Improvement of a Manufacturing Process
The case study of Corticeira Amorim (Equipar)

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Abstract
Corticeira Amorim, company where this study is conducted, is the world leader in this sector and gives a continuous focus to the improvement of its processes and products. Consistent with this strategy, this study aims to improve the manufacturing process of one Corticeira Amorim's products, the agglomerated corks produced in the factory of Coruche (Equipar). To achieve the proposed objective, the application of Theory of Constraints was identified as appropriate. This theory argues that improving a manufacturing process is possible by identifying the constraint and improving it.

In this work one cycle of the Theory of Constraints is performed. The Mechanical Finishes production stage was identified as the constraint and several improvements have been proposed to solve it, which were promptly implemented at the shop floor. The resolution of this constraint was achieved, meaning an increase of 27% in the capacity of the manufacturing process. This value results in a potential annual gain of approximately 1.5 million euros.

Keywords: improvement, manufacturing process, theory of constraints

1. Introduction
Portugal is actually the world leader in the production and distribution of cork. In terms of production holds 49.6% of the global share, which corresponds to an annual production of 100,000 tons in cork products. It is also the largest exporter, exporting annually the equivalent of about EUR 845,370,000, which corresponds to 64.7% of world exports. In an increasingly competitive environment and with the higher level of service demanded by customers, only companies able to diversify its portfolio of activities and provide efficient and low-cost processes are the ones which can survive. Within this context this study is done in collaboration with the company Corticeira Amorim. This company is the world leader in the cork industry. Also noteworthy is the great investment this organization does on innovation and development, especially for improving their processes and products.

This paper will focus on the manufacturing process of agglomerate cork stoppers, at the factory located in Coruche (known as Equipar). This process will be analyzed in detail using a methodology proposed based on the Theory of Constraints.

2. Theory of Constraints
2.1 The Context
Theory of Constraints (TOC) is a management philosophy created and developed by Goldratt (Goldratt et al., 1984; Goldratt et al., 1986; Goldratt, 1994, 1997).
The TOC concept concentrates on how to manage the constraint of the system, the bottleneck resource or capacity constraint resource (Goldratt et al., 1984). In the beginning it was not well received in the academic world. But several academic studies proved the great impact this theory could achieve once implemented. Amongst those studies, the ones made by Aggarwal (1985), Johnson (1986) and Koziol (1988) were determinant for the acceptance of TOC in the academic world as well as for the business companies.

2.2 The five TOC focusing steps
For implementing TOC successfully five steps were suggested by Goldratt et al. (2005).

Step 1: identify the system’s constraint.  
In this step, the constraint is identified. The constraint is the activity in the system whose capacity is less than the demand placed on it. This is a key step, because since the constraint determines the system performance, the maximum performance can only be achieved by knowing where the constraint is (Pretorius, 2014).

Step 2: exploit the system’s constraint. 
In this step the utilization of the constraint is exploited by maximizing the efficiency of the constraint activity. Chou et al. (2012) state that this step can be implemented by eliminating all waste or non-productive time activities at the constraint.

Step 3: subordinate all other factors to decisions made in step 2. 
The non-constraint activities should be synchronized with the constraint in order not to produce excess inventory. In this way the production in non-constraints is determined by the capacity of the constraint and not by their own potential.

Step 4: elevate system’s constraint. 
Once further system improvement is not possible with exploiting and subordination, the next possible step would be the increase in capacity of the constraint activity to eliminate it as a constraint. This means that additional equipment should be acquired in the necessary quantity to eliminate the constraint identified in the first step.

Step 5: if the constraint has been broken, go back to step 1 to prevent inertia to become the next constraint. 
This step guarantees that TOC can be considered as a continuous improvement philosophy.

Pretorius (2014) suggests some in-between decision points in addition to the five focusing steps. There are two main points which worth mentioning. The first point is located after the second step and it is important to decide whether it is possible to subordinate the system to the decisions made in the previous step. The second point is located after the completion of the third step, where the author suggests that before proceeding to the fourth step one should examine whether the implementation of the previous steps (2 and 3) allowed the removal of the constraint. If this has happened is not necessary to develop the fourth step. But if the constraint identified still remains then the fourth step should be studied.

