistical data about the faulty products of each product code.

- **Packaging**

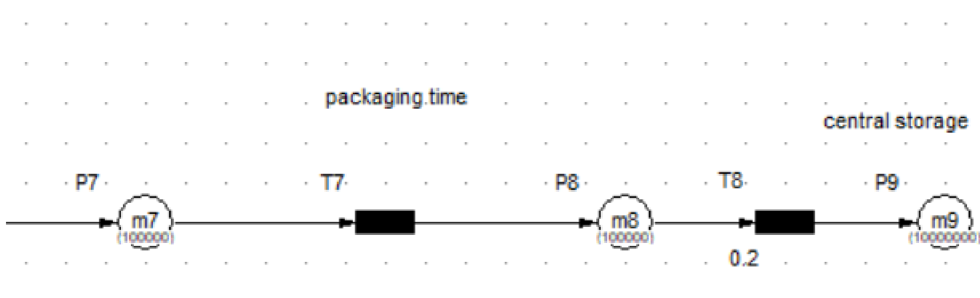


Figure 55. Packaging

Transition T7 shows the packaging process, which consists of manual packaging of palettes, manual filling of bags, automatic palletizing and wrapping. Wrapping completes the stage of packaging process of a palette; during this process, an automatic wrapping machine covers the palette with film in order to protect the products and avoid any damage. Transition T8 represents the final transfer of palette/bag to the central buffer.

4.1.1.4.2 Models of the Individual Products

The following figures present the different versions of every model of the individual products.

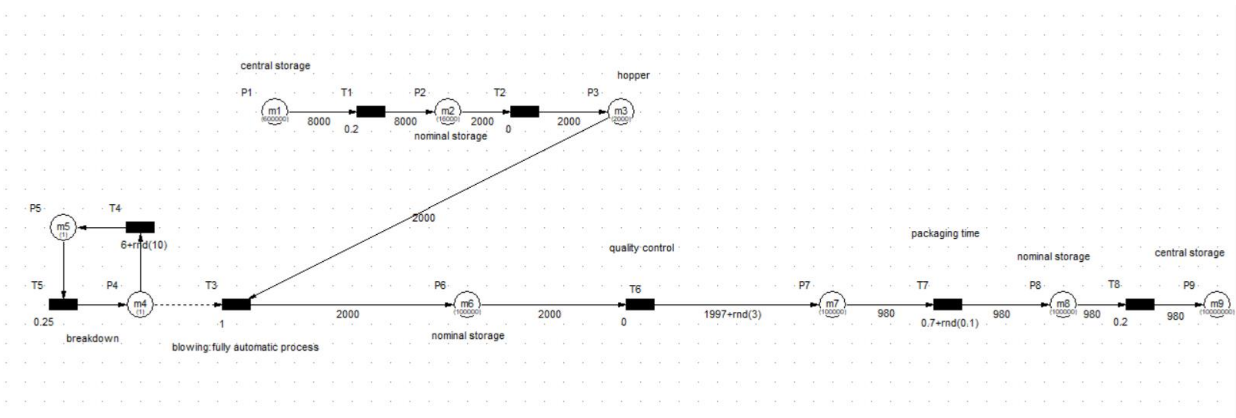


Figure 56. Model of Bottle-1.5lt Grape (packaging: palette)

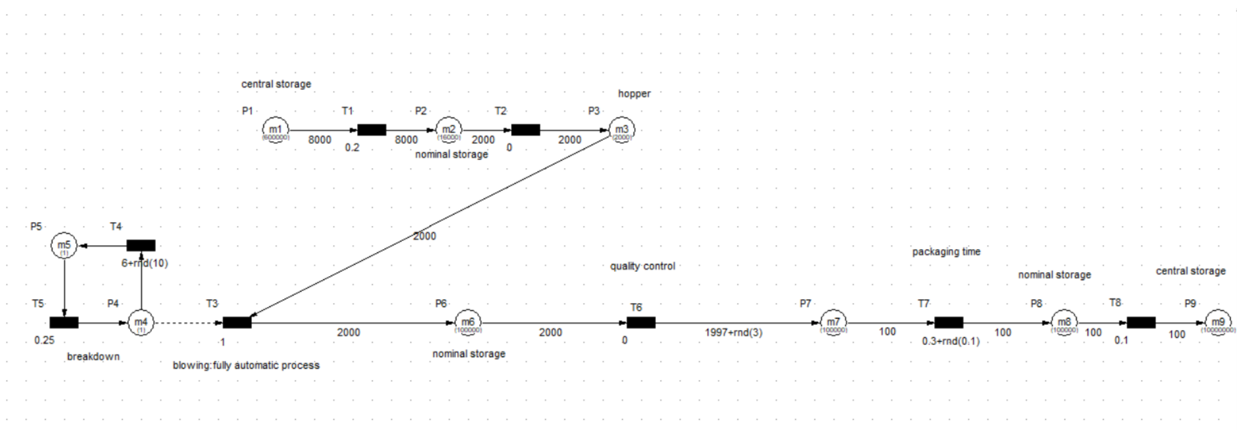


Figure 57. Model of Bottle-1.5lt Grape (packaging: bag)

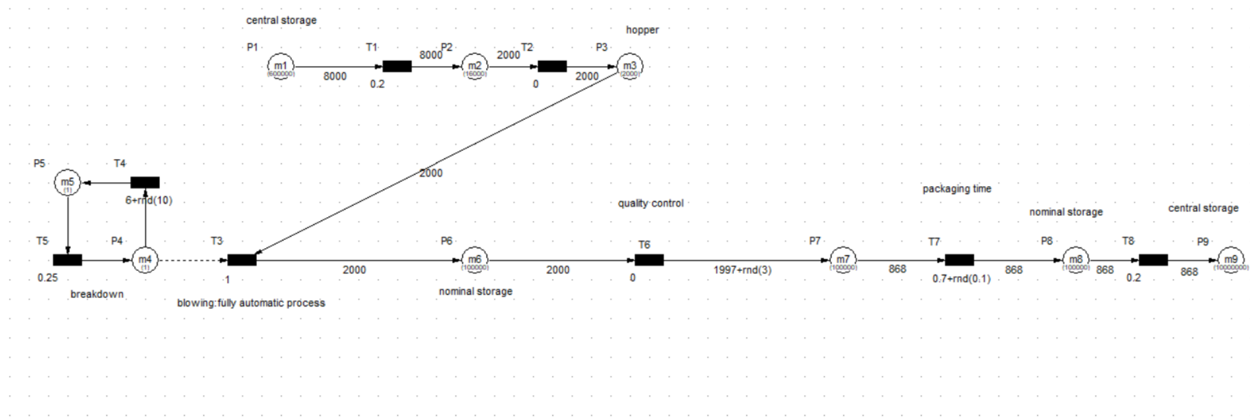


Figure 58. Model of Bottle – 1.5lt ONE (packaging: palette)

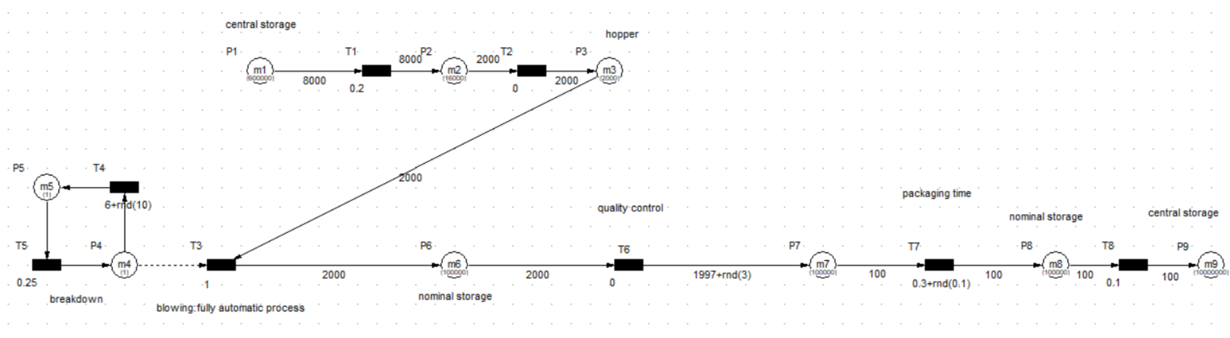


Figure 59. Model of Bottle – 1.5lt ONE (packaging: bag)

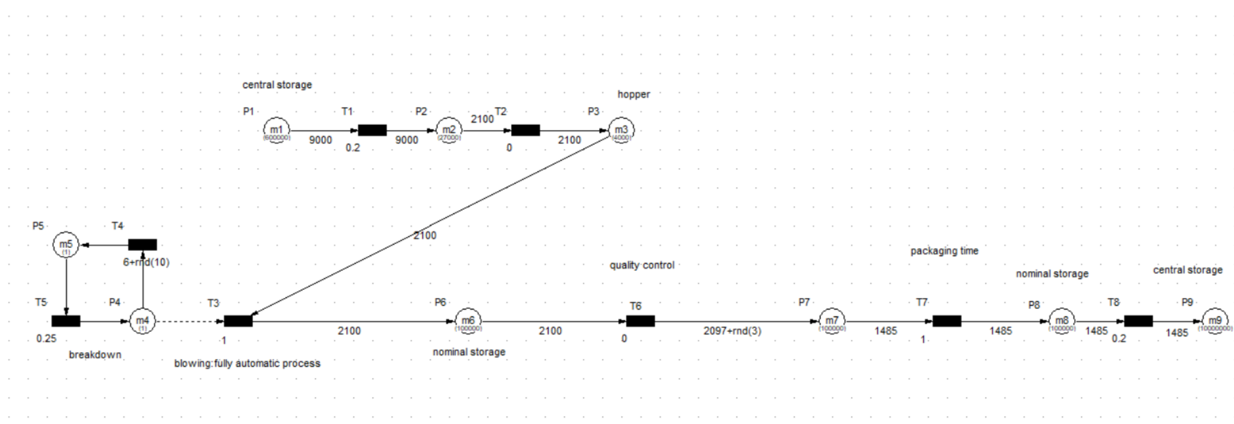


Figure 60. Model of Bottle – 1lt Milk

Tables 17-19 summarize the meaning and capacities of the places (the nodes where raw material and products are placed), the transitions (the steps that are required in order materials or intermediate products to be turned into a final product), the arc weights (i.e. batches, random values for quality control) that complete the models of the individual products with Petri Nets and explain the definition of each one.

Name	Definition	Bottle 1.5lt Grape	Bottle 1.5lt ONE	Bottle 1lt Milk
P1	Central buffer	600,000 pcs	600,000 pcs	600,000 pcs
P2	Temporary buffer for palette of preforms	16,000 pcs	16,000 pcs	27,000 pcs
P3	Hopper machine	2,000 pcs	2,000 pcs	4,000 pcs
P4	Control place for activation of breakdown	0 or 1	0 or 1	0 or 1
P5	Control place for activation of repair	0 or 1	0 or 1	0 or 1
P6	In-between nominal place	100,000 pcs	100,000 pcs	100,000 pcs
P7	Temporary buffer for bottles	100,000 pcs	100,000 pcs	100,000 pcs
P8	In-between nominal place	100,000 pcs	100,000 pcs	100,000 pcs
P9	Inventory storage	10,000,000 pcs	10,000,000 pcs	10,000,000 pcs

Table 17. Places of each model: Definition & Capacity

Name	Definition	Bottle 1.5lt Grape ***Pallet***	Bottle 1.5lt Grape ***Bag***	Bottle 1.5lt ONE ***Pallet***	Bottle 1.5lt ONE ***Bag***	Bottle 1lt Milk
T1	Transfer of palette to blowing machine (h)	0.2	0.2	0.2	0.2	0.2

T2	Dummy transition for activation of next operation (h)	0	0	0	0	0
T3	Production of bottles: Fully automatic process of blowing machine (h)	1	1	1	1	1
T4	Time between breakdowns (h)	[6,16]	[6,16]	[6,16]	[6,16]	[6,16]
T5	Repair (h)	0.25	0.25	0.25	0.25	0.25
T6	Quality control (h)	0	0	0	0	0
T7	Packaging (h)	[0.7,0.8]	[0.3,0.4]	[0.7,0.8]	[0.3,0.4]	1
T8	Transfer of palette/bag to inventory storage (h)	0.2	0.1	0.2	0.1	0.2

Table 18. Transitions of each model: Definition & Delay

Name	Connection	Bottle 1.5lt Grape *Pallet*	Bottle 1.5lt Grape *Bag*	Bottle 1.5lt ONE *Pallet*	Bottle 1.5lt ONE *Bag*	Bottle 1lt Milk
I1	P1→T1	8,000	8,000	8,000	8,000	9,000
O1	T1→P2	8,000	8,000	8,000	8,000	9,000
I2	P2→T2	2,000	2,000	2,000	2,000	2,100
O2	T2→P3	2,000	2,000	2,000	2,000	2,100
I3	P3→T3	2,000	2,000	2,000	2,000	2,100
I4	P4→T3 *activator arc*	1	1	1	1	1
I5	P4→T4	1	1	1	1	1
O3	T4→P5	1	1	1	1	1
I6	P5→T5	1	1	1	1	1
O4	T5→P4	1	1	1	1	1
O5	T3→P6	2,000	2,000	2,000	2,000	2,100
I7	P6→T6	2,000	2,000	2,000	2,000	2,100
O6	T6→P7	[1,997 , 2000]	[1,997 , 2000]	[1,997 , 2000]	[1,997 , 2000]	[2,097 , 2,100]
I8	P7→T7	980	100	868	100	1,485
O7	T7→P8	980	100	868	100	1,485
I9	P8→T8	980	100	868	100	1,485
O8	T8→P9	980	100	868	100	1,485

Table 19. Arcs of each model: Connection & Weight

4.1.1.5 Evaluation of Simulation Results

Table 20 summarize the results that were obtained from the simulation running of every model of product category C.

		Palette Packaging				Bag Packaging			
Product	INPUT *Preforms (pcs)*	OUTPUT *Total (pcs)*	OUTPUT *(pcs)*	Production Time *(h)*	Packaging Time *(h)*	OUTPUT *Total (pcs)*	OUTPUT *(pcs)*	Production Time *(h)*	Packaging Time *(h)*
1.5lt grape	32,000	31,928	31,360	16.2	24	31,972	31,900	16.8	97
	8,000	7,995	7,840	4.6	7.2	7,997	7,900	4.6	25.5
1.5lt ONE	32,000	31,982	31,248	16.5	26	31,979	31,900	16.6	97
	8,000	7,996	7,812	4.4	7.8	7,993	7,900	4.3	25.2
1lt milk	36,000	35,978	35,640	17.5	25.4				
	9,000	8,393	7,425	4.2	7				

Table 20. Simulation results of fundamental models (Category C)

Product	Fundamental Model *(pcs)*	Actual production *(pcs)*	Success Rate
BOTTLE 1,5lt GRAPE	15,495	15,360	99.13%
BOTTLE 1,5lt ONE	15,495	15,360	99.13%
BOTTLE 1lt MILK	16,267	16,800	96.72%

Table 21. Comparison between the output of fundamental models (category C) and the actual production (8-hour shift)

Table 21 compares the actual production values of product Category C and the production values that obtained as outputs from simulations of the fundamental models. The values show the production of bottles every 8 hours that correspond to one shift. The modelling of this category provides very sufficient results with success rates more than 96% that verifies the efficiency of the implemented models.

4.1.2 Modelling of Alternative Scenarios

In this section, the modelling of alternative scenarios is presented thoroughly, as well as the simulation of each model that was implemented on VisualObjectNet++ software. The definition of the production steps of the alternative scenarios is the same with those in the previous sections, as there is no change in the production process.

4.1.2.1 Alternative Scenarios Concerning the Production Process of Product Category A

The alternative scenarios of category A, that consists of preforms, are focused on changing the current moulds, with new ones with more cavities in order to increase the production ratio per hour. A new mould costs approximately 40,000€; the cost is related to the number of cavities. Additionally, note that the old mould is not useful anymore and cannot be used in any other way. There has been no application of alternative scenarios to products that are very new in the range, neither to products that have already reached the maximum capacity of cavities for these specific injection moulding machines. It would not be effective to study and analyze an alternative scenario of introducing a new injection moulding machine, which costs around 500,000€, as the company could not afford to proceed to such an investment.

4.1.2.1.1 Alterations of the Implemented Models

- **Preform Φ110-110gr**

The quantitative parameters, as well as the structure of the PN model in the alternative scenario are the same with those of the fundamental scenario, except for the number of cavities of the mould. There are 8 cavities in the new mould, whereas there were 6 cavities in the old mould. More specifically, the production per hour would increase to 930 pieces. Thus, the parameters of new scenario that have been changed are the arcs of place P2 to transitionT2 and of T2 to P5, since the quantity of raw material needed is higher for more pieces of final product. These changes are presented in Table 22.

Name	Connection	Initial Scenario	Scenario with Increased Productivity
I1	P1→T1	1,100	1,100
O1	TI→P2	1,100	1,100
I2	P2→T2	104	77
I3	P3→T2 *activator arc*	1	1

I4	P3→T3	1	1
I5	P4→T4	1	1
O3	T4→P3	1	1
O4	T2→P5	932	697
I6	P5→T5	1,000	1,000
O5	T5→P6	1,000	1,000
I7	P6→T6	1,000	1,000
O6	T6→P7	1,000	1,000

Table 22. Changes between initial scenario and scenario with increased productivity of preform Φ110-110gr

- **Preform Φ110-140gr**

The quantitative parameters, as well as the structure of the PN model in the alternative scenario are the same with those of the fundamental scenario, except for the number of cavities of the mould. There are 8 cavities in the new mould, whereas there were 6 cavities in the old mould, which increases the production to 824 pieces per hour. Thus, the parameters of the new scenario that have been changed, are the weight of arcs of place P2 to transitionT2 and the weight of the arc of T2 to P5, since the quantity of necessary raw material is higher for more pieces of final product. These changes are presented in Table 23.

		Initial Scenario		**Scenario with Increased Productivity**	
Name	**Connection**	***Octabin***	***Cardboard Box***	***Octabin***	***Cardboard Box***
I1	P1→T1	1,100	1,100	1,100	1,100
O1	TI→P2	1,100	1,100	1,100	1,100
I2	P2→T2	116	116	87	88
I3	P3→T2 *activator arc*	1	1	1	1
I4	P3→T3	1	1	1	1
O2	T3→P4	1	1	1	1
I5	P4→T4	1	1	1	1
O3	T4→P3	1	1	1	1
O4	T2→P5	824	824	618	620
I6	P5→T5	1,000	1,000	1,000	1,000
O5	T5→P6	1,000	1,000	1,000	1,000
I7	P6→T6	1,000	1,000	1,000	1,000
O6	T6→P7	1,000	1,000	1,000	1,000

I8	P7→T7	-	216	-	216
O7	T7→P8	-	216	-	216

Table 23. Changes between initial scenario and scenario with increased productivity of preform Φ110-140gr

- **Preform Φ82-50gr**

The quantitative parameters, as well as the structure of the PN model in the alternative scenario are the same with those of the fundamental scenario, except for the number of cavities of the mould. There are 12 cavities in the new mould, whereas there were 6 cavities in the old mould, which increases the production to 2,160 pieces per hour. Thus, in the new scenario, the parameters that have been changed are the arcs of place P2 to transition T2 and of T2 to P5, since the quantity of raw material needed is higher for more pieces of final product. These changes are presented in Table 24.

Name	Connection	Initial Scenario	Scenario with Increased Productivity
I1	P1→T1	1,100	1,100
O1	TI→P2	1,100	1,100
I2	P2→T2	108	54
I3	P3→T2 *activator arc*	1	1
I4	P3→T3	1	1
O2	T3→P4	1	1
I5	P4→T4	1	1
O3	T4→P3	1	1
O4	T2→P5	2,160	1,080
I6	P5→T5	1,000	570
O5	T5→P6	1,000	570
I7	P6→T6	1,000	570
O6	T6→P7	1,000	570

Table 24. Changes between initial scenario and scenario with increased productivity of preform Φ82-50gr

The quantitative parameters, as well as the structure of the PN model in the alternative scenario are the same with those of the fundamental scenario, except for the number of cavities of the mould. There are 12 cavities in the new mould, whereas there were 8 cavities in the old mould, which increases the production per hour to 1,728 pieces. Thus, in the new scenario, the parameters that have been changed, are the arcs of place P2 to transition T2 and of T2 to P5, since the quantity of raw material needed is higher for more pieces of final product. These changes are presented in Table 25.

		Initial Scenario		Scenario with Increased Productivity	
Name	**Connection**	***Octabin***	***Cardboard Box***	***Octabin***	***Cardboard Box***
I1	P1→T1	1,100	1,100	1,100	1,100
O1	TI→P2	1,100	1,100	1,100	1,100
I2	P2→T2	80	80	52	52
I3	P3→T2 *activator arc*	1	1	1	1
I4	P3→T3	1	1	1	1
O2	T3→P4	1	1	1	1
I5	P4→T4	1	1	1	1
O3	T4→P3	1	1	1	1
O4	T2→P5	1,728	1,728	1,152	1,152
I6	P5→T5	6,800	6,800	6,800	6,800
O5	T5→P6	6,800	6,800	6,800	6,800
I7	P6→T6	6,800	6,800	6,800	6,800
O6	T6→P7	6,800	6,800	6,800	6,800
I8	P7→T7	-	384	-	384
O7	T7→P8	-	384	-	384

Table 25. Changes between initial scenario and scenario with increased productivity of preform Φ63-45gr

Table 26 summarizes the values of the arc weights (i.e. batches, random values for quality control) that complete the models of alternative scenarios with Petri Nets. The tables of places and transitions are the same as those in the previous section of modelling the fundamental models.

Name	Φ110 110gr	Φ110 140gr *Octabin*	Φ110 140gr *Cardboard Box*	Φ82 50gr	Φ63 45gr Octabin	Φ63 45gr *Cardboard Box*
I1	1,100	1,100	1,100	1,100	1,100	1,100
I2	1,100	1,100	1,100	1,100	1,100	1,100
I3	104	116	116	108	80	80
I4	1	1	1	1	1	1
I5	1	1	1	1	1	1
I6	1	1	1	1	1	1
I7	1	1	1	1	1	1
I8	1	1	1	1	1	1
I9	932	824	824	2,160	1,728	1,728
I10	1,000	1,000	1,000	1,000	6,800	6,800

I11	1,000	1,000	1,000	1,000	6,800	6,800
I12	1,000	1,000	1,000	1,000	6,800	6,800
I13	1,000	1,000	1,000	1,000	6,800	6,800
I14	-	-	216	-	-	384
I15	-	-	216	-	-	384

Table 26. Arcs of each alternative model: Connection & Weight

4.1.2.1.2 Evaluation of Simulation Results of Alternative Scenarios

Table 27 summarizes the results that were obtained from the running the simulation of product category A.

Product	INPUT *PET Resin (kg)*	OUTPUT *Total (pcs)*	OUTPUT *Packaging (pcs)*	Production Time *(h)*
Φ110 110gr	1,100	9,786	9,000	10.70
	2,200	19,575	19,000	22
	550	4,893	4,000	5.5
Φ110 140gr	1,100	7,622	7,000	10.60
	2,200	15,450	15,000	20.25
	550	3,708	3,000	4.80
Φ82 50gr	1,100	21,600	21,090	11.30
	2,200	43,740	43,320	21.60
	550	10,800	10,260	5.20
Φ63 45gr	1,100	23,760	20,400	14.80
	2,200	47,520	40,800	28.43
	550	11,664	6,800	7.50

Table 27. Simulation results of alternative scenarios (Category A)

Tables 35-28 present the potential impact of the alternative scenarios on the operation process. In particular, the alternative scenarios contribute to the reduction of the time needed for the production of a specific quantity, as well as to the increase of the mean productivity of the line.

- **Preform Φ110-140gr**

Scenario	Input *(kg)*	Total Output *(pcs)*	Production Time *(h)*	Reduction of Production Time
Initial Scenario *(6 cavities)*	1,100	7,750	13.5	22.22%
Scenario with Increased Productivity *(8 cavities)*	1,100	7,622	10.5	

Table 28. Reduction of production time for preform Φ110-140gr

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(6 cavities)*	8	4,805	37.19%
Scenario with Increased Productivity *(8 cavities)*	8	6,592	

Table 29. Increase of productivity for preform Φ110-140gr

Change of the cavities of mould from six to eight reduces the production time of 1,100 kg of PET resin three hours, which corresponds to 22.22%. This rate is very important for the production process, even if the final products are less by 128 pieces, which is a very slight difference and is considered insignificant. Moreover, the productivity increases by 37.19%, since 1,787 more preforms are produced on a shift of eight hours.