2.3 Comparison between TOC and other continuous improvement philosophies
Several studies illustrate that the application of this theory leads to better or at least the same outcome when comparing it to the application of other continuous improvement technics like lean or just-in-time (Cook, 1994; Holt, 1999). Also Pirasteh et al. (2006) did a comparison where the application of lean and six-sigma was made to a first group of factories and to another group of factories it was applied lean, six-sigma and TOC. The results after this application were really significant, showing that the last group had a much better performance.

2.4 Applications of TOC in the industry
Pegels et al. (2005) state that TOC is widely used in the industry, mainly because of its potential in identifying problems and optimize them, achieving process improvements in terms of productivity and efficiency.

Draman et al. (1998) studied a successful implementation of TOC to an industry whose primary products were custom-formulated paints. This study is relevant because it shows how the change in the working philosophy can have a great deal of impact optimizing a manufacturing process. As results of implementing TOC to the industry, the plant started producing batches in 8 to 36 hours while it used to take six to ten days.
In another study done by Umble et al. (2006) the application of the Theory of Constraints in a Japanese tool manufacturing company was made. To improve the system the five focusing steps were applied and some significant achievements were obtained. Setup times had been reduced throughout the plant, improving the product flow through the system. Overall productivity had an increase of 20%. WIP inventory and lead times had both been reduced by 50%.

3. Case-study
This work was developed in a factory of Corticeira Amorim (Equipar), the world leader in selling cork stoppers. In this factory, located in Coruche, agglomerated cork stoppers for still, sparkling and cider wine are produced. This factory is able to produce on average 1.5 millions of cork stoppers each day. The main objective of the study was the improvement of this manufacturing process and if possible to increase its capacity. As studied in the literature review this could be possible by applying TOC to the process. The application of TOC in this factory was done to part of this factory where some stages of the process occur. The manufacturing process in study is divided in the following steps as illustrated in Figure 1.

![Figure 1 – Manufacturing process of cork stoppers](image)

The first step of the process is Grinding, where the granulate which will be part of the cork stoppers is formed. Afterwards the four stages under study occur. These stages, under study, are bounded by a dashed line. Extrusion is the stage where the agglomerate body of technical stoppers is produced from a mixture of granules and chemicals with binding, plasticizing and lubricant properties through mechanical compression. Then Mechanical Finishes (MF) is where by abrasive polishing the cork stoppers achieve their final dimensions. In the Washing stage, bleaching agents and disinfectants are used to treat the cork stoppers. Finally, with the Sorting stage it is possible to ensure visual quality standards that were agreed with customer. Already out of the limits of this study the final stages of production take place, which depends on the type of client and can be either Packing or Marking.

To finish the description of the case study it is important to remark that there are mainly two types of cork stoppers produced in this factory. The main difference between both groups is the size. The smallest cork stoppers belong to the group AGLO, used mainly in table wines. The biggest ones belong to the group ESP, which are mainly to sparkling or cider wines. The machines in each stage for producing each group need to be different or at least need to be equipped with different equipment.

4. TOC Application
To improve the agglomerate cork stoppers production the five focusing steps of TOC were implemented using the methodology illustrated in Figure 2. This methodology results from the five focusing steps in addition to the two in-between points proposed by Pretorius (2014). This methodology was followed and the study began by examining point 1: identifying the constraint.

At this point it is important to note that the main purpose of applying the Theory of Constraints was to increase the productive capacity by improving this manufacturing process.

4.1 Identify the system’s constraint
In the first step of TOC application the constraint should be identified. In order to do so, the capacities of the different steps were measured and calculated.
First, some measurements were made to determine the processing times for each step. Equation (1) was used to validate the amount of measurements taken:

$$n = \left( \frac{Z \times s}{A \times x} \right)^2$$  \hspace{1cm} (1)

In this equation, $n$ is the number of observations required given the error $A$, $Z$ is the confidence interval considered, $s$ represents the estimated standard deviation and $x$ is the average time of measurements already done. After making these measures and validate them, it was possible to calculate the daily capacity of each processing activity.