- **Preform Φ110-110gr**

Scenario	Input *(kg)*	Total Output *(pieces)*	Production Time (h)	Reduction of Production Time
Initial Scenario *(6 cavities)*	1,100	9,975	15	23.30%
Scenario with Increased Productivity *(8 cavities)*	1,100	9,786	11.50	

Table 30. Reduction of production time for preform Φ110-110gr

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(6 cavities)*	8	5,425	33.14%
Scenario with Increased Productivity *(8 cavities)*	8	7,223	

Table 31. Increase of productivity for preform Φ110-140gr

Change of the cavities of mould from six to eight reduces the production time of 1,100 kg of PET resin by 23.30%. Moreover, the productivity increases by 33.14%, since 1,798 more preforms are produced on a shift of eight hours.

- **Preform Φ82-50gr**

Scenario	Input *(kg)*	Total Output *(pieces)*	Production Time (h)	Reduction of Production Time
Initial Scenario *(6 cavities)*	1,100	20,760	20	45.27%
Scenario with Increased Productivity *(12 cavities)*	1,100	21,600	11	

Table 32. Reduction of production time for preform Φ82-50gr

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(6 cavities)*	8	8,370	100%
Scenario with Increased Productivity *(12 cavities)*	8	16,740	

Table 33. Increase of productivity for preform Φ82-50gr

Change of the cavities of mould from six to eight reduced the production time of 1,100 kg of PET resin by 45.27%. Moreover, the productivity increases 100%, since 8,370 more preforms are produced on a shift of eight hours. This change could have a great impact on the production system, since the company is planning to invest on increase of the production of 720ml jar, which needs this preform in order to being produced.

- **Preform Φ63-45gr**

Scenario	Input *(kg)*	Total Output *(pieces)*	Production Time (h)	Reduction of Production Time
Initial Scenario *(8 cavities)*	1,100	20,760	20.1	25.37%

Scenario with Increased Productivity *(12 cavities)*	1,100	23,760	15	

Table 34. Reduction of production time for preform Φ63-45gr

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(8 cavities)*	8	8,928	50%
Scenario with Increased Productivity *(12 cavities)*	8	13,392	

Table 35. Increase of productivity for preform Φ63-45gr

Investing on a new mould with 12 cavities results in a reduction of production time by 25.37%. Additionally, the productivity increases by 50%. However, this is a new product and the company has invested on the mould with eight cavities lately, thus they do not plan on purchasing a new mould at the moment, even if it would increase the productivity that much.

4.1.2.2 Alternative Scenarios Concerning the Production Process of Product Category B

The alternative scenarios of category B are focused on realistic instant changes or modifications in the production process.

4.1.2.2.1 Alterations of the Implemented Models

- **Bottle – 3lt**

The alternative scenario for the improved production process of 3lt bottle is focused on the purchase of a new (or used) blowing machine, which costs approximately 50,000€, with a larger production ratio per hour that can be adjusted in the production ratio of preforms in the injection moulding machine, so as the total production system to be as effective as possible with the least possible delays in the whole process. Such a blowing machine provides a nominal production of 730 pieces per hour, contrary to 450 pieces per hour of the existing blowing machine.

The quantitative parameters on the model remain the same with those on the fundamental scenario, apart from the arc weights that connect place P8 with transition T8, T8 with P11 and the weights which represent the batches that go to quality control.

- **Bottle – 5lt**

The alternative scenario for the improved production process of 5lt bottle is the same as the one of 3lt bottle and is focused on the purchase of the same blowing machine, with a larger production ratio per hour that can be adjusted in the production ratio of preforms in the injection moulding machine, so as the total production system to be as effective as possible with the least possible delays in the whole process.

The quantitative parameters on the model remain the same with those on the fundamental scenario, apart from the arc weights that connect place P8 with transition T8, T8 with P11 and the weights which represent the batches that go to quality control.

- **Jar – 720ml**

The alternative scenario of 720ml jar is focused on the operation of a blowing machine, that the company owns and is not currently in use, because there are certain modifications that should be done on the moulds. Specifically, this machine works with moulds of 2 cavities, whereas the current mould of 720ml jar has one cavity. The modification of single cavity to 2 cavities costs approximately 1,500€. The production ratio can increase to 1,200 pieces per hour, on the contrary to hourly production of 500 pieces of the existing machine.

The quantitative parameters on the model remain the same with those on the fundamental scenario, apart from the arc weights that connect place P8 with transition T8, T8 with P11 and the weights which represent the batches that go to quality control.

- **Jar 720ml & Preform Φ82-50gr**

This alternative scenario represents the improved production system that consists of changes on both production processes of 720ml jar and Φ82 50gr preform at the same time. This alternative scenario is a combination of the alternative model of Φ82 50gr preform that was described in the previous section of the fundamental scenario and the alternative scenario of 720ml jar that is presented above.

Table 36 and 37 summarize the values of the arc weights (i.e. batches, random values for quality control) that complete the models of alternative scenarios with Petri nets. The tables of places and transitions are the same with those in the previous section of modelling the fundamental scenarios.

Name	**Bottle 3lt**	**Bottle 5lt *Palette***	**Bottle 5lt *Bag***
I1	1,100	1,100	1,100
I2	1,100	1,100	1,100
I3	64	64	64
I4	1	1	1
I5	1	1	1

I6	1	1	1
I7	1	1	1
I8	1	1	1
I9	757	640	640
I10	1,500	1,500	1,500
I11	1,500	1,500	1,500
I12	1,500	1,500	1,500
I13	1,500	1,500	1,500
I14	1,500	1,500	1,500
I15	1,500	1,500	1,500
I16	732	732	732
I17	732	732	732
I18	732	732	732
I19	1	1	1
I20	1	1	1
I21	1	1	1
I22	1	1	1
I23	1	1	1
I24	732	732	732
I25	732	732	732
I26	[729 , 732]	[729 , 732]	[729 , 732]
I27	504	329	32
I28	504	329	32
I29	504	329	32
I30	504	329	32

Table 36. Arcs of alternative scenarios: Connection & delay

Name	**Jar 720ml**	**Jar 720ml & Preform Φ82 50gr**
I1	1,100	1,100
I2	1,100	1,100
I3	54	108
I4	1	1
I5	1	1
I6	1	1
I7	1	1
I8	1	1
I9	1,080	2,160
I10	570	570

I11	570	570
I12	570	570
I13	570	570
I14	570	570
I15	570	570
I16	1,200	1,200
I17	1	1
I18	1	1
I19	1	1
I20	1	1
I21	1	1
I22	1,200	1,200
I23	1,200	1,200
I24	[1,196 , 1,200]	[1,196 , 1,200]
I25	2,240	2,240
I26	2,240	2,240
I27	2,240	2,240
I28	2,240	2,240

Table 37. Arcs of alternative scenarios: Connection & delay

4.1.2.2.2 Evaluation of Simulation Results

Table 38 summarizes the results that were obtained from running the simulation of alternative scenarios for product category B.

			Palette Packaging			
Product	**INPUT** ***PET Resin (kg)***	**INPUT** ***Preforms (pcs)***	**OUTPUT** ***Total (pcs)***	**OUTPUT** ***(pcs)***	**Production Time *(h)***	**Packaging Time *(h)***
3lt	1,100	3,000	14,795	14,112	21.3	21.00
	1,100	0	11,877	11,592	19.90	19.30
	0	3,000	2,922	2,520	4.80	4.47
5lt	1,100	0	10,408	10,199	20.5	20.00
	1,100	3,000	13,333	12,831	19.2	18.90
	0	3,000	2,923	2,632	5.2	4.10
720ml	1,100	0	20,367	20,160	22.4	21.00
	0	5,000	4,493	2,240	4.2	4.20
	1,100	5,000	24,859	22,400	22	22.00
	1,100	0	20,960	20,160	19.7	19.50

720ml&Φ82-50gr	0	5,000	4,495	2,240	4.25	4.00
	1,100	5,000	25,452	24,640	22.3	22.00

Table 38. Simulation results of alternative scenarios (Category B)

Tables 39-46 present the potential impact of the alternative scenario on the operation process. Specifically, the alternative scenarios contribute to the reduction of the time needed for the production of a specific quantity, as well as to the increase of the productivity.

- **Bottle-3lt**

Scenario	Input *(kg)*	Total Output *(pieces)*	Production Time (h)	Reduction of Production Time
Initial Scenario *(450 pcs/h)*	1,100	14,901	33.8	35.78%
Scenario with Increased Productivity *(730 pcs/h)*	1,100	14,793	21.7	

Table 39. Reduction of production time of bottle-3lt

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(450 pcs/h)*	8	3,501	61.75%
Scenario with Increased Productivity *(730 pcs/h)*	8	5,663	

Table 40. Increase of productivity of bottle-3lt

The increased capacity of a new machine to an average amount of 730pcs/h, contributes to the reduction of production time by 35.78%, which corresponds to approximately 12 hours that is a huge value for a production system. Moreover, it increases the productivity by 61.75%. The fact that this is one of the best-selling product codes, such an investment could have a great impact on the company's profits.

- **Bottle-5lt**

Scenario	Input *(kg)*	Total Output *(pieces)*	Production Time (h)	Reduction of Production Time

Initial Scenario *(450 pcs/h)*	1,100	10,384	26	23.70%
Scenario with Increased Productivity *(730 pcs/h)*	1,100	10,410	20	

Table 41. Reduction of production time of bottle-5lt

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(450 pcs/h)*	8	3,385	69.30%
Scenario with Increased Productivity *(730 pcs/h)*	8	5,663	

Table 42. Increase of productivity of bottle-5lt

The increased capacity of a new machine to an average amount of 730pcs/h, contributes to the reduction of production time by 23.70%, which corresponds to approximately 6 hours that is a great value for a production system. Additionally, it increases the productivity by 69.30%. Similarly, to the case of the 3lt bottle, the fact that the 5lt bottle is one of the best-selling product codes, the improvement of such an investment could have a great impact on the company's profits.

- **Jar-720ml**

Scenario	Input *(kg)*	Total Output *(pieces)*	Production Time (h)	Reduction of Production Time
Initial Scenario *(500 pcs/h)*	1,100	20,477	43	51.16%
Scenario with Increased Productivity *(1,200 pcs/h)*	1,100	20,358	21	

Table 43. Reduction of production time of jar 720ml

Scenario	Production Time *(h)*	Total Output *(pieces)*	Increase of Productivity
Initial Scenario *(450 pcs/h)*	8	3,872	139.80%

Scenario with Increased Productivity (*1,200 pcs/h*)	8	9,285	

Table 44. Increase of productivity of jar-720ml

By producing this jar to a new machine, as it is described in section 4.2.2.2.1, the production time is being reduced by 51.16%, which is equivalent to 22 hours, that is more than half time. The most remarkable fact is the increase of productivity by 139.80%. In addition to the low price of modifying the existing mould, this alternative scenario could be beneficial for the company, given the fact that there is a sufficient demand.

- **Jar 720ml & Preform Φ82-50gr**

Scenario	**Input *(kg)***	**Total Output *(pieces)***	**Production Time (h)**	**Reduction of Production Time**
Initial Scenario	1,100	20,477	43	53.95%
Scenario with Increased Productivity	1,100	20,966	19.8	

Table 45. Reduction of production time of jar-720ml & preform Φ82-50gr

Scenario	**Production Time *(h)***	**Total Output *(pieces)***	**Increase of Productivity**
Initial Scenario	8	3,872	108.91%
Scenario with Increased Productivity	8	8,089	

Table 46. Increase of productivity of jar-720ml & preform Φ82-50gr

Change of mould of the Φ82 50gr preform and the production line of the 720ml jar, the production time is being reduced by 23.8 hours and the productivity increases to 108.91%, which has a great impact on the operation process. However, it requires a great investment.

4.1.2.3 Alternative Scenarios Concerning the Production Process of Product Category C

The alternative scenarios of category C are focused on realistic inexpensive changes in the production process. Such a change is a modification of the packaging process in order to decrease the delay of this step. This scenario can be achieved by investing on purchasing a palletizing machine (palletizer) with a very short delay, equal to couple of minutes, which is considered as zero on the following models. A palletizer costs approximately 20,000€. Each blowing machine of the following products needs a different palletizer, except for 1.5lt – Grape and 1.5lt- ONE bottles that are produced in the same blowing machine.

4.1.2.3.1 Alterations of Implemented Models

- **Bottle-1.5lt Grape**

The production process is exactly the same with that one on the fundamental scenario. The only difference is the transition T7, which represents the packaging process, and has taken the value of zero on this alternative scenario.

- **Bottle-1.5lt ONE**

The production process is exactly the same with that on the fundamental scenario. The only difference is the transition T7, which represents the packaging process, and has taken the value of zero on this alternative scenario.

- **Bottle-1lt Milk**

The production process is exactly the same with that one on the fundamental scenario. The only difference is the transition T7, which represents the packaging process, and has taken the value of zero on this alternative scenario.

Table 47 summarizes the values of the transitions (the steps that are required in order materials or in-process parts to be transformed into a final product).

Name	**Definition**	**Bottle 1.5lt Grape *Palette***	**Bottle 1.5lt Grape *Bag***	**Bottle 1.5lt ONE *Palette***	**Bottle 1.5lt ONE *Bag***	**Bottle 1lt Milk**
T1	Transfer of raw material to injection machine (h)	0.2	0.2	0.2	0.2	0.2
T2	Production of preforms: Fully automatic process of injection machine (h)	0	0	0	0	0

T3	Time between breakdowns (h)	1	1	1	1	1
T4	Repair (h)	[6,16]	[6,16]	[6,16]	[6,16]	[6,16]
T5	Packaging (h)	0.25	0.25	0.25	0.25	0.25
T6	Transfer of palette to inventory storage (h)	0	0	0	0	0
T7	Packaging of cardboard box (h)	0	0	0	0	0
T8	Transfer of palette/bag to inventory storage (h)	0.2	0.1	0.2	0.1	0.2

Table 47. Transitions of each model: Definition & Delay

4.1.2.3.2 Evaluation of Simulation Results

Table 48 summarizes the results that were obtained from the simulation running of alternative scenarios for product category C.

		Palette Packaging			
Product	**INPUT** ***Preforms (pcs)***	**OUTPUT** ***Total (pcs)***	**OUTPUT** ***(pcs)***	**Production Time *(h)***	**Packaging Time *(h)***
1.5lt Grape	32,000	31,977	31,360	17	17
	8,000	6,037	5,880	4.26	4.26
1.5lt ONE	32,000	31,970	31,248	17	17
	8,000	7,994	5,208	4.26	4.26
1lt Milk	36,000	32,706	32,670	18.13	18.13
	9,000	8,353	7,425	4.4	4.4

Table 48. Simulation results of alternative scenarios (Category C)

Tables 49-51 present the potential impact of the alternative scenarios on the operation process. Specifically, the alternative models contribute to the reduction of the time needed for the production of a specific quantity, as well as to the increase of the productivity.

- **Bottle-1.5lt Grape**

Scenario	Production Time *(h)*	Total Output *(pieces)*	Total Output *(palettes)*	Increase of packed products
Initial Scenario	8	8,820	9	55.55%
Scenario with Increase of packed bottles	8	13,720	14	

Table 49. Increase of packed products: Bottle-1.5lt Grape

The alternative scenario of using a palletizing machine for the packaging, increases the number of packed palettes by 5, which correspond to a rate of 55.55%.

- **Bottle-1.5lt ONE**

Scenario	Production Time *(h)*	Total Output *(pieces)*	Total Output *(palettes)*	Increase of packed products
Initial Scenario	8	7,812	9	77.77%
Scenario with Increase of packed bottles	8	13,888	16	

Table 50. Increase of packed products: Bottle-1.5lt ONE

The alternative scenario of using a palletizing machine for the packaging, increases the number of packed palettes by 7, which correspond to a rate of 77.77%.

- **Bottle-1lt Milk**

Scenario	Production Time *(h)*	Total Output *(pieces)*	Total Output *(palettes)*	Increase of packed products
Initial Scenario	8	8,910	6	50%

Scenario with Increase of packed bottles	8	13,365	9	

Table 51. Increase of packed products: Bottle-1lt Milk

The alternative scenario of using a palletizing machine for the packaging, increases the number of packed palettes by 3, which correspond to a rate of 50%.

All the above alternative scenarios for products of Category C improve the production process in a very efficient way. More specifically, it is an investment that could be beneficial in long term, given the fact that these products play an important role to the company's profit and have a great share at sales.

Chapter 5

5 Demand Forecasting for 2018

5.1 Application of Forecasting Methods in the Company

This chapter describes the demand forecasting models that have been applied using previous year data and presents the chosen one. More precisely, the methods that have been applied are quantitative and not qualitative, due to the fact that the data provided were satisfactory enough to lead to realistic and unbiased results, decreasing the high levels of randomness that appear on the qualitative methods. The forecasting methods that have been applied are the following: Simple Moving Average, Double Moving Average, Simple Exponential Smoothing (Brown's method) and Holt-Winters method [40]-[43].

Monthly data of each product for the last six years were provided. The monthly demand of some products is zero, consequently for a better analysis and more sufficient results, the data have been categorized in four-month periods, which has a better impact on the production planning as well, since company needs to control larger quantities. Hence, the following demand forecasting is for the three four-month periods of 2018 (January-April, May-August, September-December).

5.1.1 Simple Moving Average

Simple Moving Average is a technique which contributes to the overall understanding of the trend in the observations and calculates the numerical average of the latest ***m*** observations in time series that is being analyzed. Every time that a new observation is available, a new numerical average can be calculated and performed as a forecasting, that is why this average is called ''moving''. After the application of Simple Moving Average method, the forecasting values of a time series Y_t , where t=1, 2, …, m, , are given by the following formula [41]:

$$\hat{Y}_{t+1} = M_{t+1} = \frac{1}{m} * \sum_j Y_{t-j+1} \quad \text{where} \quad j = 1,2, \dots, m$$

Where:

$\hat{Y}_{t+1}$: Forecasting value for period *(t+1)*

M_{t+1}: Simple moving average for period *(t+1)*

m: Number of periods used for the calculation of simple moving average

This method was applied for every four-month period. In particular, for the calculations of the demand forecasting of January-April 2018, data for the periods January-April 2012, January-April 2013, January-April 2014, January-April 2015, January-April 2016 and January-April 2017 were used, and correspondingly for the rest time-periods. Table 52 indicates the availability of data by product and year, due to the fact that each product has been launched in a different year. Purple colored line in the charts (Figures 61-74) shows the actual demand, whereas orange one shows the forecasting values.

Product	2012	2013	2014	2015	2016	2017
PREFORM Φ48-195gr	√	√	√	√	√	√
PREFORM Φ110-110gr	√	√	√	√	√	√
PREFORM Φ110-140gr	√	√	√	√	√	√
PREFORM Φ82-50gr	-	-	-	√	√	√
PREFORM Φ63-45gr	-	-	-	√	√	√
PREFORM Φ63-30gr	-	-	-	-	-	-
BOTTLE 3lt	-	-	√	√	√	√
BOTTLE 5lt	√	√	√	√	√	√
JAR 720ml	-	-	-	√	√	√
JAR 1gal	√	√	√	√	√	√
JAR 2lt (HONEY)	√	√	√	√	√	√
JAR 2lt (SQUARE)	-	-	-	√	√	√
BOTTLE 1.5lt (GRAPE)	√	√	√	√	√	√
BOTTLE 1.5lt (ONE)	√	√	√	√	√	√
BOTTLE 1lt (MILK)	√	√	√	√	√	√

Table 52. Availability of data of each product

5.1.1.1 Product Category A

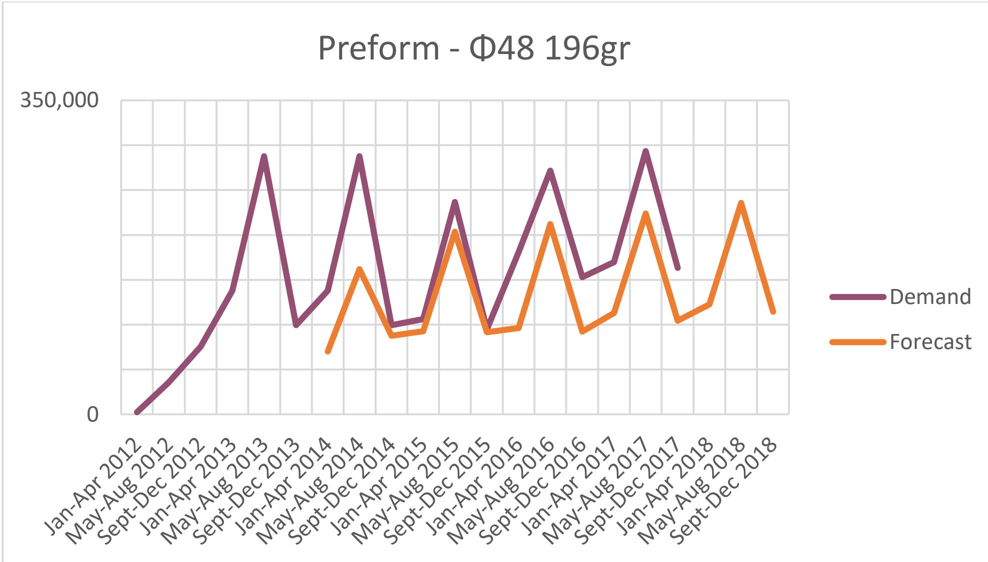


Figure 61. Demand forecasting of preform Φ48-196gr with the application of Simple Moving Average method

This time series plot shows a seasonal pattern with upward secular trend. The results that were obtained are very satisfactory and follow the same pattern as the past observations.

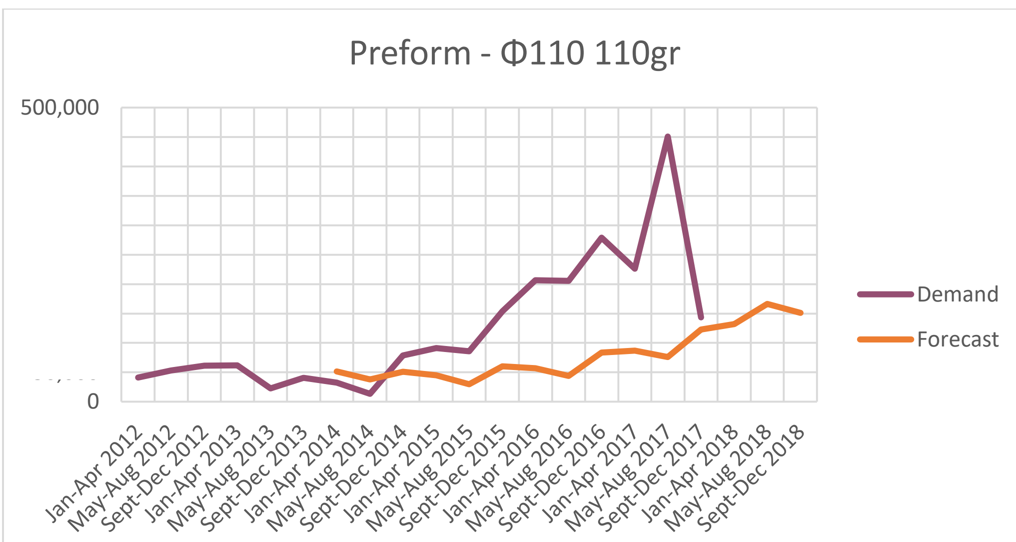


Figure 62. Demand forecasting of preform Φ110-110gr with the application of Simple Moving Average method

This time series shows irregular variation with upward secular trend. Moreover, the results follow the upward trend, but they do not correspond to the extreme values.