According to the procedure illustrated in Figure 2, following the calculation of the capacities the supplying systems should be analyzed. This analysis is important to know if these systems are a hindrance to the proper running of the different stages. This analysis showed that for all stages, except MF, its supplying system was adjusted. The supplying of MF is done through a conveyor belt, which was not adjusted to the maximum capacity of this stage. The study done to this conveyor belt pointed that it restricted MF to 75% of its available capacity.

Thereafter the third point of the first step (1. Identify) of the methodology proposed was examined. At this point the efficiencies of the various stages of the process were studied. The relevance of this study is because, due to the efficiencies of the respective stages, the stage with less capacity may not represent the constraint of the process. This analysis was performed and the efficiency of each stage is illustrated in Table 1.

**Table 1 – Efficiencies of manufacturing stages**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Mechanical Finishes</th>
<th>Washing</th>
<th>Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>95%</td>
<td>70%</td>
<td>95%</td>
</tr>
</tbody>
</table>

After performing these three steps of the proposed methodology, the values representing the productive capacity of the various stages of the process shown in Table 2 were obtained.

**Table 2 – Capacities of different steps**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Mechanical Finishes</th>
<th>Washing</th>
<th>Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclusion</td>
<td>Esp</td>
<td>Esp</td>
<td>Esp</td>
</tr>
<tr>
<td></td>
<td>1148</td>
<td>771</td>
<td>2738</td>
</tr>
<tr>
<td>AGLO</td>
<td>791</td>
<td>756</td>
<td>1824</td>
</tr>
<tr>
<td>Total</td>
<td>1934</td>
<td>1527</td>
<td>4560</td>
</tr>
</tbody>
</table>

In this table the activity with less capacity is highlighted. It is possible to conclude that the constraint for both types of cork stoppers was the stage Mechanical Finishes. It is also possible to conclude that, due to its constraint, the process capacity was of 1.5 million cork stoppers per day.

After this, the last point of the first step of the methodology in use was studied. At this point the objective is to confirm the previous findings with the observation of reality. For this an experience took place for over four days, by setting the production in this factory to the
maximum possible. During this experiment the main purpose was to count the intermediate inventory between different stages. By doing this counting it was expected to find out in which of the stages the inventory was accumulated in higher proportions. This stage would be the constraint of the process.

Figure 3 illustrates the accumulation of inventory between Extrusion and MF and as can be observed an average of about 9 batches per day were accumulated.

![Figure 3 – Number of batches between Extrusion and MF](image)

Figure 3 – Number of batches between Extrusion and MF

\[ y = 8.7x + 0.5 \]

In conclusion of this experiment, it can be observed that the stage where inventory is accumulated in higher proportions is MF. This result confirmed the previously calculations showing that MF was the constraint.

It is important at this point to describe the current situation of MF, since it represents the constraint. The actual scenario is illustrated in Figure 6. It is made up of three different types of milling machines. The first type of machines (M1), represented in the first line of Figure 6, is where the stoppers achieve the final diameter. Then in the second type, represented as M2 in Figure 6, the stoppers achieve its final length. Finally the third type of machine (M3) make a chamfer in the cork stoppers.

**4.2 Exploit the system’s constraint**

To exploit the constraint the three areas shown in Figure 2 will be explored and if possible improved.

**4.2.1 Improve Supplying System**

The supplying of MF is done through seven deposits (six with automatic activation and one manual), which supply the cork stoppers to the first type of machines in MF, the fourteen M1’s. Between the deposits and the M1’s a single conveyor belt does the connection. This means that in each supply a single deposit can be supplying the cork stoppers and only one M1 can be receiving them.