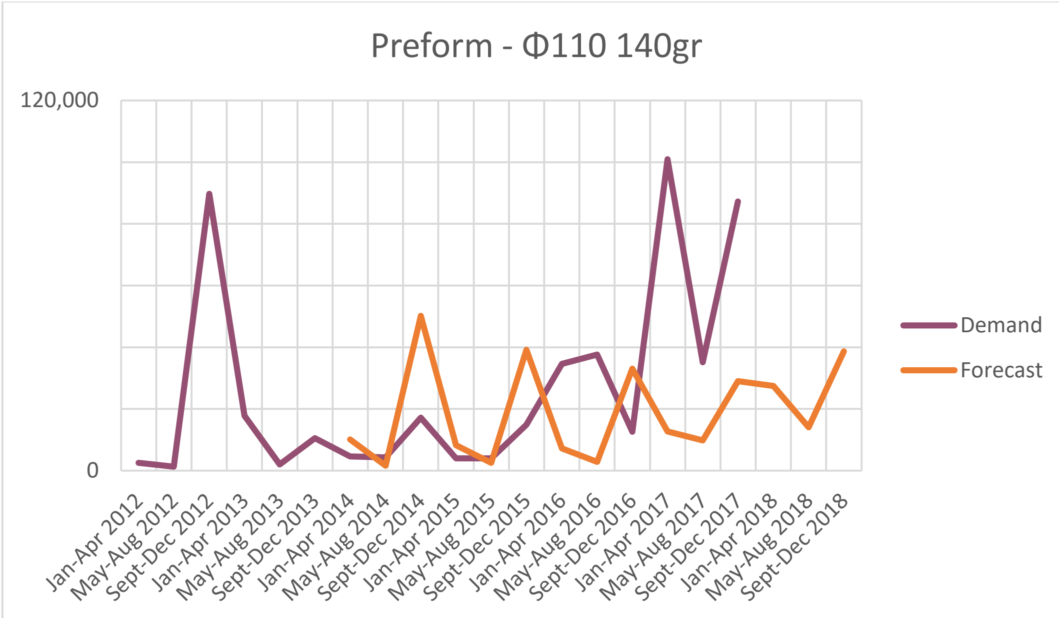


Figure 63. Demand forecasting of preform Φ110-140gr with the application of Simple Moving Average method

The plot of time series shows cyclical pattern with upward secular trend. The results that were obtained follow the upward trend, but they do not match the extreme high values.

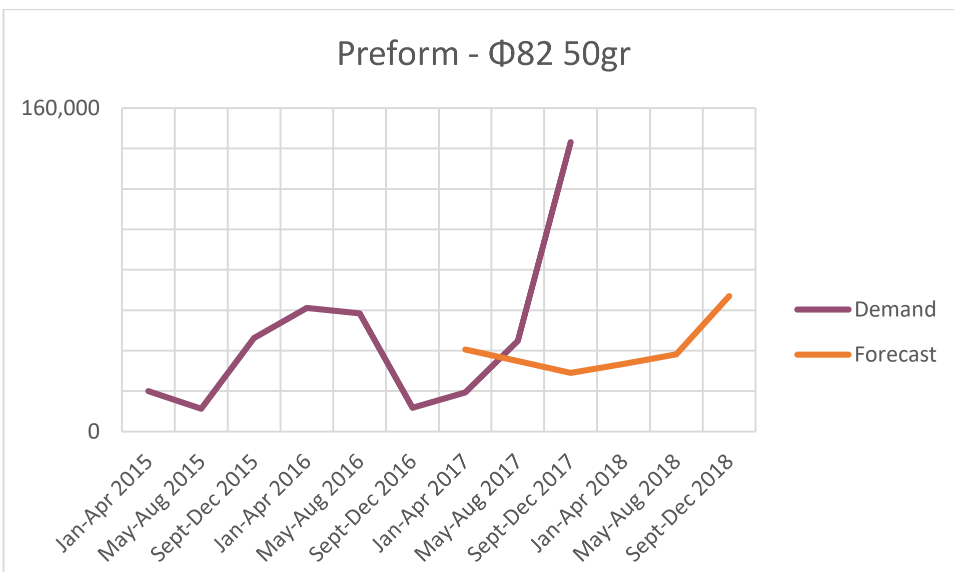


Figure 64. Demand forecasting of preform Φ82-50gr with the application of Simple Moving Average method

The plot of time series shows irregular variation with upward secular trend. The results that were obtained follow an upward trend as well, but they are not satisfactory, due to the fact that the time series is short-term and the available data of the last two years are not enough to obtain accurate results.

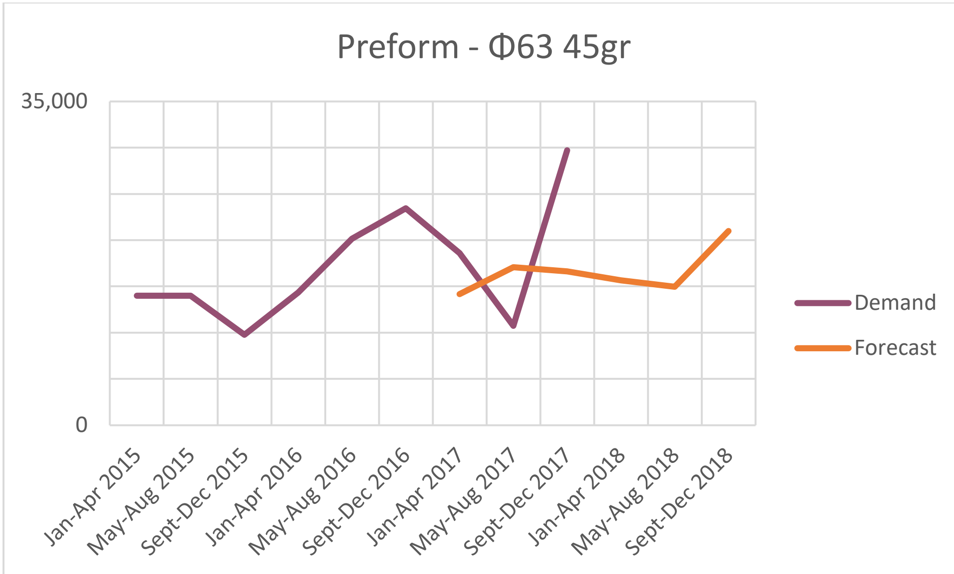


Figure 65. Demand forecasting of preform Φ63-45gr with the application of Simple Moving Average method

The plot of time series shows irregular variation with upward secular trend. The results follow an upward trend, but similarly to preform Φ82-50gr, they are not satisfactory, as the time series is short-term.

5.1.1.2 Product Category B

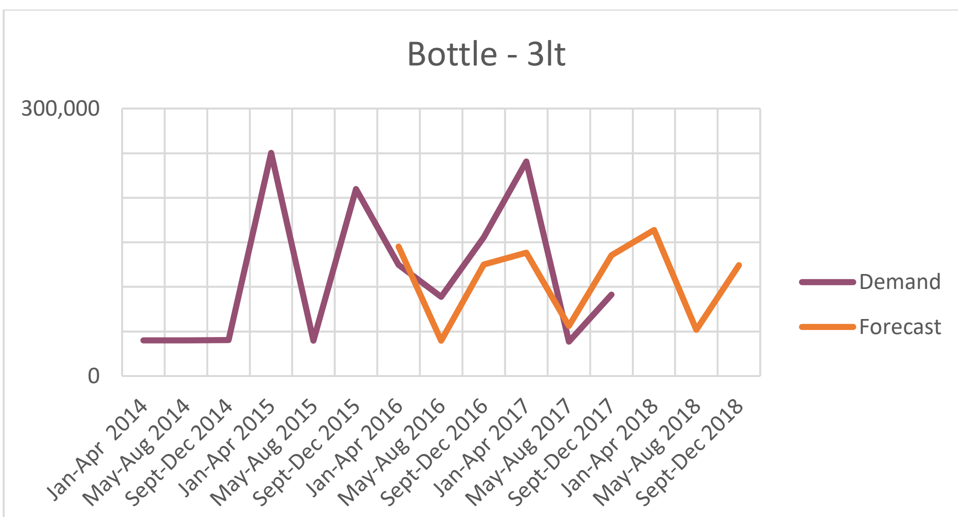


Figure 66. Demand forecasting of bottle-3lt with the application of Simple Moving Average method

The plot of time series shows cyclical pattern with slight upward secular trend. The results that were obtained follow the same pattern and they are sufficient.

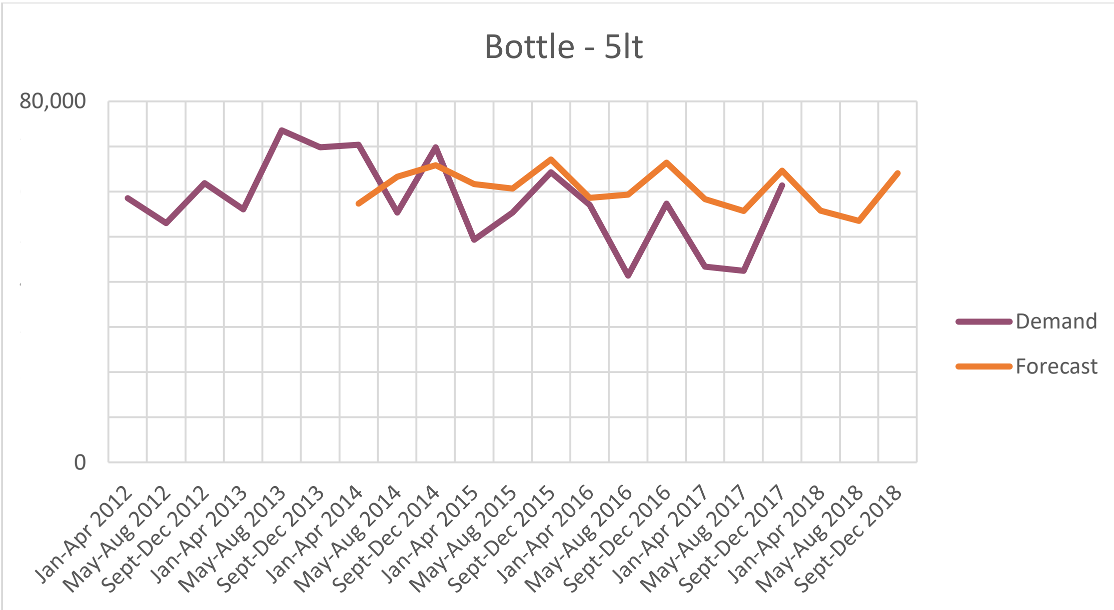


Figure 67. Demand forecasting of bottle-5lt with the application of Simple Moving Average method

The time series shows irregular variation with slight downward secular trend. The results show a slight downward secular trend and low deviation.

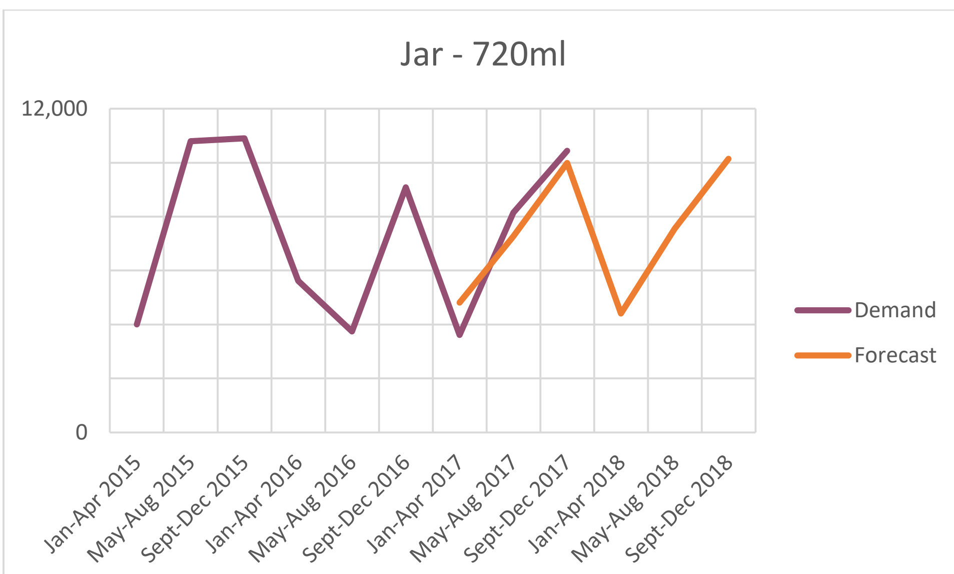


Figure 68. Demand forecasting of jar-720ml with the application of Simple Moving Average method

The time series show a cyclical pattern with slight upward secular trend. The results that were obtained follow the same pattern and they are very good even if the time series is short-term.

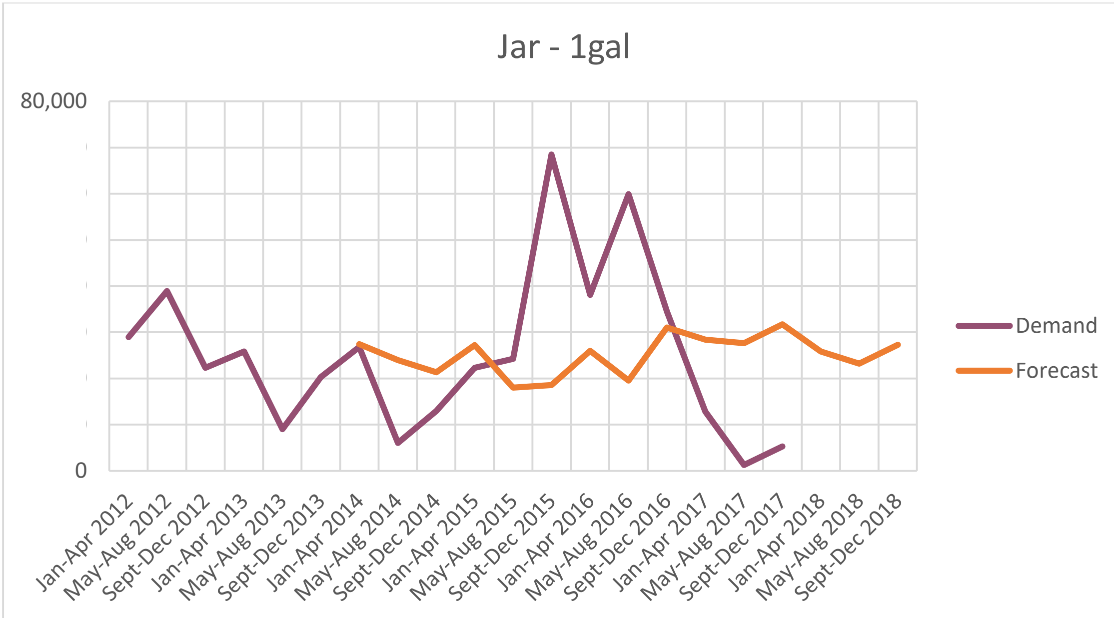


Figure 69. Demand forecasting of jar-1gal with the application of Simple Moving Average method

The time series shows a cyclical pattern with no trend. The results neither follow the same pattern, nor correspond to the extreme values.

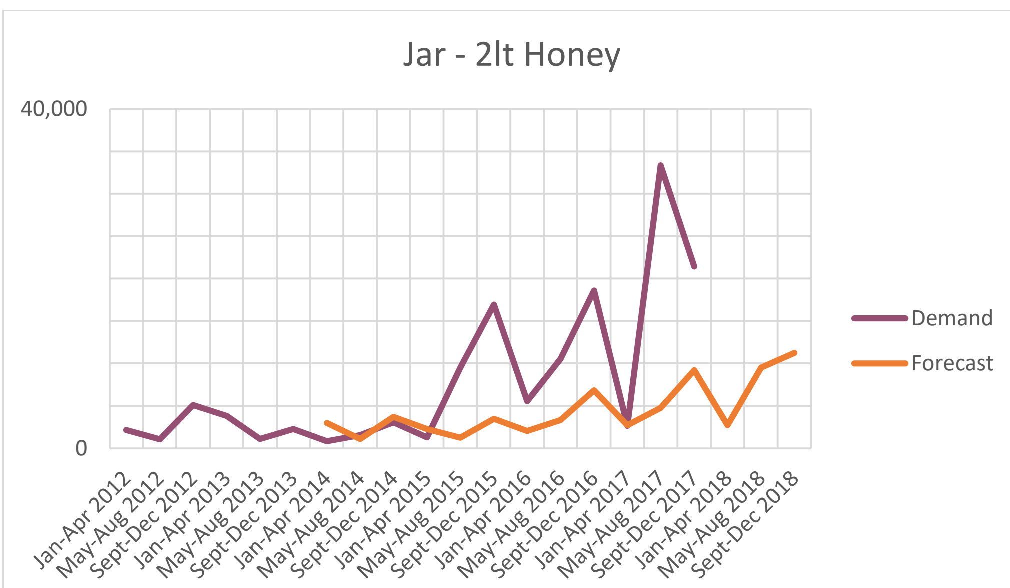


Figure 70. Demand forecasting of jar-2lt Honey with the application of Simple Moving Average method

The plot of time series shows a cyclical pattern with upward secular trend. The results that were obtained follow the same pattern, but they are inadequate, as they show high deviation between the extreme values.

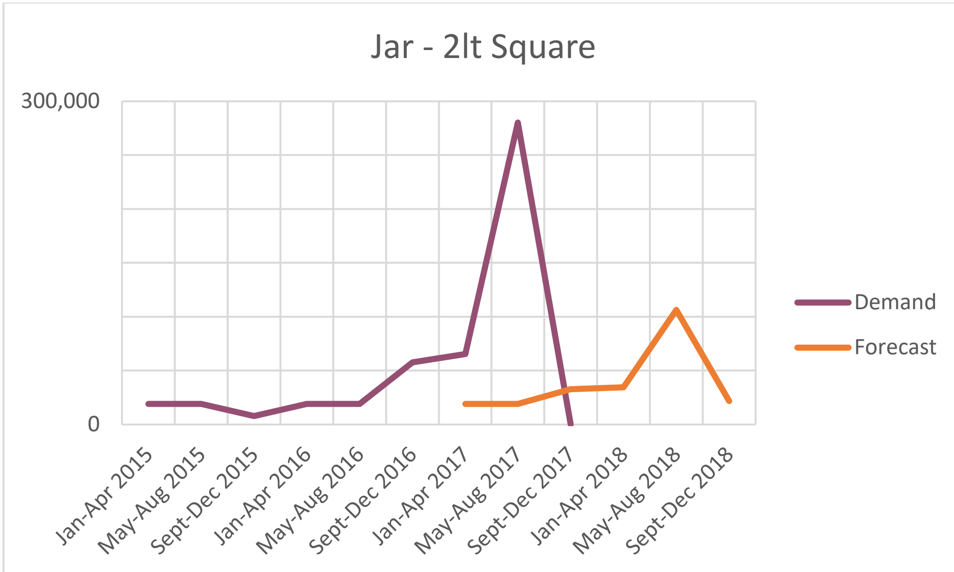


Figure 71. Demand forecasting of jar-2lt Square with the application of Simple Moving Average method

The time series shows irregular variation with upward secular trend. Similarly, the results follow the same pattern, but they show high deviation.

5.1.1.3 Product Category C

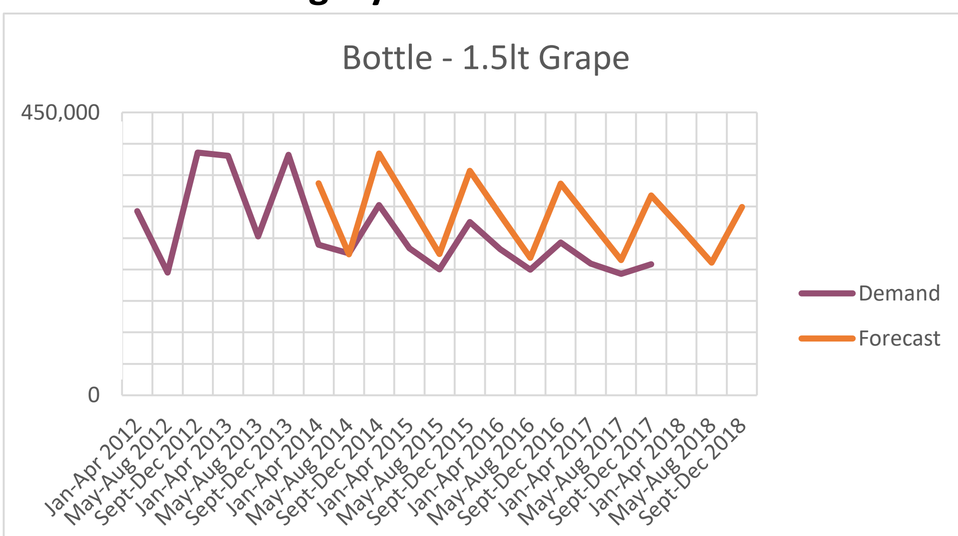


Figure 72. Demand forecasting of bottle-1.5lt Grape with the application of Simple Moving Average method

The plot of time series shows a seasonal pattern with downward secular trend. The results are very satisfactory and follow the same pattern.

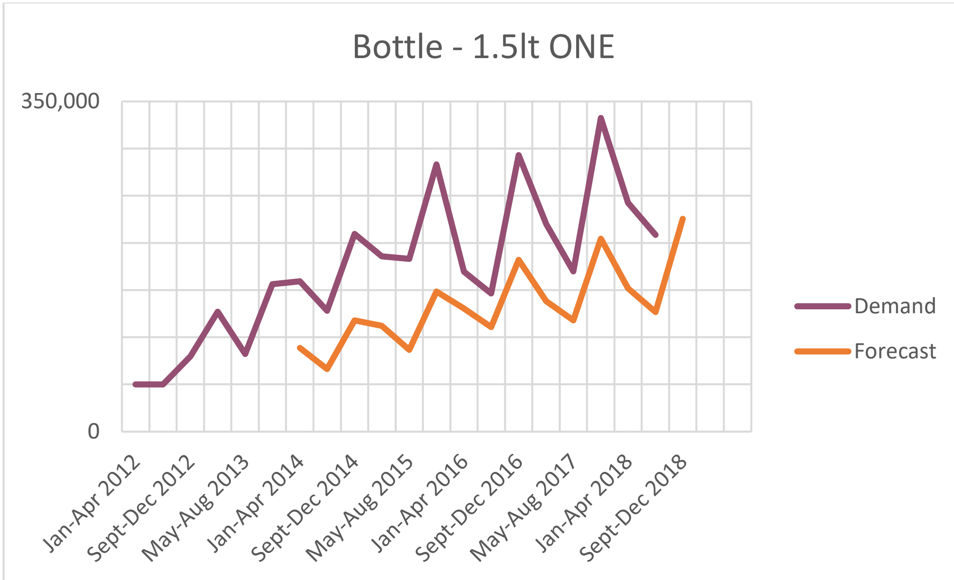


Figure 73. Demand forecasting of bottle-1.5lt ONE with the application of Simple Moving Average method

The time series shows a seasonal pattern with upward secular trend, as the results that were obtained, which are very satisfactory and follow the extreme values as well.

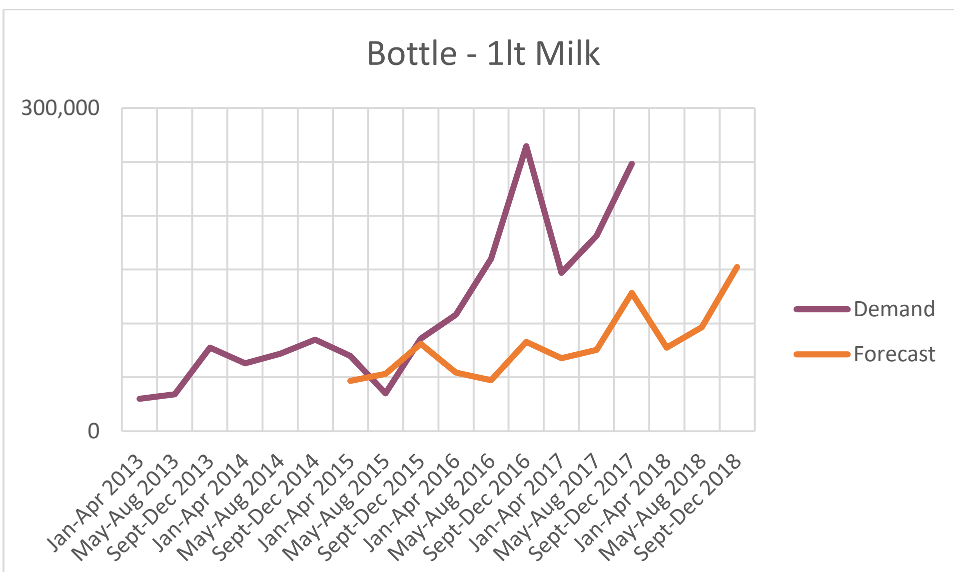


Figure 74. Demand forecasting of bottle-1lt Milk with the application of Simple Moving Average method

The plot of time series shows irregular variation with upward secular trend. The results that were obtained follow the same pattern, but there is a significant deviation between the values.