An analysis done to the supplying of MF indicated that it limits this stage to 75% of its full capacity. Knowing this fact it was extremely important to study this process and if possible suggest options to improve it.
The option of increasing the quantity of cork stoppers in each supply was the one studied. A single calculation was done to know what was the variation needed in order to adjust the supplying system to the full capacity of MF. By defining an objective equal to the capacity of MF, it was possible to find that in order to improve this process a variation of 33% for each deposit was needed. Knowing this, the study was then divided in the two types of deposits.

Through observation of the deposit activated manually, it was possible to conclude that the conveyor belt of this deposit was too slow and few cork stoppers were supplied at each time. By consulting the Maintenance department of this factory, the replacement of this belt’s engine was the best option. After the industrial director’s approval this engine was implemented. To know the success or failure of this application a supply through this deposit was done and analyzed. As a result it showed a better performance of 103%, which compared to the 33% needed, indicated the success.

Following this, the study of the six remaining deposits was carried out. Again, in collaboration with the maintenance department, it was concluded that there were two options for increasing the number of corks supplied per second. The first would be to have a larger tray and the second to extend the hole of these deposits. This second option could only be implemented after the first. If not part of the stoppers would fall onto the floor. These two improvements were performed and several tests were done. As results of these tests, improvements between 90% and 130% were achieved for the six deposits. Again comparing these values with the 33% needed the success of this implementation was observed.

4.2.2 Machines allocation
At this point it is important to remember that this stage is divided in two main groups, which are the groups of cork stoppers produced in this Equipar. The actual organization can be seen in Figure 6, where the first eight production lines are allocated to group ESP and the last six are allocated to group AGLO.

The purpose of this analysis was to know the best allocation for this process. The best allocation would be the one where the capacities were the most equally distributed according to their necessities. To do so several simulations were performed by imposing some restrictions and by defining the objective as the equation (2):

\[
\text{Objectiv} = \min \left| \frac{\text{Cap}_{\text{ESP}} - \text{Nec}_{\text{ESP}}}{\text{Cap}_{\text{AGLO}} - \text{Nec}_{\text{AGLO}}} \right|
\] (2)

By performing this calculation it was possible to achieve a configuration that respecting some restrictions presented better results than the current situation. In this new scenario an improvement of approximately 81% was achieved, in terms of a more even distribution. In the current allocation the difference calculated by equation 1 between the two groups was 307,674 stoppers. With the new scenario this difference is only 58,926 stoppers. This new scenario is presented in Figure 7 and it will be implemented in this factory in the near future.

4.2.3 Efficiency
The efficiency of this activity was measured and 70% efficiency was the outcome. Having efficiency lower than 100% the study of several activities performed in Mechanical Finishes was judged as important.

4.2.3.1 Workers organization
After having observed the distribution of work and have talked with the workers, the identification of potential improvements in terms of human resources was made.

The need to implement improvements was due to the fact that the workers did not have well allotted tasks and were not allocated to specific areas, which increased the response time against possible problems, such as the machines being jammed for long periods of time.

![Figure 7 – Proposed scenario for MF](image-url)
Knowing this, the following procedure was proposed and implemented. It is important to state that in MF there are three workers.

- **Worker 1:**
  Firstly the role of the first worker was analyzed. The M1’s are the machines with the lowest production capacity and because of that the ones who need special attention. Therefore it was decided that the main role of the first worker is to monitor the line with M1’s. As a secondary function he or she can help monitor the second line, constituted by the M2’s. So the priority area of this first worker is the first line in Figure 6 and Figure 7 and the secondary one is the second line in the same figures.

- **Worker 2:**
  The second worker shall be responsible for overseeing the remaining machines. Its area of operation is the line of M2’s and the one with M3’s in Figure 6 and Figure 7.

- **Specialized Worker:**
  Finally the last worker, the specialized one, remains responsible for the functions already assigned to him, like changing machines, change abrasives and clean wheels. In addition he has to do all other functions which in the current situation are executed by all workers, such as moving the empty/full baskets, make the necessary records and cleaning the area. His area of operation due to the duties performed would have to be the whole area of MF.

With this new work method, it is possible to organize the work being done in MF. By assigning specific tasks to each worker it would be possible to increase the efficiency in this stage, mainly because the two workers responsible for overseeing the machines do not have any tasks allotted besides the overseeing of machines. With that it would be possible to reduce the stopping times of the machines caused by a jam.

4.2.3.2 Problems between Shifts
Another inefficiency found is related with problems between working shifts. There were mainly two problems.

- **First Problem:**
  The first problem is that the workers did not identify the last production batches. So when a shift began its work, some batches were not properly identified. To know the impact of this problem, the time needed to fill the identifying sheets of batches was measured and found that on average it takes about 5 minutes per batch.

As MF can be producing eleven batches, in the beginning of each shift the identification of all batches would consume about 55 minutes to a single worker. Since this is a secondary task, this time is too high and represented an inefficiency because it did not allow the worker to perform its priority tasks. Identified this situation it was suggested that whenever a batch started being produced its identification sheet should be filled. This was a usual procedure during the shift but with this suggestion the same should be done in the end of the shift. So between shifts all batches are properly identified. With this suggestion the workers during their shift do not need never to devote more than 5 consecutive minutes to this task, which differs from the previous situation in which they could spend 55 minutes dedicated to it. Having examined this point with the industrial director, it was decided to implement this suggestion.

- **Second problem:**
  The second problem is caused by workers, who, at the end of each shift stopped the machines. This was done after the registration of the amount of stoppers produced on each machine. If this was not done, the machines continued to produce stoppers that would only be counted as produced in the next shift. This point was considered as an inefficiency, because the machines were able to work and deliver product, but they were not producing. It was observed that between shifts the machines remained without producing for an average 10 minutes. If we account 200 stoppers produced per minute and per machine, and knowing that MF can be producing eleven batches at each time this leads to a value of 22,000 stoppers which are not produced. As in each day there are three shifts, this represents a daily loss of about 66,000 cork stoppers. To overcome this situation the following was suggested: at the end of each shift the workers should record the amount of stoppers produced without stopping the machines. This was only possible to be implemented after careful discussion with the workers, in which the benefits have been demonstrated.

4.2.3.3 Changing Machines
Another inefficiency found in this stage was related to machines changing. These changes often happen in MF and occur whenever a production line needs to start producing a different type of cork stopper than the one which is currently being produced. This change is made by the specialized worker, who needs
to change all the machines that will produce the new cork stoppers. There are two types of changes which are going to be discussed next.

- **First Type:**
The first type of change happens when the new stoppers to be produced belong to the same group as the stoppers being produced. This type of change has a daily frequency. Several observations were made and studied to know the best way to perform these changes. It was noted that to optimize this process it should be avoided a regular situation, the displacement of the worker who is making the change. These displacements often occur because workers either forget to take all the necessary tools or because they cannot take them all at once. During this displacement the machine remains stopped, and this is the reason why this is an inefficiency. To assist workers and improve their performance, acquiring a tools car, such as already exists in other areas of the factory was suggested. The study of the payback of this investment had as result a value of 0.59 years. Realizing the advantages of purchasing this tools car and its profitability the decision to make the investment was done. The investment was then performed and the new car is currently being used.

- **Second Type:**
The second type of changes occurs when the new type of stoppers to be produced belong to a different group than the type of stoppers currently being produced. This type of change occurs every three months and takes about 8 hours, which corresponds to a shift, to be carried out. This type of change is more complex than the one studied before. The study of work was developed and several inefficiencies were found. To overcome these problems and after meeting with the industrial director it was suggested the implementation of some boxes which contain all the material needed to perform these changes. The advantage these boxes bring to this process, is that workers do not need to search for the material and the material is ready to be used. With the implementation of these boxes the time needed to perform this change was reduced for 2 hours, which represents an improvement of 78%.