In general, although the formula of Simple Moving Average method is the simplest among all the other forecasting methods that have been tested in this study, in many cases, it produces satisfactory forecasting results, since it follows the seasonal and cyclical patterns, as well as the secular trend.

However, it is not so reliable when there is sudden sales drop or jump or when the time series is short. Specifically, the worst forecasting results were obtained from products with a few available past observations or new products, such as 720ml jar, Φ82-50gr and Φ63-45gr preforms. The most satisfactory results were obtained from products with more available past observations, which show a seasonal or cyclical pattern, such as Φ82-196gr preform and bottles of 3lt, 5lt, 1.5lt.

5.1.2 Double Moving Average

This forecasting technique is applied when the observations of the time series illustrate a trend. According to this method, simple moving average is applied twice; once to the original data and then to the resulting single moving average data. During the analysis, linear trend of the observations is taken under consideration. The application of this method consists of five steps [2]:

1st step: Calculation of simple moving average for ***m*** periods, $\mathbf{M_t}$. That is:

$$M_{t+1} = \frac{1}{m} * \sum_j Y_{t-j+1}\,, \text{ where } \; j = 1,2,\ldots,m$$

2nd step: Calculation of double moving average for ***m*** periods, $\mathbf{M'_t}$. That is:

$$M'_{t+1} = \frac{1}{m} * \sum_j M_{t-j+1}\,, \text{ where } \; j = 1,2,\ldots,m$$

3rd step: Calculation of difference, $\mathbf{a_t}$. That is:

$$a_t = 2 * M_t - M'_t$$

4th step: Calculation of adjusting parameter for trend, $\mathbf{b_t}$. That is:

$$b_t = \frac{2}{(m-1)} * (M_t - M'_t)$$

5th step: Calculation of forecasting values, $\hat{Y}_{t+1}$, for future period ***h***. That is:

$$\hat{Y}_{t+h} = a_t + h * b_t$$

This method was applied for every four-month period, as well. The obtained results are presented on the following graphs (Figures 75-88). Purple colored line shows the actual demand, whereas orange one shows the forecasting values.

5.1.2.1 Product Category A

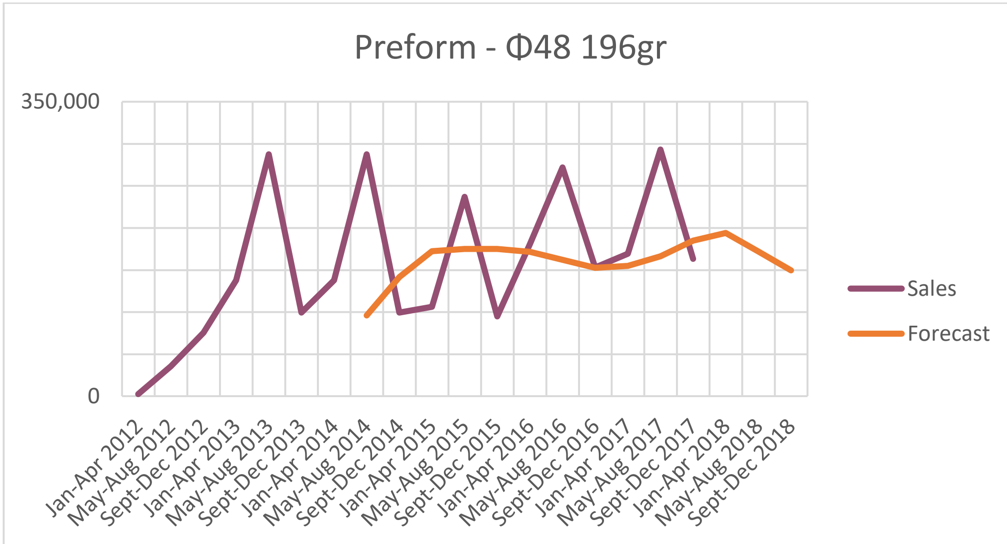


Figure 75. Demand forecasting of preform Φ48-196gr with the application of Double Moving Average method

The results that were obtained do not follow the same pattern as the actual observations. Their fluctuation is very smooth, without peaks and troughs and they do not approach the higher or lower values.

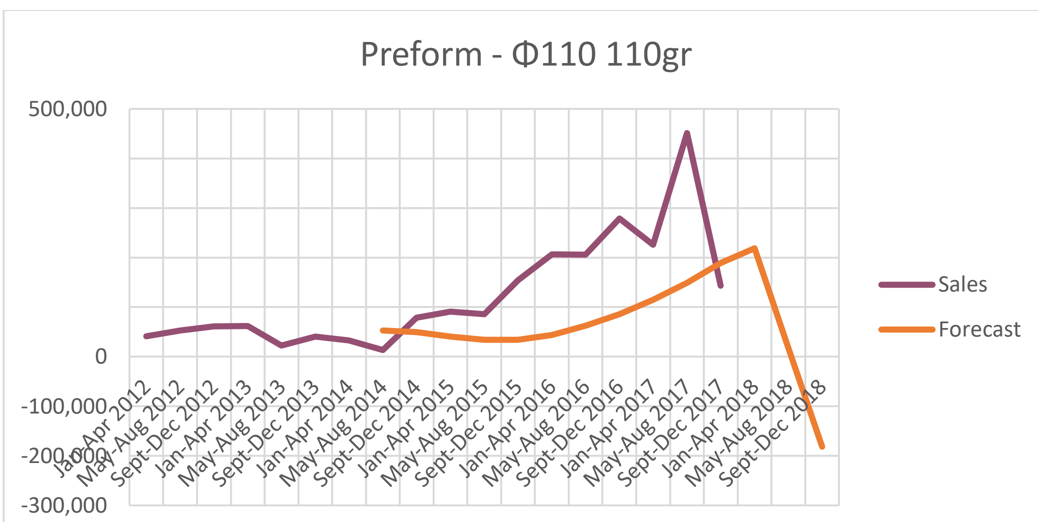


Figure 76. Demand forecasting of preform Φ110-110gr with the application of Double Moving Average method

The results that were obtained do not follow the same pattern as the past observations and they are very inadequate. Note that they approach negative values.

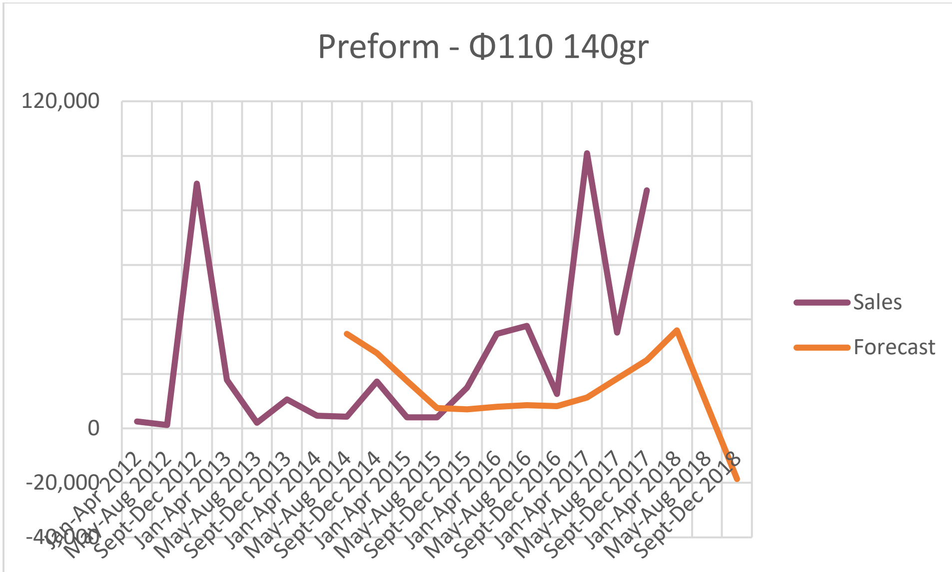


Figure 77. Demand forecasting of preform Φ110-140gr with the application of Double Moving Average method

The results show high deviation and they do not follow the same pattern as the past observations. Additionally, they are not satisfactory as they do not follow the same trend and they approach negative values.

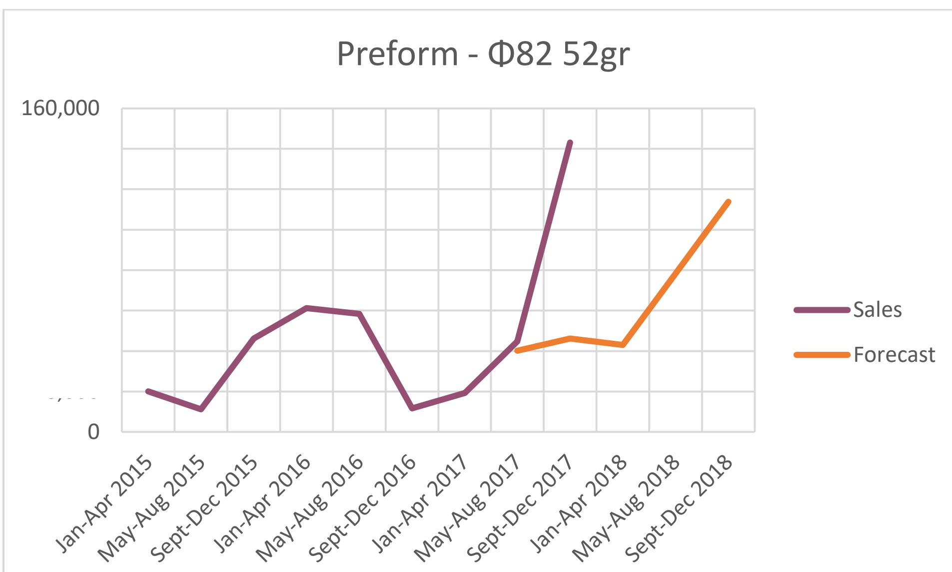


Figure 78. Demand forecasting of preform Φ82-50gr with the application of Double Moving Average method

The results are better than those of the previous products, follow the pattern of the past observations and correspond to the extreme values.

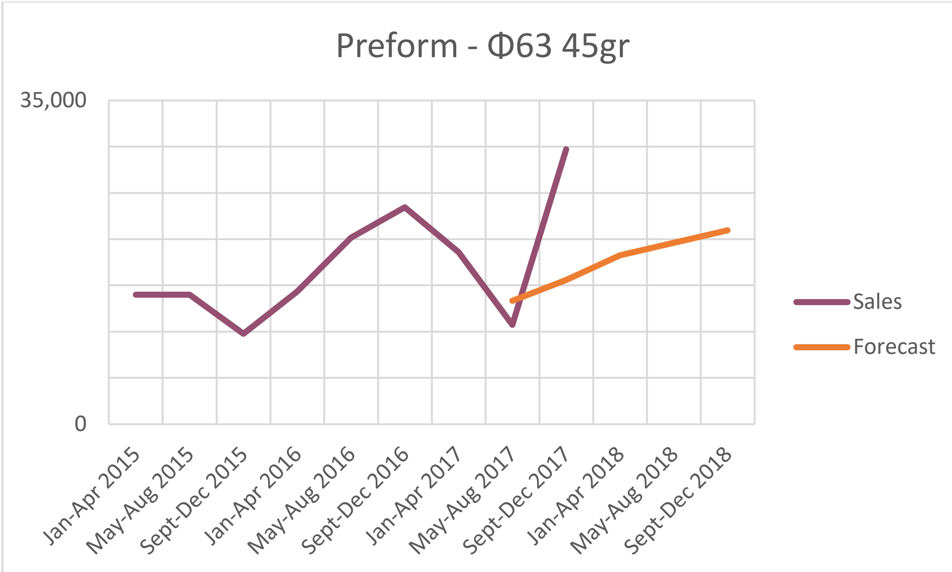


Figure 79. Demand forecasting of preform Φ63-45gr with the application of Double Moving Average method

The results that were obtained are not satisfactory and they do not follow the same pattern as the past observations. The fact that time series is short-term has great impact on the accuracy of the results.

5.1.2.2 Product Category B

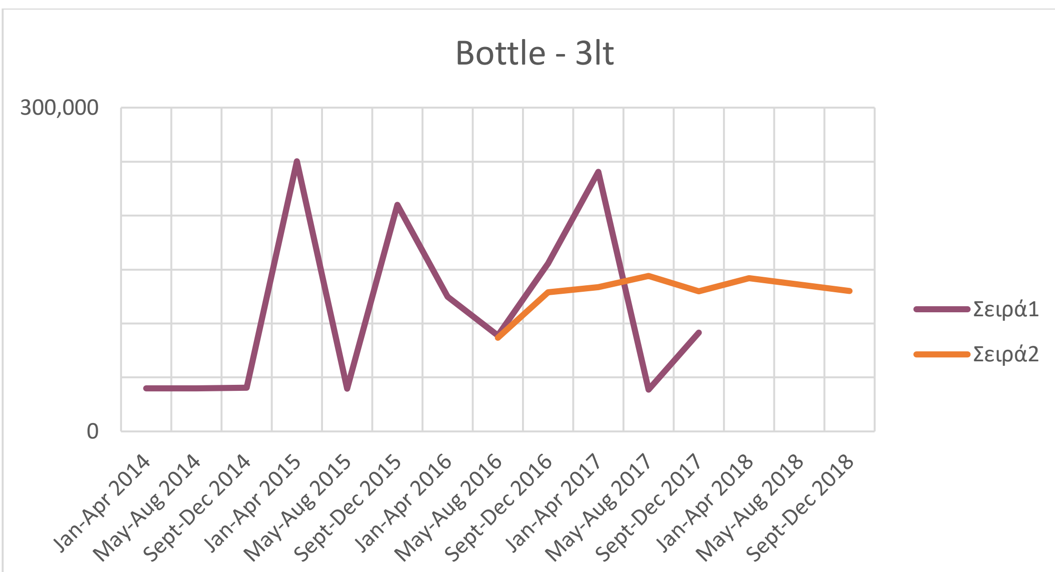


Figure 80. Demand forecasting of bottle-3lt with the application of Double Moving Average method

The results do not show any significant fluctuation, as they appear to be smoother without peaks or troughs. Moreover, they do not correspond to high or low values, but they follow the same trend, as the past observations.

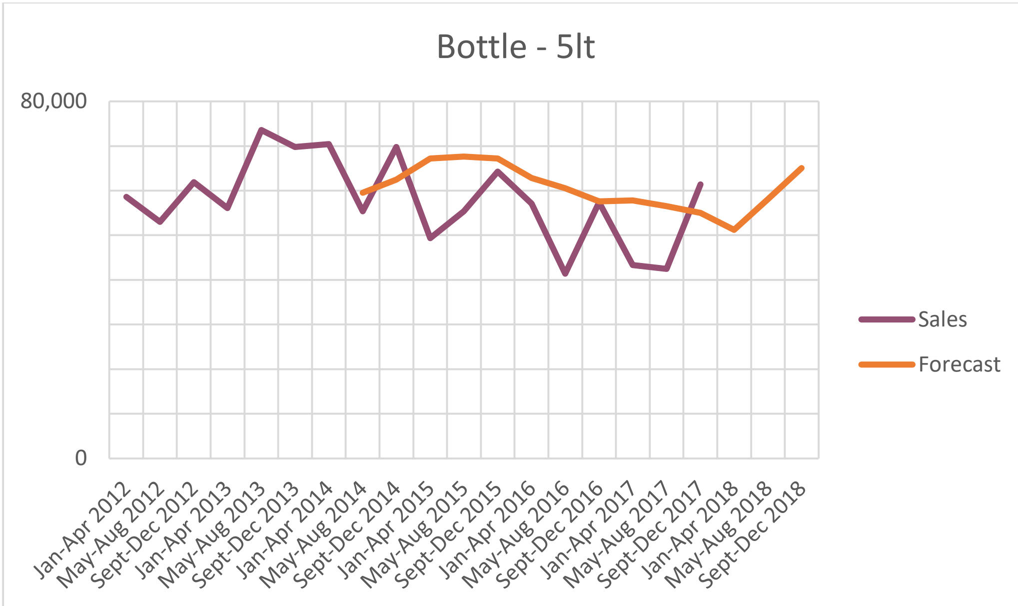


Figure 81. Demand forecasting of bottle-5lt with the application of Double Moving Average method

The results that were obtained correspond to the same downward trend, as the past observations. Moreover, they do not show very high deviation from the past observations.

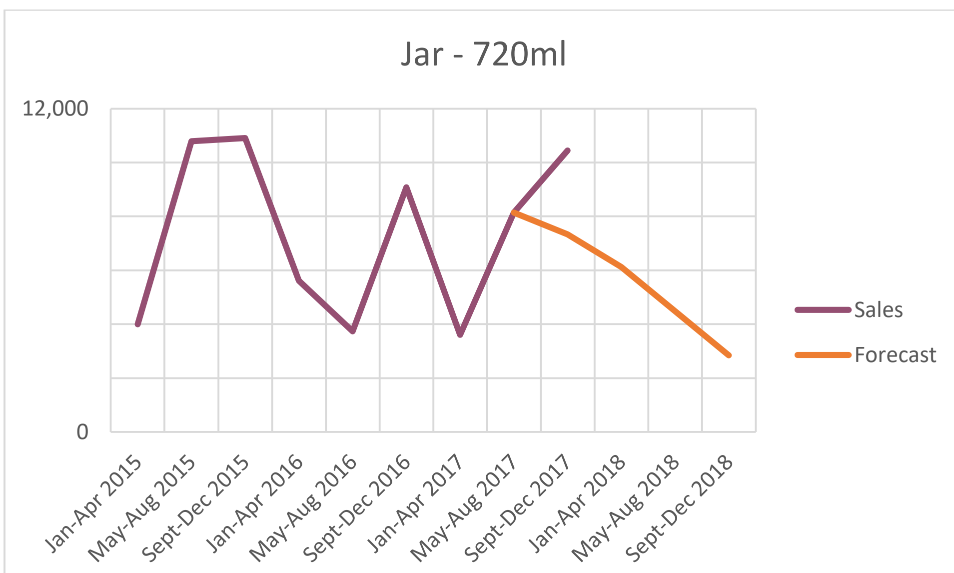


Figure 82. Demand forecasting of jar-720ml with the application of Double Moving Average method

The results that were obtained are very bad. They do not follow the same trend or pattern, as the past observations and they do not show any fluctuation. However, note that the time series is sort-term, which affects the accuracy of the double moving average method.

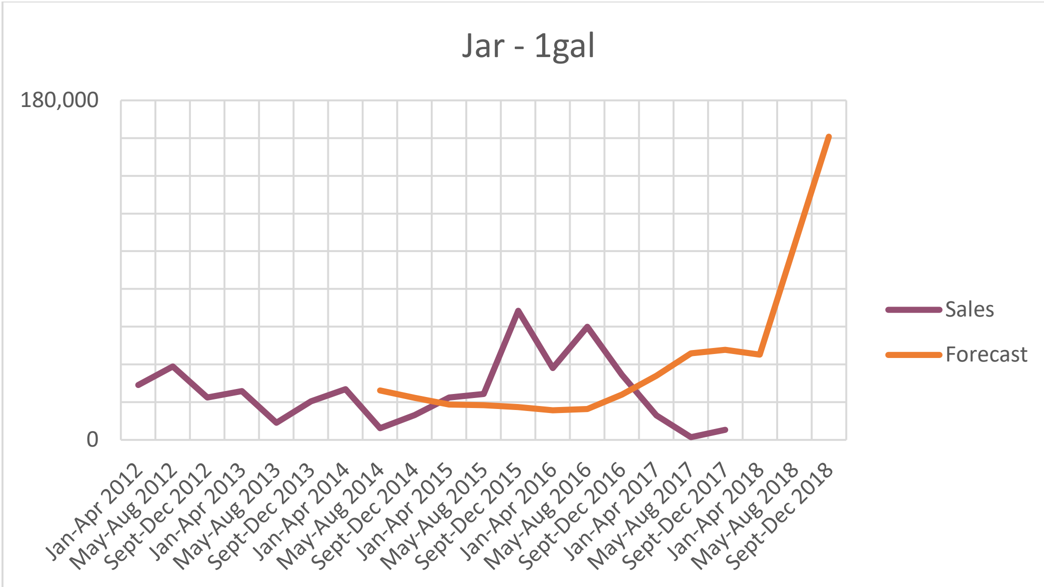


Figure 83. Demand forecasting of jar-1gal with the application of Double Moving Average method

Even though the time series is long-term, the results that were obtained do not show fluctuation, as well as they do not follow the same pattern as the past observations. Moreover, the deviation from the past observations is very high.

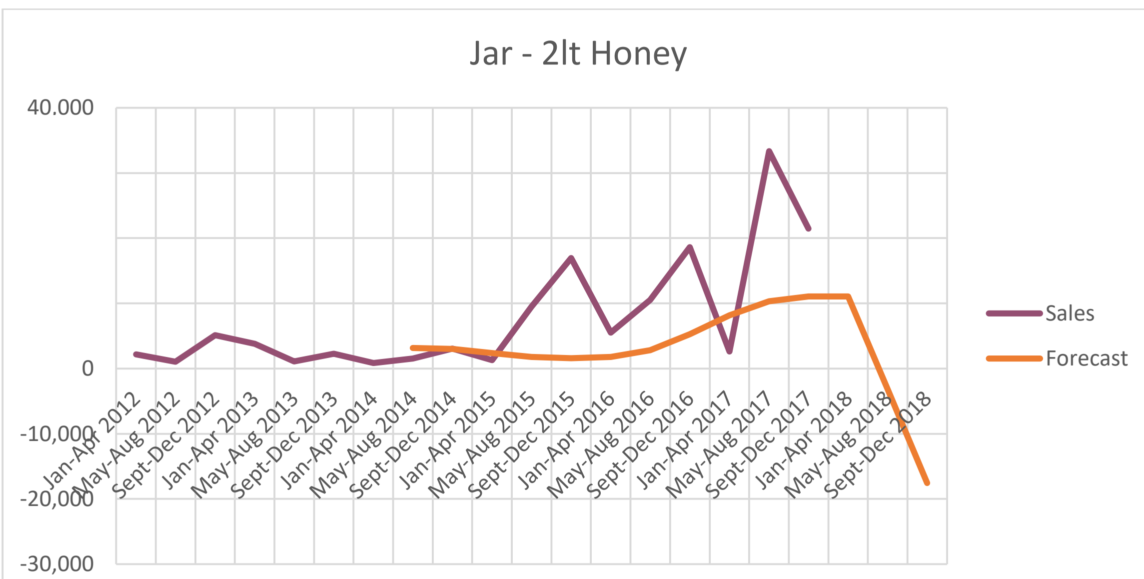


Figure 84. Demand forecasting of jar-2lt Honey with the application of Double Moving Average method

The results that were obtained are not satisfactory. They do not follow the same pattern as the past observations, they do not correspond to high values, as they show no fluctuation and they approach negative values.

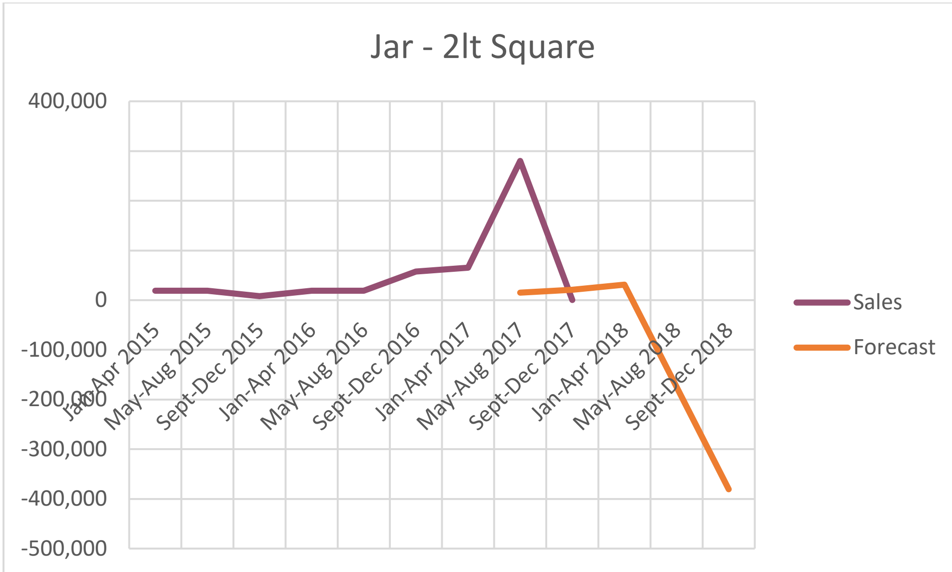


Figure 85. Demand forecasting of jar-2lt Square with the application of Double Moving Average method

The results that were obtained are not satisfactory. They do not follow the same trend with the past observations and approach negative values. However, note that the time series is short-term, hence, this has great impact on the accuracy of the results of the method.

5.1.2.3 Product Category C

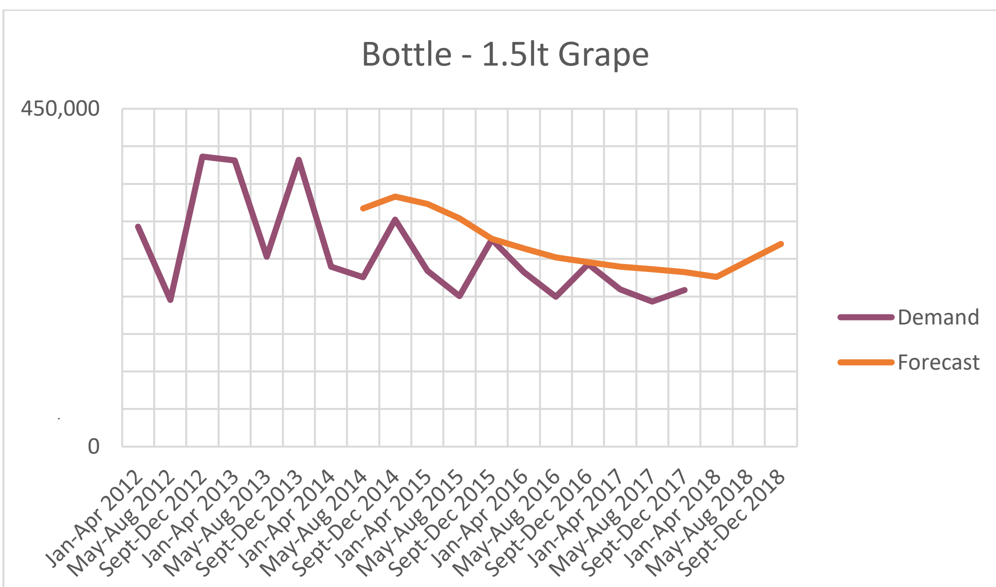


Figure 86. Demand forecasting of bottle-1.5lt Grape with the application of Double Moving Average method

The results are satisfactory. They follow the same downward trend as the past observations and present low deviation from them, but there is no significant fluctuation.

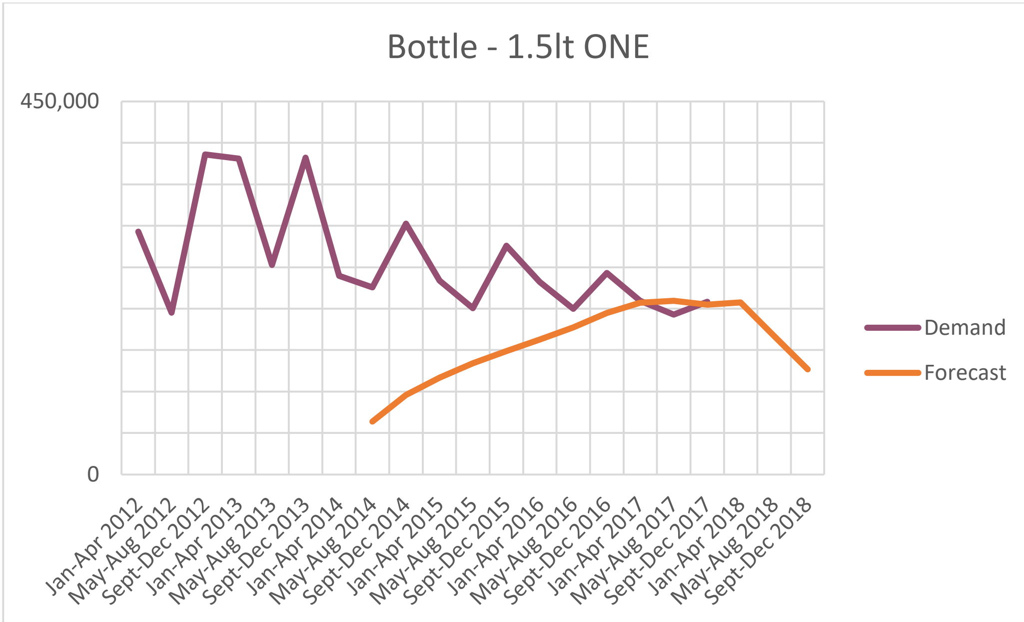


Figure 87. Demand forecasting of bottle-1.5lt ONE with the application of Double Moving Average method

The results show high deviation from the past observations. They do not follow the same pattern or trend and they do not show fluctuation.

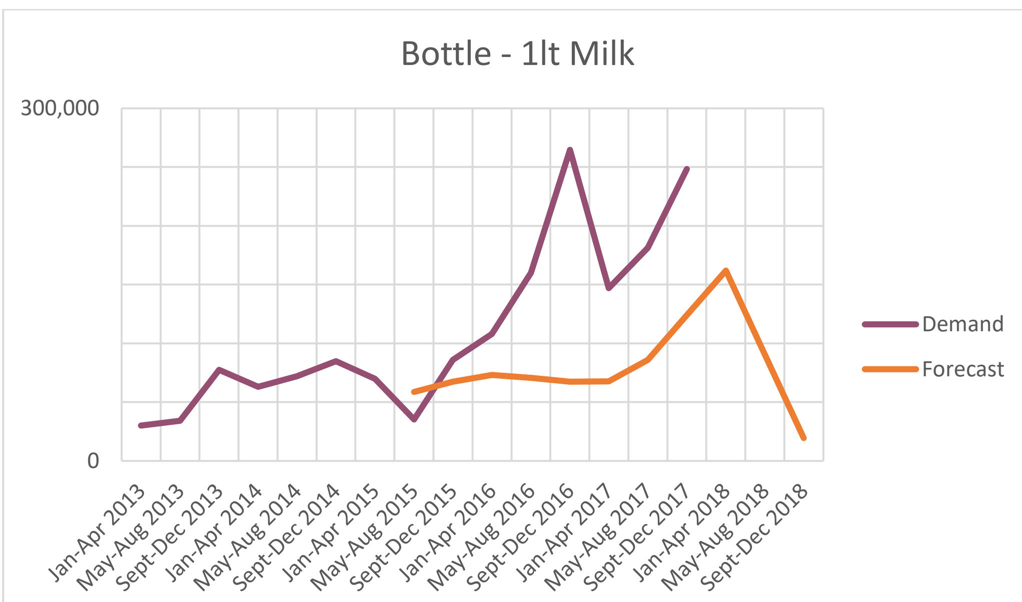


Figure 88. Demand forecasting of bottle-1lt Milk with the application of Double Moving Average method

The pattern and the trend of the results that were obtained are similar to those of the past observations. However, they present deviation.

In general, the method of Double Moving Average obtained the worst results for almost every product, as the deviation is high and it follows neither the seasonality nor the trend. Moreover, as far as short-term time series and time series that present very low values (close to zero) are concerned, the results that were obtained are very bad (i.e. preform Φ110-110gr and Φ110-140gr, jar 2lt honey and square).

5.1.3 Simple Exponential Smoothing (Brown's Method)

According to Simple Exponential Smoothing technique, time series are weighted unevenly. Specifically, the weight decreases exponentially as the observations get older. For example, the latest observation gets a greater weight than the second latest, while the second latest get a greater weight than the third latest, and so on [46]. That kind of weighting is defined by a smoothing factor for the level (smoothing coefficient), $\boldsymbol{\alpha}$. For a better comprehending of the application of this method, the forecasting values of a time series are given by the following formula [2], [42]:

$$\hat{Y}_{t+1} = a * Y_t + a * (1-a) * Y_{t-1} + a * (1-a)^2 * Y_{t-2} + \cdots + a * (1-a)^n * Y_{t-n}$$

Where $0 \leq \boldsymbol{\alpha} \leq 1$.

According to the previous formula, the forecasting $\hat{Y}_t$ for period t, that obtained at the beginning of this period, is given by the following formula:

$$\hat{Y}_t = a * Y_{t-1} + a * (1-a) * Y_{t-2} + a * (1-a)^2 * Y_{t-3} + \cdots + a * (1-a)^n * Y_{t-1-n}$$

Consequently, in accordance with both previous formulas, the Brown's method equation takes the form of

$$\hat{Y}_{t+1} = a * Y_t + (1-a) * \hat{Y}_t$$

Where $t = 2,3, \ldots, n$ and the initial condition is $\hat{Y}_2 = Y_1$.

5.1.3.1 Choosing the Most Sufficient Value of Smoothing Coefficient

The different values of $\boldsymbol{\alpha}$ have a great impact on forecasting and error. Specifically, if the values are large, the model is affected namely by most recent observations, on the contrary to the smaller values that contribute to the model by weighting more the past observations. When $\boldsymbol{\alpha}$ is close to 1, it indicates that the latest observations have great influence on the forecast, whereas when $\boldsymbol{\alpha}$ is close to zero, it indicates that old observations contribute to a greater extent to the forecast [42].

Choosing the best value of $\boldsymbol{\alpha}$ is crucial for the forecasting results and it is based on trial and error or judgement by experience. Namely, the value which minimizes the errors, such as RMSE, is the most sufficient one. Consequently, the problem of choosing the most sufficient value solved as a linear programming problem of minimizing the value of error (RMSE) described in section 5.2, with $\boldsymbol{\alpha}$ being the only unknown variable.

This method was applied for every four-month period, as well. The obtained results are presented on the following graphs (Figures 89-102). Purple colored line shows the actual demand, whereas orange one shows the forecasting values.

5.1.3.2 Product Category A

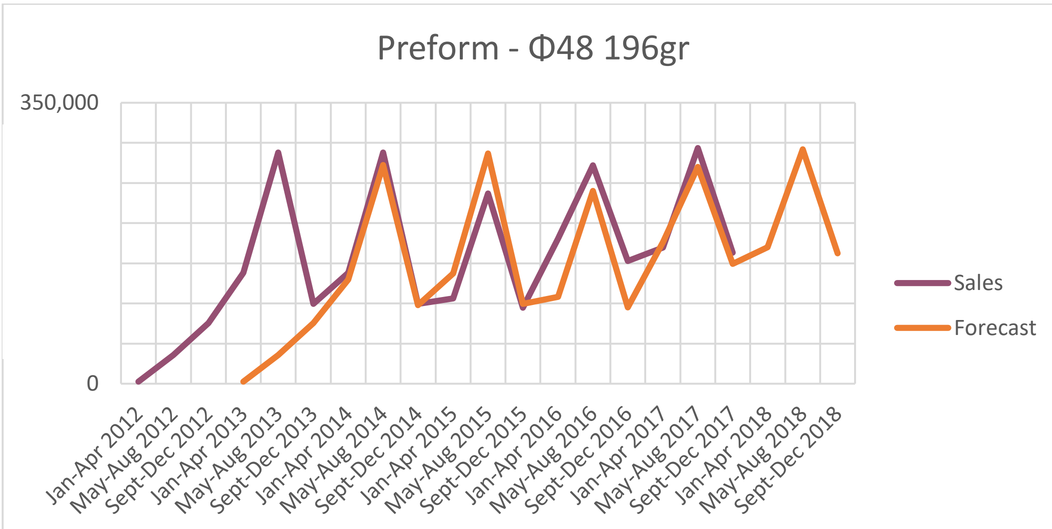


Figure 89. Demand forecasting of preform Φ48-196gr with the application of Brown's method

The results are very satisfactory, as they follow the same pattern and trend with the past observations and correspond to the majority of the values (high and low). Moreover, the deviation is very low.

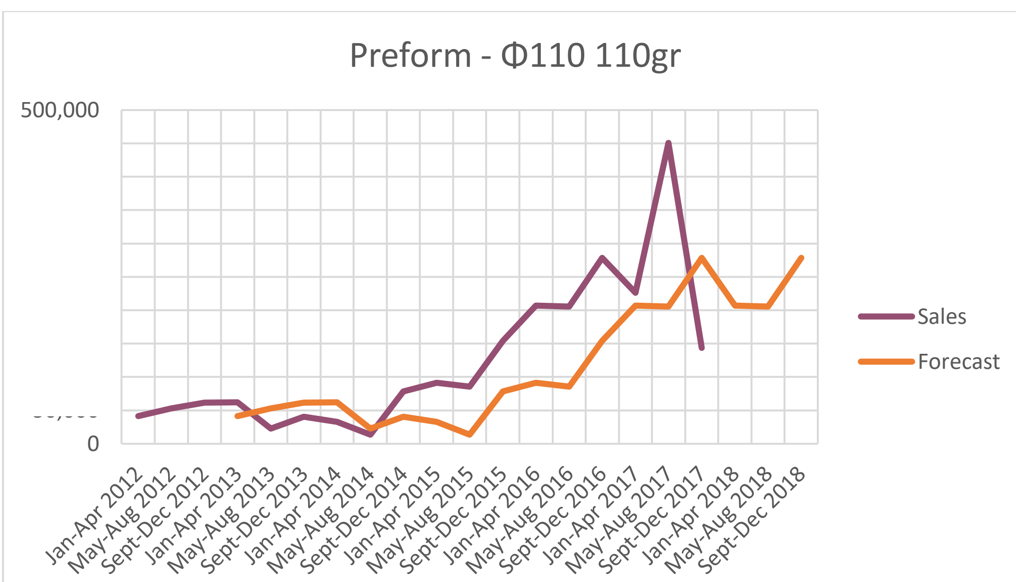


Figure 90. Demand forecasting of preform Φ110-110gr with the application of Brown's method

The results that were obtained follow the same pattern and trend as the past observations and they do not show a high deviation.

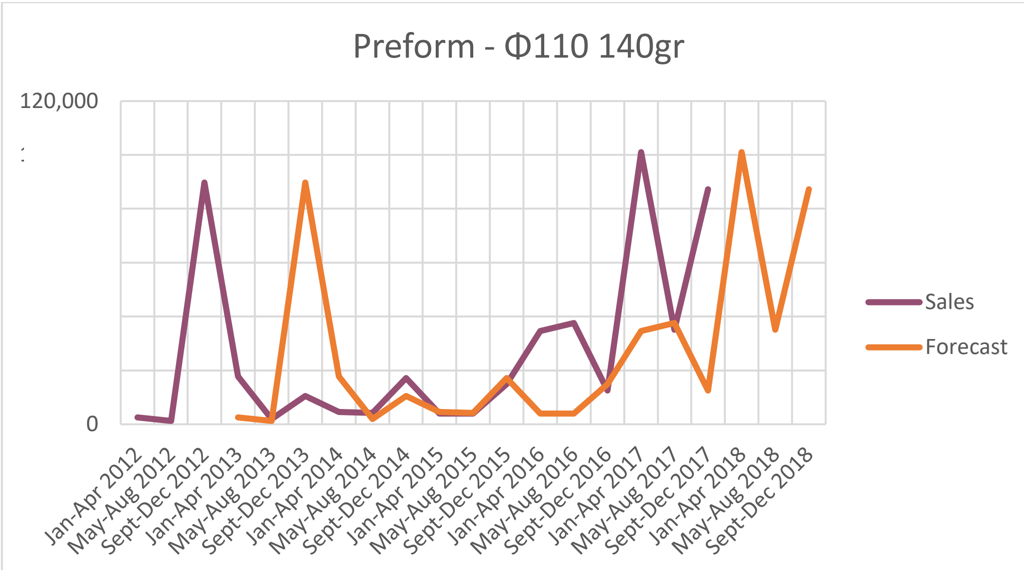


Figure 91. Demand forecasting of preform Φ110-140gr with the application of Brown's method

The results that were obtained are very good, as they follow the same pattern and trend with the past observations and also, they reach the extreme values (high and low).

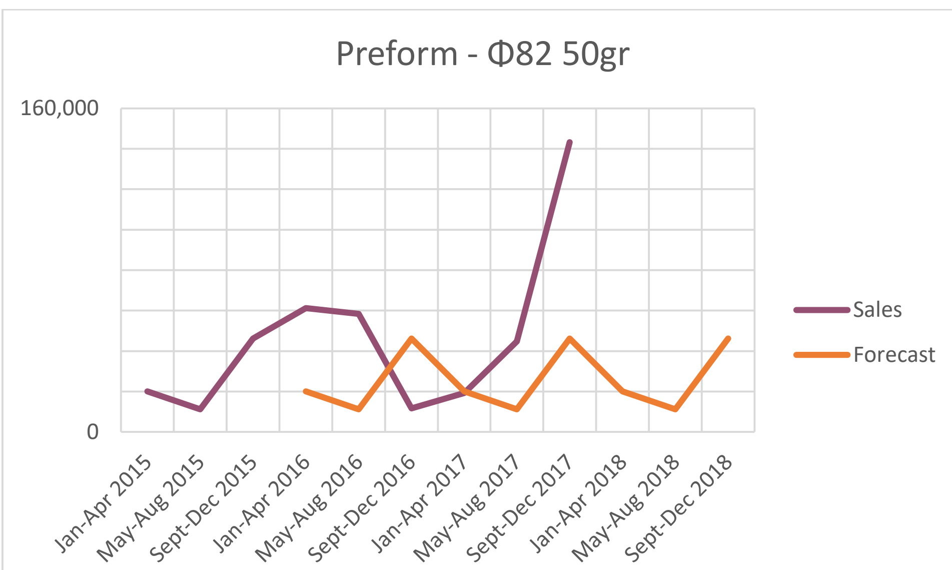


Figure 92. Demand forecasting of preform Φ82-50gr with the application of Brown's method

The results do not follow the same pattern as the past observations and show more fluctuations. However, note that the time series is short-term, which affects the accuracy of the results.

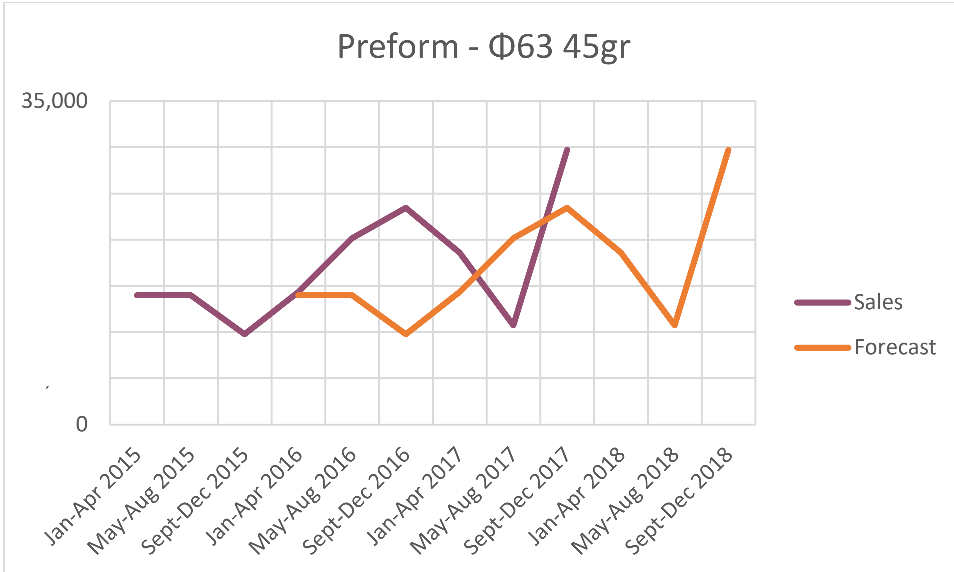


Figure 93. Demand forecasting of preform Φ63-45gr with the application of Brown's method

The results are very satisfactory, as they follow the same pattern and trend as the past observations and they do not show any significant deviation.

5.1.3.3 Product Category B

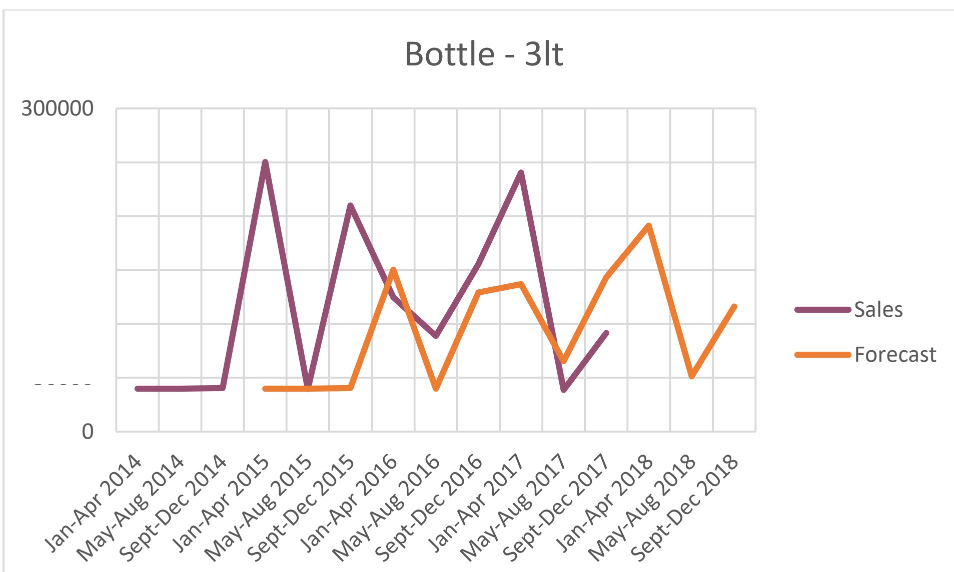


Figure 94. Demand forecasting of bottle-3lt with the application of Brown's method

The results are satisfactory. They follow the same pattern and trend with the past observations. However, as far as high values are concerned, they show a slight deviation.

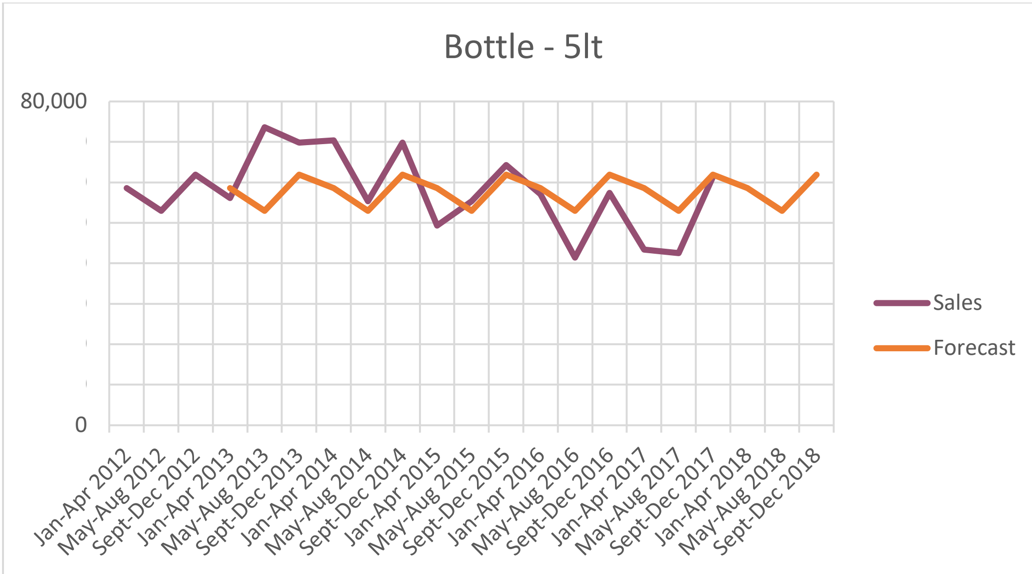


Figure 95. Demand forecasting of bottle-5lt with the application of Brown's method

The results are not very similar to the pattern of the past observations and show a variance on the high and low values.

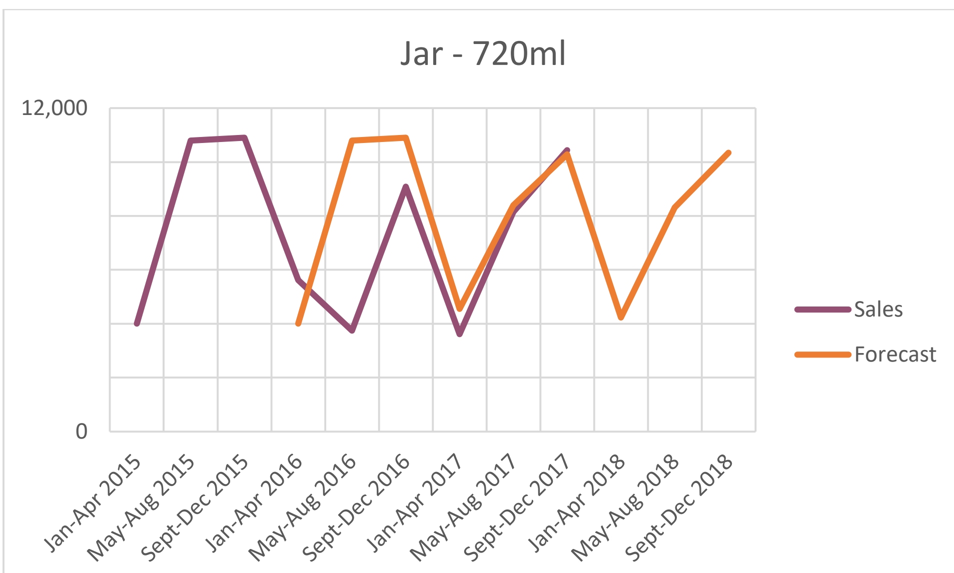


Figure 96. Demand forecasting of jar-720ml with the application of Brown's method

Although the time series is short-term, the results that were obtained follow the same pattern and trend as the past observations and correspond to the extreme values.

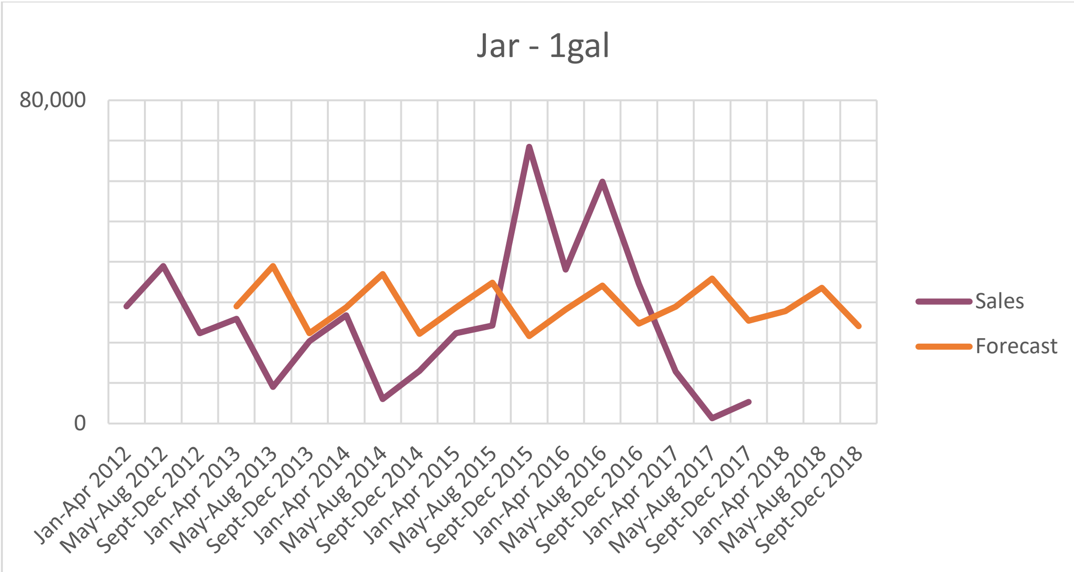


Figure 97. Demand forecasting of jar-1gal with the application of Brown's method

The results that were obtained follow the same trend as the past observations, but since there is deviation between them, they do not correspond to the extreme values.

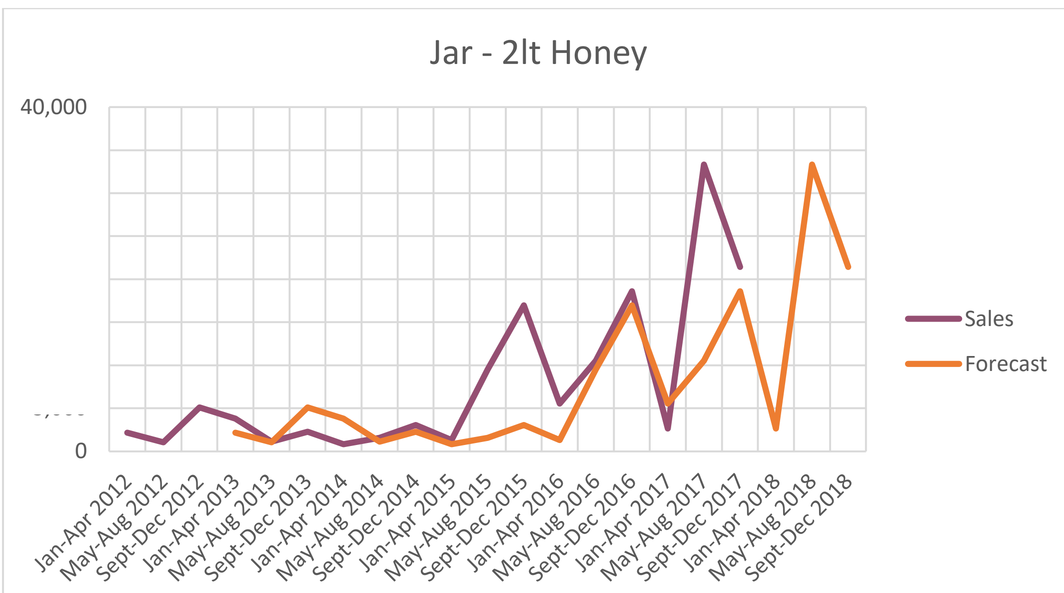


Figure 98. Demand forecasting of jar-2lt Honey with the application of Brown's method

The results are very satisfactory, since they follow the same pattern and trend as the past observations. Also, they match the very high or low values.

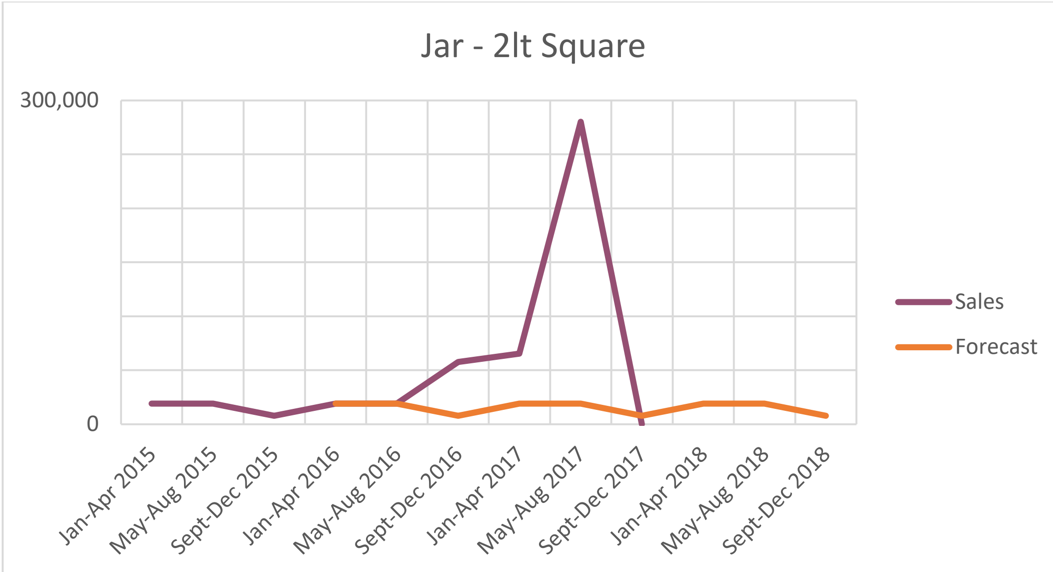


Figure 99. Demand forecasting of jar-2lt square with the application of Brown's method

Initially, note that this time series is short-term, which has a great impact on the accuracy of the forecasting results. Specifically, the results that were obtained do not follow the same pattern or trend as the past observations. Moreover, they do not match any extreme value, as they present a smoother variation.

5.1.3.4 Product Category C

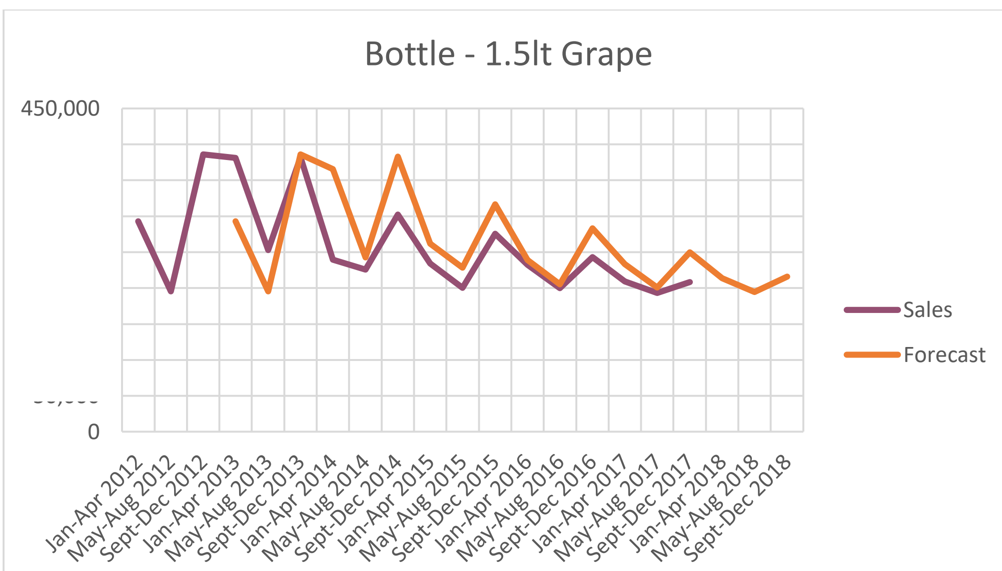


Figure 100. Demand forecasting of bottle-1.5lt Grape with the application of Brown's method

The results that were obtained are adequate and follow the same trend and pattern as the past observations. The variance is very slight, thus the results correspond to high and low values.

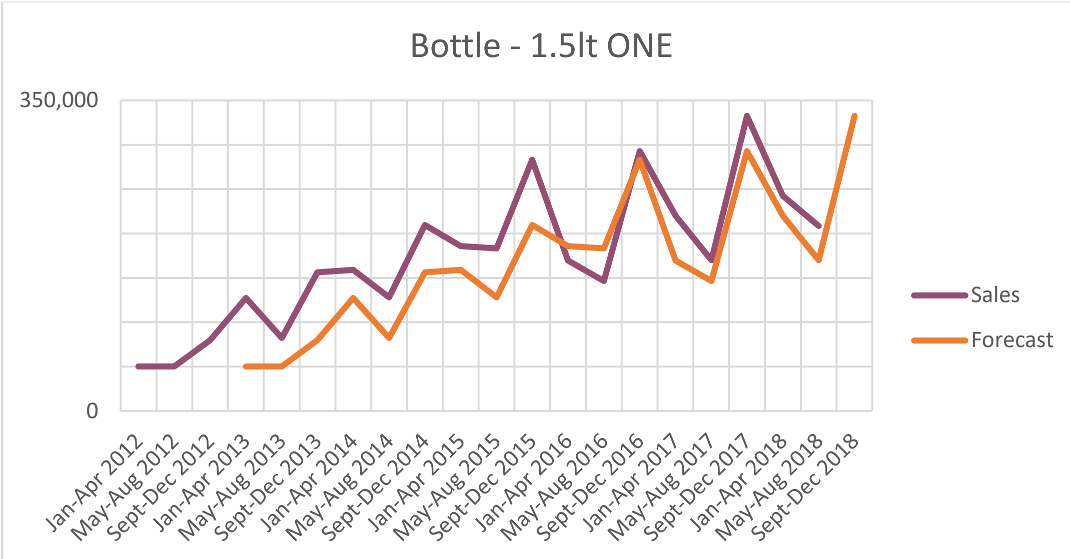


Figure 101. Demand forecasting of bottle-1.5lt ONE with the application of Brown's method

The results follow the pattern and trend as the past observations, with a slight deviation. Moreover, they correspond to the extreme values of the time series.

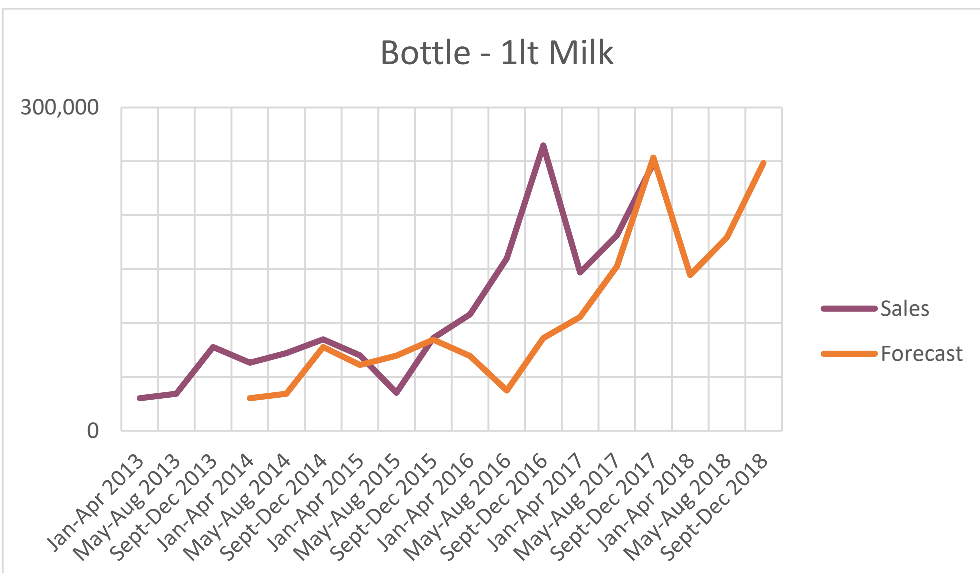


Figure 102. Demand forecasting of bottle-1lt ONE with the application of Brown's method

The results follow the trend of the past observations. Although, there is a slight deviation between them, the forecasting values correspond to high and low values.

In general, the method of Simple Exponential Smoothing (Brown's) obtained very satisfactory results, considering that trend and seasonality are adjusted to the forecasting. Besides, it is more reliable as far as prediction of extreme values is concerned, such as those of Φ82-196gr, Φ110-110gr, Φ110-140gr preforms and bottles of 1.5lt. The worst results were obtained of Φ82-50gr preform and 2lt square jar.

The first one shows irregular variation and is a new product with less available past observations; the second one is a product with very low actual demand and one peak, as it has stopped being produced for couple of periods.

5.1.4 Holt-Winters Method (Triple Exponential Smoothing)

This forecasting method is applied when the observations of a time series show trend (upward or downward) and seasonality, in other words, when it shows seasonal fluctuations, which are repetitive (i.e. every year, week, month) in the same or similar way [40], [41]. This forecasting technique consists of the following three smoothing constants:

- Alpha, ***α***, for the level of the time series
- Beta, ***β***, for the trend of the time series
- Gamma, ***γ***, for the seasonality of the time series

The application of this forecasting method consists of the following steps [2]:

1st step: Overall smoothing of the observations of the time series given by the following equation:

$$A_t = a * \left(\frac{Y_t}{S_{t-L}}\right) + (1-a) * (A_{t-1} + T_{t-1}) \quad , 0 \leq \alpha \leq 1$$

Where:

A_t: Smoothed observation of time series

S_t: Seasonal index of period t

L: Periodicity, that is the number of periods in series. For instance, L=12 for monthly data. In this case, L=3, as the data have been grouped in three four-month periods per year.

a: Smoothing constant of the level of time series

2nd step: Trend smoothing, given by the following formula:

$$T_t = \beta * (A_t + A_{t-1}) + (1-\beta) * T_{t-1} \quad , \quad 0 \leq \beta \leq 1$$

Where:

T_t: Smoothed value of trend

β: Smoothing constant of the trend of time series

<u>3rd step:</u> Seasonal smoothing, given by the following formula:

$$S_t = \gamma * \left(\frac{Y_t}{A_t}\right) + (1-\gamma) * S_{t-L} \quad , 0 \leq \gamma \leq 1$$

Where:

S_t: Smoothed value of seasonality

γ: Smoothing constant of the seasonality of time series

<u>4th step:</u> Forecasting of $\hat{Y}_{t+h}$ at ***h*** periods ahead for the first year, according to the following formula:

$$\hat{Y}_{t+h} = (A_t + h * T_t) * S_{t+h-L} \quad , h = 1,2, \dots, L$$

Initial conditions are defined according to Chatfield, who estimates the initial values of A_t, T_t, and S_t, which are related to the first year, by using the observations of time series of the first year. More specifically,

- For $t = 1,2, \dots, L-1$, A_t values are not defined, whereas for $t = L$, A_L is given by:
$$A_L = \frac{(Y_1 + Y_2 + \cdots + Y_L)}{L}$$
- For $t = 1,2, \dots, L-1$, T_t values are not defined, whereas for $t = L$, let $T_L = 0$
- For $t = 1,2, \dots, L$, S_t is given by: $S_t = \frac{Y_t}{A_L}$

The different values of ***α, β, γ*** have a great impact on forecasting and error. Choosing the best value of ***α, β, γ*** is crucial for the forecasting results and is based on trial and error or judgement by experience. Namely, the value which minimizes the errors, such as RMSE, is the most sufficient one. Consequently, the problem of choosing the most sufficient value solved as a linear programming problem of minimizing the value of error (RMSE) described in section 5.2, with ***α, β, γ*** being the only unknown variables.

This method was applied for every four-month period, as well. The results obtained are presented on the following graphs (Figures 103-116). Purple colored line shows the actual demand, whereas orange one shows the forecasting values.

5.1.4.1 Product Category A

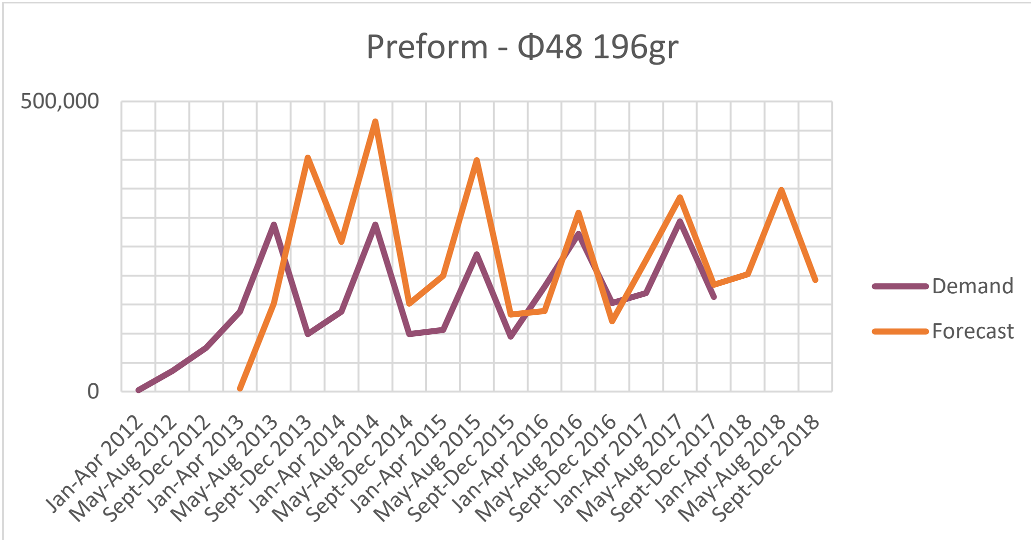


Figure 103. Demand forecasting of preform Φ48-196gr with the application of Holt-Winters method

Although, there is a deviation between the past observations and the results that were obtained, the forecast follows the same pattern and trend as the demand in the past, providing adequate results.

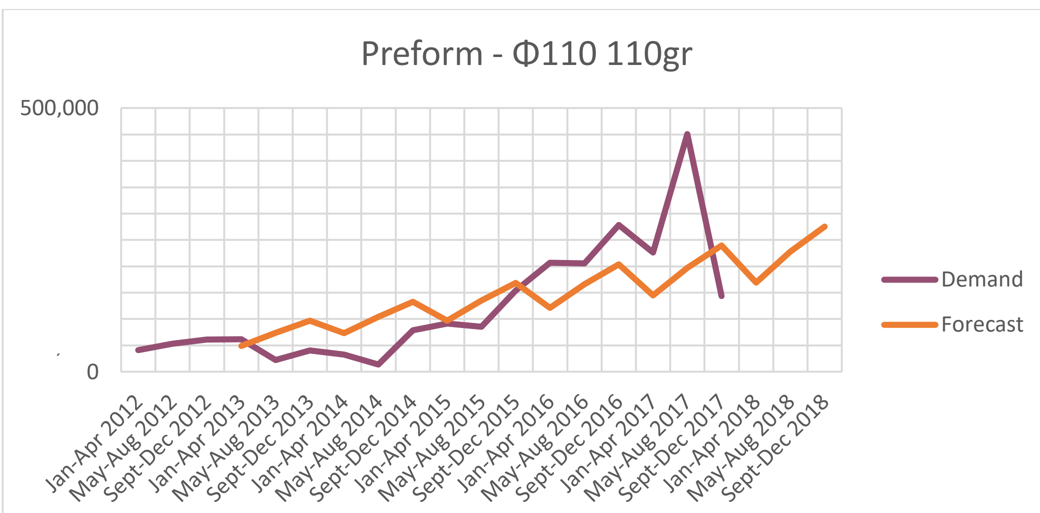


Figure 104. Demand forecasting of preform Φ110-110gr with the application of Holt-Winters method

The results that were obtained follow the same trend as the past observations and show almost the same fluctuation.

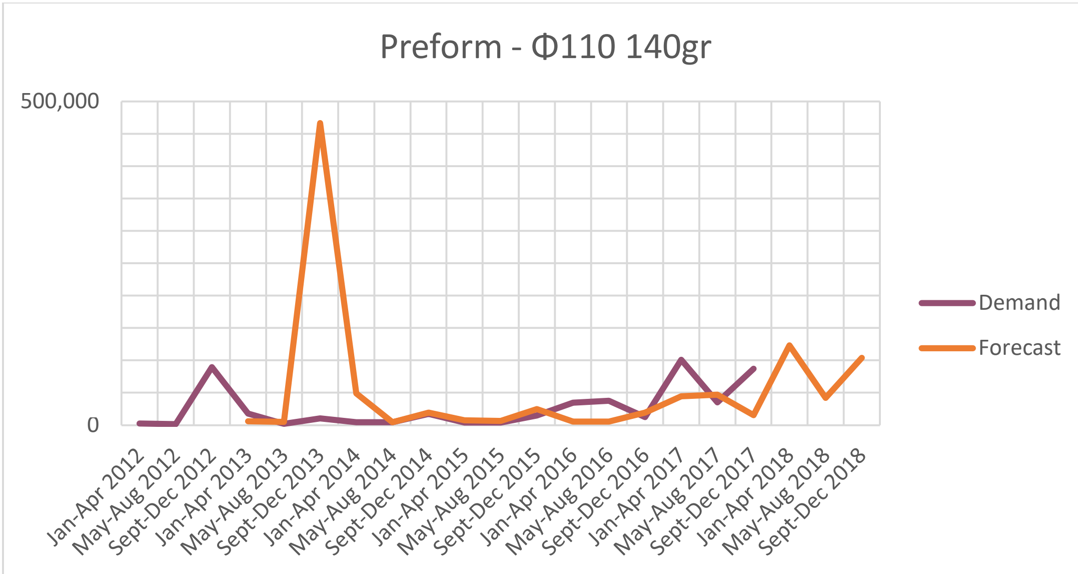


Figure 105. Demand forecasting of preform Φ110-140gr with the application of Holt-Winters method

The results obtained follow the same pattern with the past observations. Although, there is a variance at values close to zero, the results are satisfactory.

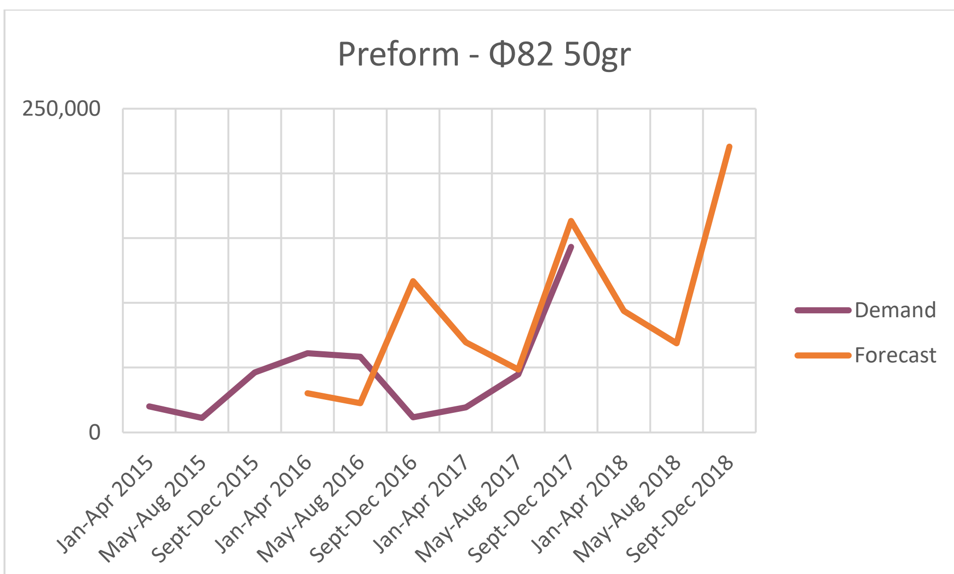


Figure 106. Demand forecasting of preform Φ82-50gr with the application of Holt-Winters method

The results follow the trend of the past observations. Moreover, note the fact that time series is short-term, which leads to a variance to the results that were obtained.

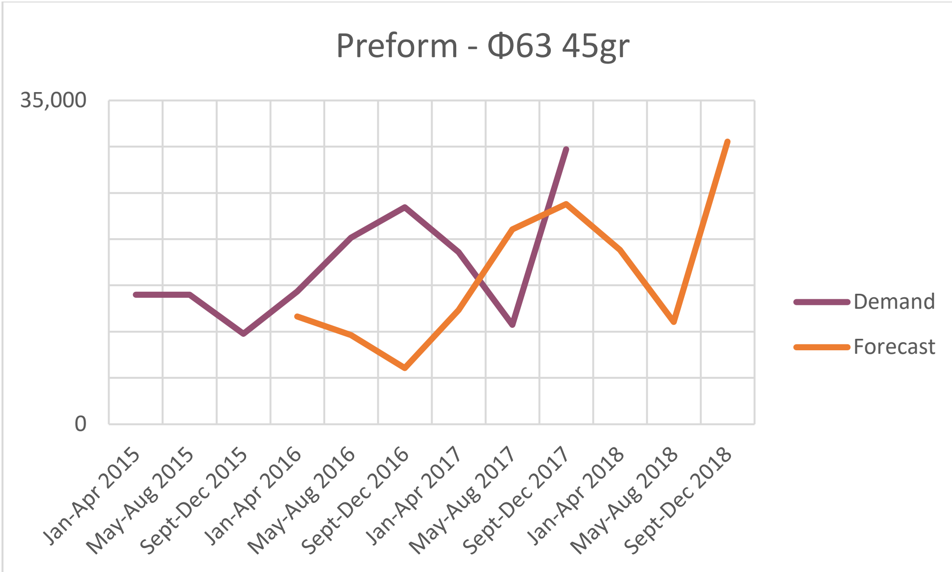


Figure 107. Demand forecasting of preform Φ63-45gr with the application of Holt-Winters method

Even though the time series is short-term, the results obtained follow the same pattern and trend as the past observations and show a slight deviation, which leads to very satisfactory results.

5.1.4.2 Product Category B

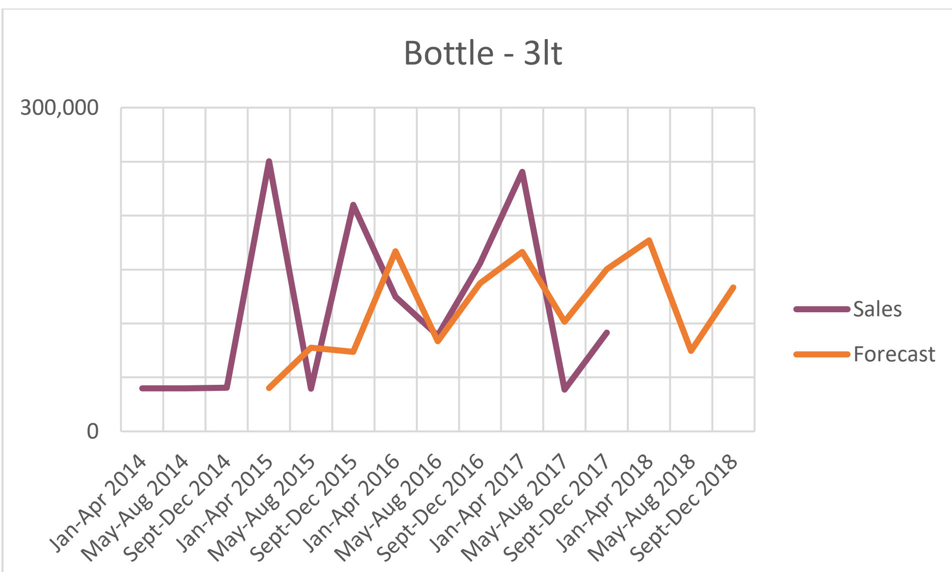


Figure 108. Demand forecasting of bottle-3lt with the application of Holt-Winters method

The results obtained follow the same pattern and trend as the past observations, but there is a slight variance, as far as the high values are concerned.

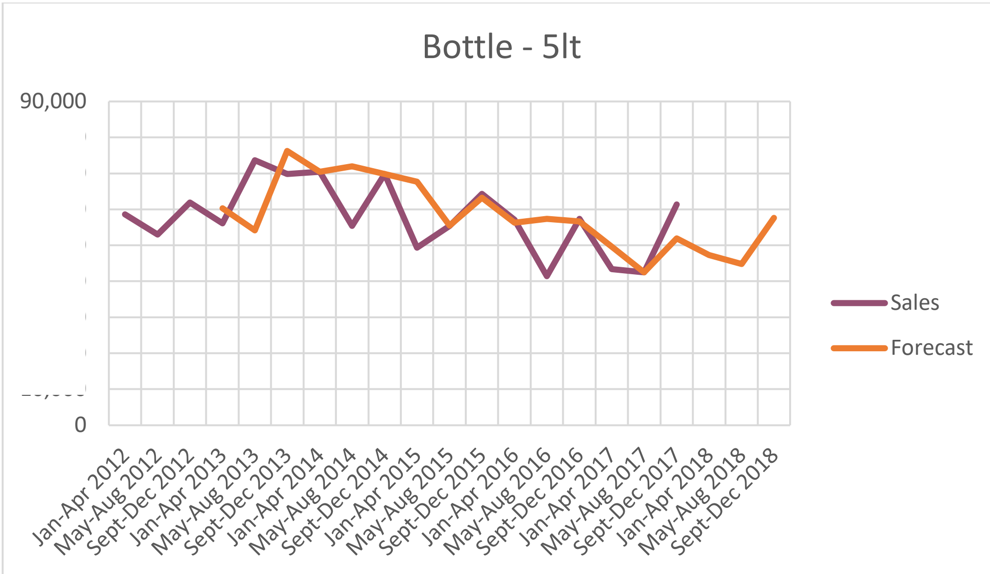


Figure 109. Demand forecasting of bottle-5lt with the application of Holt-Winters method

The results that were obtained follow the same trend as the past observations, but they present smoother fluctuations. However, they correspond to the extreme high values.

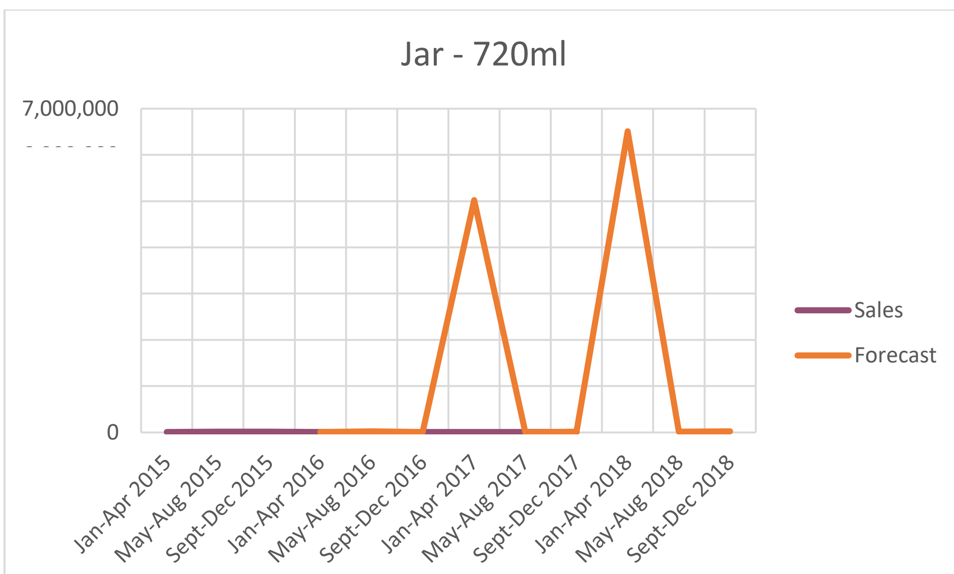


Figure 110. Demand forecasting of jar-720ml with the application of Holt-Winters method

The results that were obtained show a very high variance from the past observations. The fact that the time series is short-term with very low values (close to zero) has a great impact on the accuracy of the results.

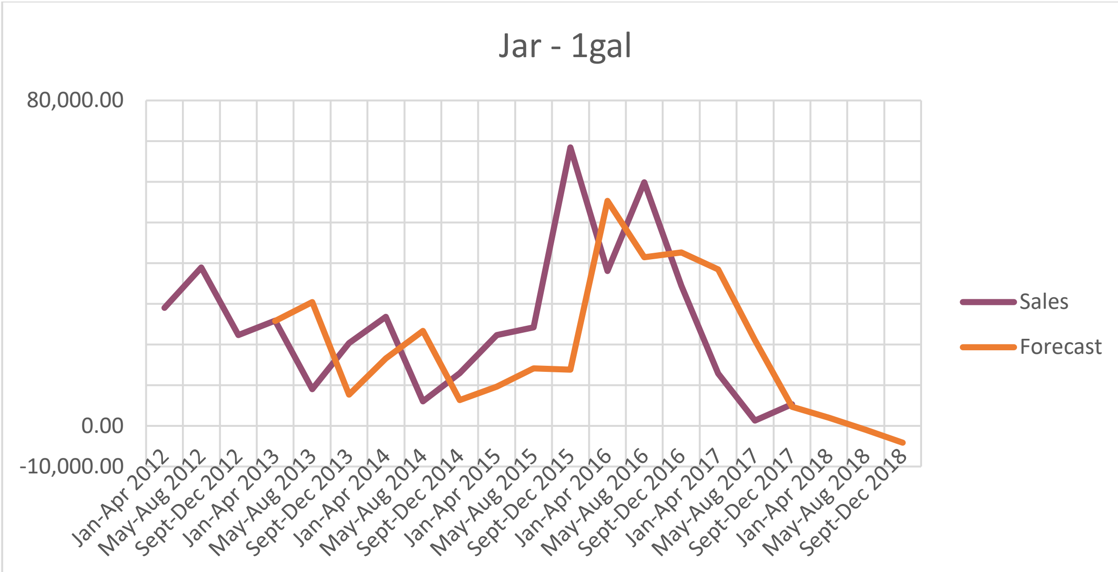


Figure 111. Demand forecasting of jar-1gal with the application of Holt-Winters method

The results that were obtained are satisfactory, since they follow the same pattern and trend as the past observations with a very slight variance.

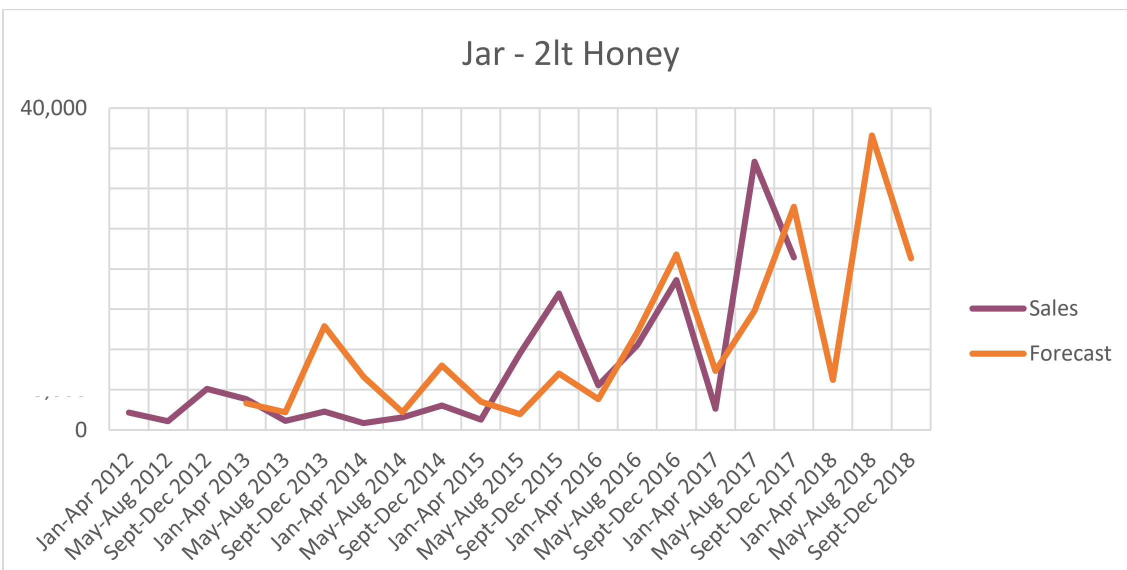


Figure 112. Demand forecasting of jar-2lt Honey with the application of Holt-Winters method

The results that were obtained are satisfactory, since they follow the same pattern and trend as the past observations. Moreover, they correspond to the extreme values.

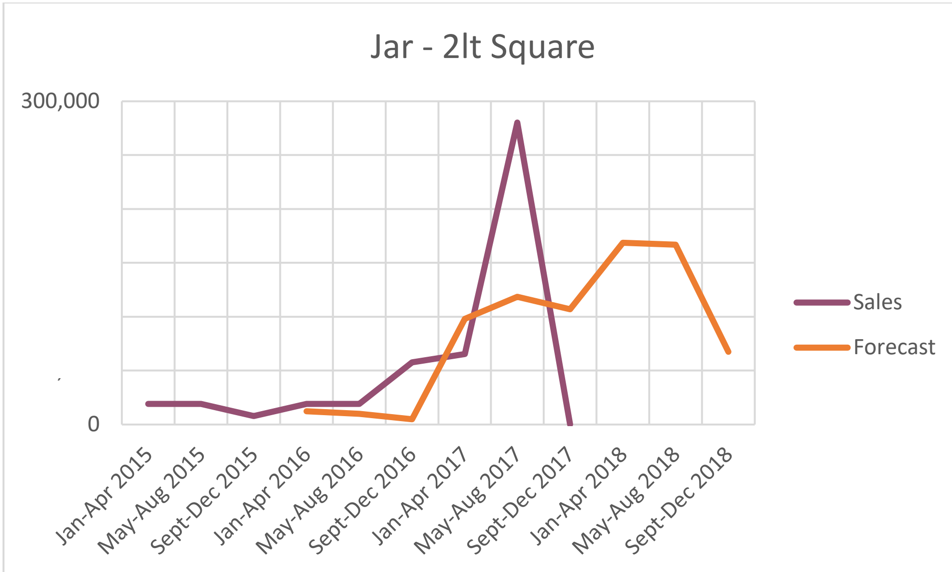


Figure 113. Demand forecasting of jar-2lt Square with the application of Holt-Winters method

The results obtained do not follow the same pattern as the past observations. Also, there is a variance between them. However, the fact that this time series is short-term should be noted, as it affects the accuracy of the results.

5.1.4.3 Product Category C

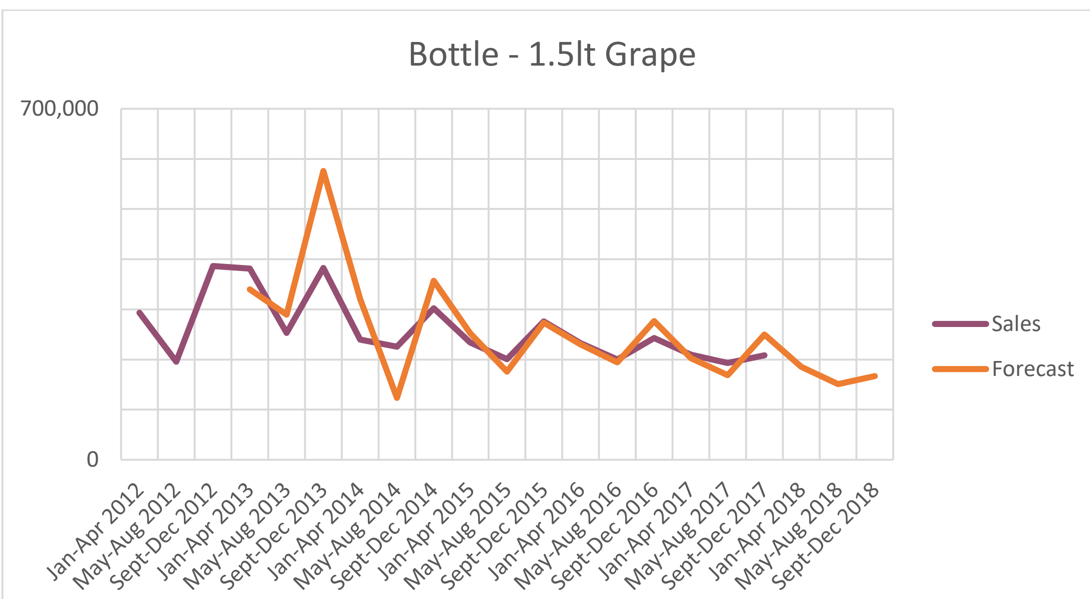


Figure 114. Demand forecasting of bottle-1.5lt Grape with the application of Holt-Winters method

The results obtained follow the same pattern and trend as the past observations. They are very satisfactory, since they correspond to the values of the past observations.

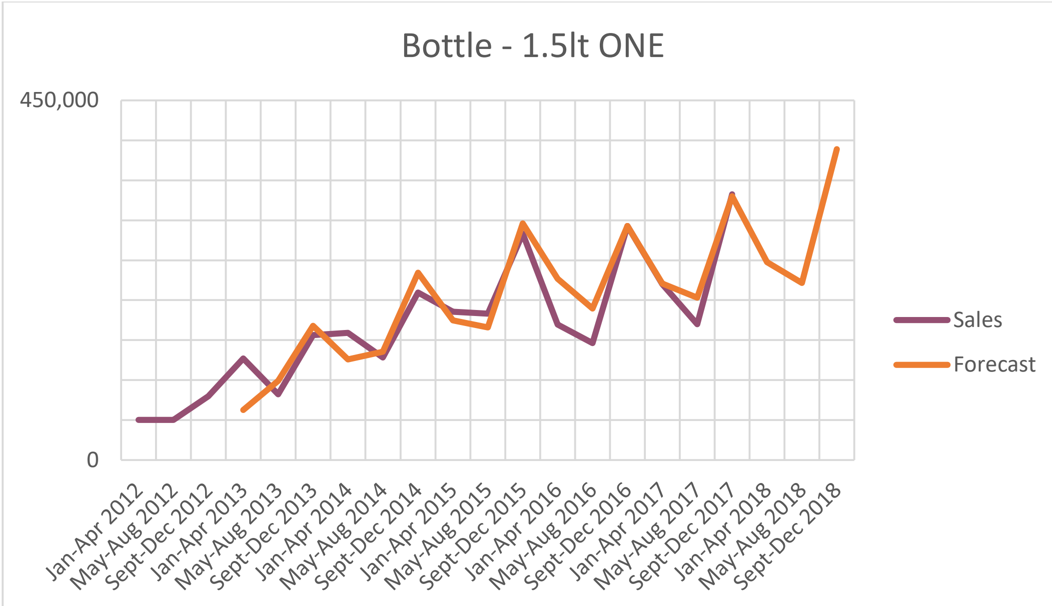


Figure 115. Demand forecasting of bottle-1.5lt ONE with the application of Holt-Winters method

The results obtained are very satisfactory, since they follow the same pattern and trend as the past observations, as well as they correspond to high and low values.

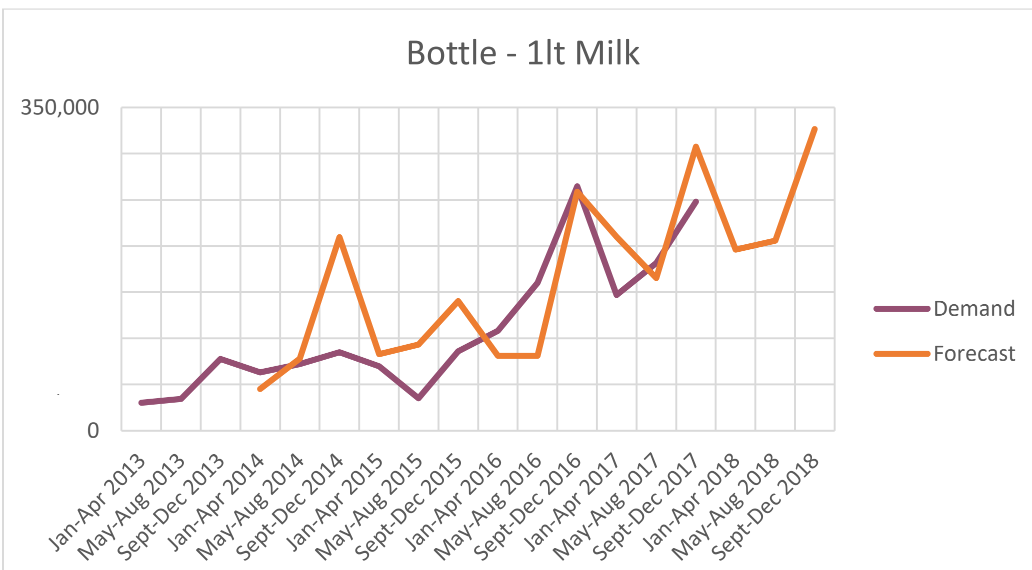


Figure 116. Demand forecasting of bottle-1lt Milk with the application of Holt-Winters method

The results obtained follow the trend of the past observations. Also, they do not follow the same pattern, but they present satisfactory results, since they correspond to high and low values.

In general, the Holt-Winters method is very accurate to the adjustment of trend and seasonality. Moreover, with respect to the results of stable time series (i.e. 5lt bottle, 1.5lt bottle), Holt-Winters method is more reliable than Brown's method. The worst results were obtained from products with many extreme values and deviation, such as 720ml and 2lt square jars, whereas the best results were obtained from 5lt and 1.5lt bottles, 1gal and 2lt honey jars, Φ82-50gr and Φ63-45gr preforms.

5.2 Accuracy of the used forecasting models

The application of each criterion in order to evaluate the accuracy of the forecasting aims at selecting the most suitable and reliable forecasting method. These criteria are based on the deviation between the forecasting and the actual value of the time series. This is called Error Measurement and that is:

$$e_t = Y_t - \hat{Y}_t \ , \quad t = 1,2, \ldots , n$$

Where:

$\hat{Y}_t$: Actual value of ***t*** period

$\hat{Y}_t$: Forecast value of ***t*** period

The deviations should be as small as possible, so as the forecasting method to be reliable. The following criteria were performed in order to select the most reliable forecasting technique [40].

5.2.1 Mean Error (ME)

Mean Error is the simplest measurement for evaluating the accuracy of a forecasting method and is influenced on a great extent of positive and negative values of the error. It is defined by the following equation [42]:

$$ME = \frac{1}{n} * \sum_t e_t \quad \text{, where } t = 1,2, \ldots , n$$

Table 53 presents the Mean Error of every forecasting technique applied to each product. Green colored values indicate the forecasting method with the minimum error for each product.

Products	Forecasting Methods			
	Simple Moving Average	Double Moving Average	Simple Exponential Smoothing (Brown’s)	Holt-Winters
PREFORM Φ48 195gr	53,767.58	**27,624**	36,248.59	-50,816
PREFORM Φ110 110gr	101,840.50	97,937	44,317.13	**5,902**

PREFORM Φ110 140gr	12,541.88	16,300	**8,652**	-22,573
PREFORM Φ82 50gr	34,284.33	50,770.167	30,625.67	**-18,708.81**
PREFORM Φ63 30gr	3,731.33	5,757.056	**3,547.83**	5,413.26
BOTTLE 3lt	16,713.06	**-1,630.622**	50,509.91	26,961.16
BOTTLE 5lt	-5,954.83	-7,015	**-12.13**	-2,426.765
JAR 720 ml	**43.50**	1,556.00	-1,383.04	-836,862.208
JAR 1gal	988.56	**5.4343**	-4,836	1,112.165
JAR 2lt HONEY	6,807.42	6,646	3,274	**-188.243**
JAR 2lt SQUARE	91,725.33	122,194.06	58,276.17	**15,215.63**
BOTTLE 1,5lt GRAPE	-59,862.31	-45,487	-20,275	**-16,633.195**
BOTTLE 1,5lt ONE	81,329.33	54,973	36,180.27	**-5,307.909**
BOTTLE 1lt MILK	73,744.21	76,850.40	38,265.89	**-19,363**

Table 53. Evaluation of forecasting methods with the application of Mean Error accuracy measurement

Table 53 show that in regard to Mean Error (ME) accuracy measurement, the Holt-Winters method indicates better results for the majority of the products.

5.2.2 Mean Absolute Deviation (MAD) or Mean Absolute Error (MAE)

The Mean Absolute Deviation is the average value of the absolute deviations between the forecasting and actual values of a time series and it is given by the following formula [42]:

$$MAD = \frac{1}{n} * \sum_t |e_t| \quad \text{, where } t = 1,2,\dots,n$$

The Table 54 presents the Mean Absolute Deviation of every forecasting technique that is applied to each product. Green colored values indicate the forecasting method with the minimum error for each product.

Products	Forecasting Methods			
	Simple Moving Average	Double Moving Average	Simple Exponential Smoothing (Brown's)	Holt-Winters
PREFORM Φ48 195gr	53,767.58	65,888.21	**48,582.38**	96,359.44
PREFORM Φ110 110gr	109,021.00	113,456.899	74,287.80	**67,105.14**
PREFORM Φ110 140gr	27,144.84	26,795.768	**22,032.33**	49,436.32
PREFORM Φ82 50gr	48,488.33	50,770.167	42,361.67	**41,006.04**
PREFORM Φ63 30gr	7,960.00	55,863.378	**6,688.83**	8,860.17
BOTTLE 3lt	**43,902.67**	59,418.933	73,699.08	71,845.39
BOTTLE 5lt	8,791.25	9,499.13	7,399.60	**6,632.38**
JAR 720 ml	**840.83**	1,556.00	1,971.48	841,858.347
JAR 1gal	17,680.25	24,967.98	17,135.09	**15,711.60**
JAR 2lt HONEY	7,451.19	8,140.47	**4,432.73**	5,290.300
JAR 2lt SQUARE	113,463.33	142,931.06	**60,879.17**	61,701.14
BOTTLE 1,5lt GRAPE	60,111.40	45,486.65	**39,678.50**	44,578.797
BOTTLE 1,5lt ONE	81,329.33	67,879.17	43,237.60	**22,501.248**
BOTTLE 1lt MILK	77,728.44	82,765.40	44,898.07	**43,733.252**

Table 54. Evaluation of forecasting methods with the application of Mean Absolute Error accuracy measurement

Table 54 shows that with respect to the accuracy measurement of Mean Absolute Deviation (MAD) or Mean Absolute Error (MAE), both Simple Exponential Smoothing (Brown's) and Holt-Winters methods appeared to be the most reliable ones, as each one shows good results in six products.

5.2.3 Mean Squared Error (MSE)

Mean Squared Error is the average value of the squared deviations between the forecasting and the actual values of a time series and is given by the following formula [42]:

$$MSE = \frac{1}{n} * \sum_t (e_t)^2, \text{ where } t = 1,2,\dots,n$$

In the same way, Root Mean Squared Error (RMSE) is being calculated and is defined by the following equation:

$$RMSE = \sqrt{\frac{1}{n} * \sum_t (e_t)^2}, \text{ where } t = 1,2,\dots,n$$

Table 55 and 56 present Mean Squared Error and Root Mean Squared Error (RMSE) of every forecasting technique applied to each product. Green colored values indicate the forecasting method with the minimum error for each product.

Products	Forecasting Methods			
	Simple Moving Average	**Double Moving Average**	**Simple Exponential Smoothing (Brown's)**	**Holt-Winters**
PREFORM Φ48 195gr	**3,981,707,583.81**	7,459,465,803.979	6,444,156,239.37	14,875,642,284.97
PREFORM Φ110 110gr	21,905,828,023.00	19,250,061,485.925	9,377,476,953.00	**7,752,471,234.12**
PREFORM Φ110 140gr	1,328,769,474.61	1,370,059,561.595	**1,253,335,423.00**	14,710,957,376.74
PREFORM Φ82 50gr	4,531,867,092.33	4,713,543,884.722	**2,607,761,203.00**	2,702,694,342.21
PREFORM Φ63 30gr	77,217,332.67	**4,826,392.35**	61,924,336.83	100,328,975.86
BOTTLE 3lt	**2,741,396,376.68**	4,947,981,083.496	10,095,258,019.99	8,805,620,223.85
BOTTLE 5lt	104,586,775.11	126,802,247.56	**86,598,001.07**	95,922,265.58
JAR 720 ml	**801,392.75**	4,927,429.38	9,431,633.71	4,198,654,586,197.390
JAR 1gal	530,434,035.32	900,363,778.64	467,711,040.91	**404,432,054.56**
JAR 2lt HONEY	118,847,279.56	110,863,442.61	55,716,951.27	**50,253,252.41**
JAR 2lt	23,845,463,071.33	35,360,673,855.34	12,164,896,302.83	**6,936,564,169.48**

SQUARE				
BOTTLE 1,5lt GRAPE	4,776,410,948.76	3,203,520,931.10	**2,731,331,202.37**	4,333,724,959.155
BOTTLE 1,5lt ONE	7,576,671,701.92	6,451,603,448.09	2,289,521,394.80	**883,669,647.046**
BOTTLE 1lt MILK	9,054,121,900.74	9,968,455,909.46	4,577,858,880.55	**3,097,726,427.46**

Table 55. Evaluation of forecasting methods with the application of Mean Squared Error accuracy measurement

Products	Forecasting Methods			
	Simple Moving Average	Double Moving Average	Simple Exponential Smoothing (Brown's)	Holt-Winters
PREFORM Φ48 195gr	**63,100.77**	86,368.199	80,275.50	121,965.74
PREFORM Φ110 110gr	148.006.1756	138,744.591	96,837.37	**88,048.12**
PREFORM Φ110 140gr	36,452.29	37,014.316	**35,402.48**	121,288.74
PREFORM Φ82 50gr	67,319.14	68,655.254	**51,066.24**	51,987.44
PREFORM Φ63 30gr	8,787.34	10,158.815	**7,869.20**	93,838.27
BOTTLE 3lt	**52,358.35**	70,341.887	100,475.16	176,778.17
BOTTLE 5lt	10,226.77	11,260.65	**9,305.80**	9,793.99
JAR 720 ml	**895.21**	2,196.91	3,071.10	2,049,061.880
JAR 1gal	23,031.15	30,006.06	21,626.63	**20,110.50**
JAR 2lt HONEY	118,847,279.56	10,529.17	7,464.38	**7,088.95**
JAR 2lt SQUARE	154,419.76	188,044.34	110,294.59	**83,286.04**
BOTTLE 1,5lt GRAPE	69,111.58	56,599.65	**52,262.14**	65,831.0334
BOTTLE 1,5lt	87,044.08	80,321.87	47,848.94	**29,726.581**

ONE				
BOTTLE 1lt MILK	95,153.15	99,842.15	67,659.88	**55,657.2226**

Table 56. Evaluation of forecasting methods with the application of Root Squared Mean Error accuracy measurement

According to Tables 55-56, the accuracy measurement of Mean Squared Error (MSE) indicates that Holt-Winters method is the most reliable one, as shows the best results in six products, whereas Simple Exponential Method (Brown's) method outweighs the others in five products.

5.2.4 Mean Percentage Error (MPE)

Mean Percentage Error denotes if a forecasting method is unbiased and is given by the following formula [43]:

$$MPE = \frac{1}{n} * \sum_t \left(\frac{e_t}{Y_t}\right) \quad \text{, where } t = 1,2,\ldots,n$$

The forecasting technique is unbiased when the values of MPE are close to zero. If the values are very large, the method is partial. Alternatively, negative values of MPE show that the forecasting values are overestimated in comparison with the actual ones. On the other hand, positive values indicate that the forecasting values are underestimated.

Table 57 presents the Mean Percentage Error of every forecasting technique applied to each product. Green colored values indicate the forecasting method with the minimum error for each product.

Products	**Forecasting Methods**			
	Simple Moving Average	**Double Moving Average**	**Simple Exponential Smoothing (Brown's)**	**Holt-Winters**
PREFORM Φ48 195gr	0.28	**-0.011**	0.18	-0.39
PREFORM Φ110 110gr	0.30	0.220	**0.04**	-0.78
PREFORM Φ110 140gr	**-0.21**	-0.671	-0.37	-3.57
PREFORM Φ82 50gr	-0.03	0.390	**-0.01**	-1.78

PREFORM Φ63 30gr	0.03	0.116	0.08	0.17
BOTTLE 3lt	0.01	-0.501	0.15	-0.18
BOTTLE 5lt	-0.14	-0.16	-0.03	-0.06
JAR 720 ml	-0.06	0.15	-0.35	-232.148
JAR 1gal	-2.36	-4.12	-2.68	-1.30
JAR 2lt HONEY	0.15	0.10	-0.07	-1.09
JAR 2lt SQUARE	-166.67	-159.04	-19.46	-273.82
BOTTLE 1,5lt GRAPE	-0.25	-0.21	-0.09	-0.046
BOTTLE 1,5lt ONE	0.39	0.23	0.21	-0.030
BOTTLE 1lt MILK	0.38	0.34	0.21	-0.295

Table 57. Evaluation of forecasting methods with the application of Mean Percentage Error accuracy measurement

Table 57 presents Simple Exponential Smoothing (Brown's) as the most reliable method with respect to accuracy measurement of Mean Percentage Error (MPE), showing best results in seven products.

5.2.5 Mean Absolute Percentage Error (MAPE)

Mean Absolute Percentage Error examines how large is the error of forecasting compared to the actual values and it is given by the following formula [42]:

$$MAPE = \frac{1}{n} * \sum_t \left(\frac{|e_t|}{Y_t}\right) \text{ , where } t = 1,2, \dots, n$$

As smaller the value of this measurement is, so more sufficient the forecasting method is. In general, the percentage errors have the advantage of being scale-independent and are applied frequently at different data sets. However, there is the disadvantage of being undefined or infinite, if there is a zero actual observation on a time series, or when extreme values are given.

Table 58 presents the Mean Absolute Percentage Error of every forecasting technique applied to each product. Green colored values indicate the forecasting method with the minimum error for each product.

Products	Forecasting Methods			
	Simple Moving Average	Double Moving Average	Simple Exponential Smoothing (Brown's)	Holt-Winters
PREFORM Φ48 195gr	0.28	0.357	**0.26**	0.64
PREFORM Φ110 110gr	0.69	0.805	**0.62**	1.04
PREFORM Φ110 140gr	**1.03**	1.491	1.09	4.07
PREFORM Φ82 50gr	0.71	**0.390**	0.98	2.15
PREFORM Φ63 30gr	0.42	**0.359**	0.37	0.49
BOTTLE 3lt	**0.38**	0.757	0.47	0.62
BOTTLE 5lt	0.18	0.19	0.13	**0.12**
JAR 720 ml	0.16	**0.15**	0.45	232.743
JAR 1gal	2.71	4.62	2.90	**1.79**
JAR 2lt HONEY	0.74	0.82	**0.71**	1.41
JAR 2lt SQUARE	167.76	159.99	**20.29**	274.60
BOTTLE 1,5lt GRAPE	0.26	0.21	**0.15**	0.165
BOTTLE 1,5lt ONE	0.39	0.31	0.26	**0.148**
BOTTLE 1lt MILK	0.49	0.51	**0.38**	0.485

Table 58. Evaluation of forecasting methods with the application of Mean Absolute Percentage Error accuracy measurement

According to Table 58, the accuracy measurement of Mean Absolute Percentage Error (MAPE) indicates that Simple Exponential Smoothing (Brown's) method appears to be the most reliable, since it outweighs the others in six products.

5.3 Conclusion

The application of the accuracy measurements for the evaluation of the forecasting models indicates that Holt-Winters method outweighs the rest of the methods that have been tested, as the results of four out of six measurements appear to be the best for the majority of the products (Table 59). Nevertheless, it fails when the actual values are very large or very small and when there is sudden sales drop or jumps. This is the point where Holt-Winters method can be described as inaccurate and Brown's has been proven to be more successful.

Error Measurements	**Forecasting Methods**			
	Simple Moving Average	**Double Moving Average**	**Brown's**	**Holt-Winters**
Mean Error (ME)	-	-	-	√
Mean Absolute Deviation (MAD)	-	-	√	√
Mean Squared Error (MSE)	-	-	-	√
Root Mean Squared Error (RMSE)	-	-	-	√
Mean Percentage Error (MPE)	-	-	√	-
Mean Absolute Percentage Error (MAPE)	-	-	√	-

Table 59. Most accurate forecasting method according to each error measurement

The above findings were presented to the executive team of the company, who came to the conclusion that as long as the results are good, they will ignore the flaws of the method and they will apply Holt-Winters technique for demand forecasting. In addition, they will evaluate the method once again at the end of the following year, given the fact that the observations of 2018 will be available and they will compare it with Brown's, which is the second best one.

The following graphs depict the demand forecasting of 2018, as obtained from the application of Holt-Winters method. Figure 117 shows the demand forecasting of each product for each period of the year. Furthermore, Figure 118 presents the total demand forecasting of each product category, which contributes to an improved production planning, as far as the operation process, the scheduling, the need of supply and production of raw materials are concerned. As a final point, it is obvious that there is an increase of demand during the periods of May-August and September-December, providing firstly the fact that during the summer there is high demand of water, which corresponds to high production of preforms for water bottles, and then the fact that after August wine is produced and later on the olive oil is bottled.

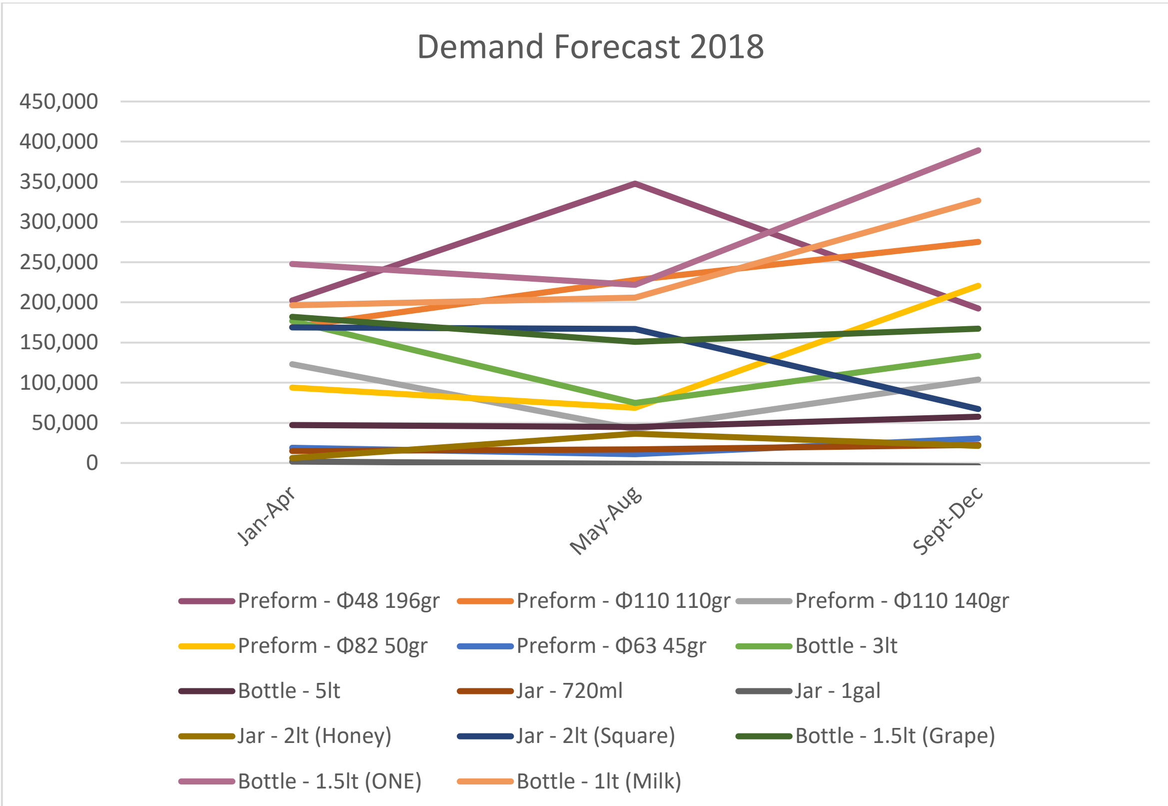


Figure 117. Demand forecast of 2018 for each product

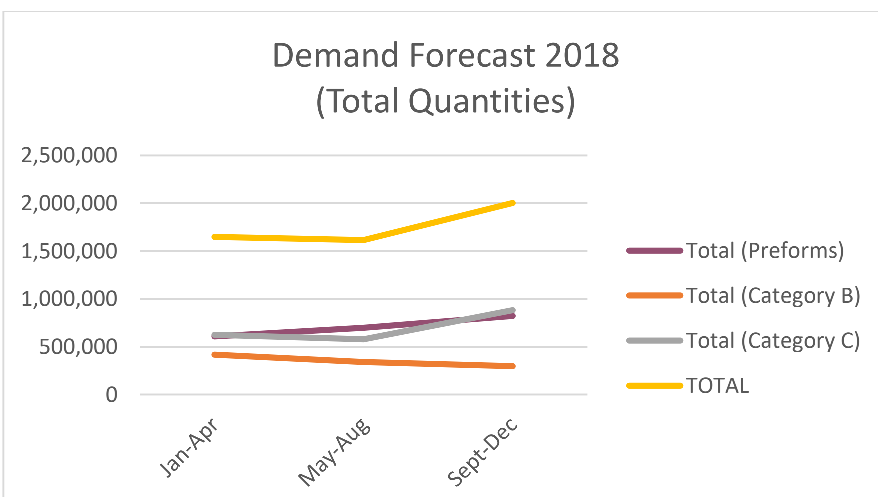


Figure 118. Demand forecast of 2018 – Total Quantities of each product category

Chapter 6

6 Conclusions & Recommendations

6.1 Summary

Current thesis looks at the operation process of *Voglyplast Co.,* a company that manufactures and produces PET preforms, bottles and jars. Initially, the relevant theoretical background, the company, its evolution throughout the years and the product range are presented. Particularly, the production process is analyzed, as well as the necessary raw materials, the order and the time when they are performed with the presentation of flow charts. The whole process of production is divided into three categories, according to the production line of each product.

Then, the modelling of the production process is performed with the utilization of timed Petri Nets with arc extensions, based on the flow charts and the information that was gathered. The next step is the simulation of each model and the recording of the results. Duration of production, delays of certain steps in the production line, input values of raw materials and output quantities of products are used for the evaluation of the results that are analyzed in order to compare the actual production observations with the data that were obtained from the verification of the model. The evaluation of these results is crucial, since it helps understanding the accuracy of the models, which can be used later on for studying any potential change. The performance of alternative scenarios follows. There are alternative scenarios for every product category. The results of the simulations of the alternative scenarios are studied, so as to analyze the effectiveness and the efficiency of alternative production lines.

According to the demand data of the last six years, the application of forecasting methods results in the demand forecasting for the following year. After the evaluation of the forecasting methods, by calculating the error measurements for each technique, the most reliable forecasting method was chosen. These results were used for the production planning.

6.2 Conclusion

The alternative scenarios that were analyzed for the industry are the following. Specifically, for product category A, the scenarios refer to the purchase of new moulds with more cavities for the injection moulding machine, so as to increase the productivity. For product category B, the introduction of new moulding machines is taken into consideration, whereas for product category C, the alternative scenarios focus on the improvement of packaging delay with the introduction of an automatic palletizer machine.

The alternative scenarios of category A result in the increase of productivity more than 20% or 30% for every product, which is a very important change in the whole production process. The alternative scenarios of product category B result in a great increase of productivity, which can change the whole production planning and effect the throughput of the industry to a great extent. The alternative scenarios for product category A, increase the quantity of final products in certain amount of time, more than 50%, which is very important for the whole operation process of the company.

Moreover, as far are as the forecasting is concerned the most appropriate method for the company is Holt-Winters and Brown's is the second best one. Holt-Winters obtains satisfactory results, with respect to trend and seasonality for the majority of products.

6.3 Recommendations

As it has been proven from the simulation of the alternative scenarios, an automatic palletizer machine would increase the quantity of packed products more than 50%. Given that the price of that type of packing machine is not that high, in combination with the fact that the packaging process will need less employees work for less time (at the same time, allows them to work in other production lines), as well as the fact that these products share a great rate in sales, the purchase of a palletizer will be profitable in short-term. Due to the fact that it can be amortized in a year, according to the current and the forecasted demand. Moreover, as the demand of products of category B increases, the existing machines will not be able to product the necessary quantities in a specific amount of time, which will lead to problems because of product shortage. Hence, an investment on a new machine or on a new mould with two cavities, as it is described in the alternative scenarios would be beneficial in long-term. As far as the changes in production lines of category A are concerned, even if they increase the productivity, the cost of new moulds is so high, that cannot be presented as beneficial, according to the current demand, because it can be amortized in more than three years.

Finally, the responsible executive members should compare the results obtained from the application of Holt-Winter forecasting method with the actual demand in the end of the year. If there are great deviations, they should compare the results with Brown's method and chose the most reliable one for the next year.

6.4 Future Work

This analysis of this thesis can contribute to a future extension with the introduction of more data that will be provided by Voglyplast Co. The following suggestions can be implemented for future work.

- Modelling of linear programming for the development of a production plan that would maximize the profit of the company
- Study of the production process after introducing updated equipment and technology
- Development of software for defining the optimal planning of the production by using data (i.e. demand, inventory level of raw material and minimization of machine setups) in real time

- Study of product development (R&D)
- Study of operation process with increased throughput of the industry, by operating all the available equipment at the same time
- Modelling with different tools and evaluation of the results compared to Petri Nets
- Forecasting by the application of different methods for short time-series (i.e. cross validation)

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