**4.2.3.4 Auxiliary equipment**
Finally, the fourth point concerning the increase of efficiency is related to the investment in auxiliary equipment. The equipment considered to have a great impact on efficiency was a device that would include sensors and lights to warn whenever the machines stop producing. This happens mainly because the machines are jammed. For this purpose it was decided to gather data that would allow performing the calculation of this investment payback.

The data gathered for this purpose was the number of daily jams in the machines, the percentage of these jams that affect the productivity and each machine average productivity. The earned time, meaning the time that could be reduced by this device in terms of identification of unexpected stops, is the variable that the payback will depend on. This is because it is not possible to know what the earned time would be. So the calculation of the payback considering some values for the earned time was done and is represented in Figure 8.

![Payback of the device proposed for some values of earned time](Image)

This study was shown to the industrial director, who, by analyzing the values of the payback achieved, considered it an important acquisition. But given the amount of investment required, this equipment was not readily acquired but will be a priority for future investments.

**4.3 First PI**
Having completed the second step of the Theory of Constraints, in which one attempts to solve the constraint, the first intermediate point should be analyzed (see methodology shown in Figure 2). At this point the decisions suggested in this cycle should be verified to know if they have an impact on other stages, and if so these stages should be adapted so that the process can be uniform. After a careful analysis it is possible to conclude that the decisions made in section 4.2 only have a direct impact on MF and therefore it is not necessary to develop the third step of the Theory of Constraints.

**4.4 Second PI**
As identified in the methodology shown in Figure 2, at this point the results from the previous steps must be verified.

Starting from the initial situation represented in Table 2, in which the orange color represents the capacity of the constraint. This is the stage
of the process with less capacity in terms of stoppers produced per day.

Following this analysis Table 3 represents the results after solving the first aspect identified as a limitation of the identified restriction. This aspect was the improvement of the supplying system (section 4.2.1). In this study it was possible to conclude that the supplying was now adjusted to MF capacity, so the resolution of this problem allowed an increase in the capacity of 366,680 stoppers for ESP group and 359,251 for AGLO group. Adding these values to the capacity of the MF shown in Table 2, the values in Table 3 are achieved. As results it can be observed that for the stoppers belonging to type ESP, MF remains the constraint, however Extrusion becomes the new constraint for the group AGLO.

**Table 3 – Situation after improvement of Supplying System**

<table>
<thead>
<tr>
<th></th>
<th>Extrusion</th>
<th>M. Finishes</th>
<th>Washing</th>
<th>Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP</td>
<td>1,148</td>
<td>1,138</td>
<td>2,736</td>
<td>1,294</td>
</tr>
<tr>
<td>AGLO</td>
<td>791</td>
<td>950</td>
<td>1,824</td>
<td>1,180</td>
</tr>
<tr>
<td>Total</td>
<td>1,939</td>
<td>2,253</td>
<td>4,560</td>
<td>2,474</td>
</tr>
</tbody>
</table>

Then it is important to analyze the results (Table 4) after the implementation of a better allocation of machines (section 4.2.2). This new allocation causes the MF to no longer be the constraint to both groups of cork stoppers. The new constraint of the whole process is now the Extrusion stage. The restriction identified in the first step is now eliminated.

**Table 4 – Situation after implementing a better machines allocation**

<table>
<thead>
<tr>
<th></th>
<th>Extrusion</th>
<th>M. Finishes</th>
<th>Washing</th>
<th>Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP</td>
<td>1,148</td>
<td>1,252</td>
<td>2,736</td>
<td>1,294</td>
</tr>
<tr>
<td>AGLO</td>
<td>791</td>
<td>950</td>
<td>1,824</td>
<td>1,180</td>
</tr>
<tr>
<td>Total</td>
<td>1,939</td>
<td>2,212</td>
<td>4,560</td>
<td>2,474</td>
</tr>
</tbody>
</table>

In addition and after the implementation of the suggestions made in section 4.2.3, it is still expected to increase the efficiency of MF by 5%. Thus, increasing the average efficiency of 70% to 75% it is possible to get new values for the capacities of this stage, which are shown in Table 5. This table illustrates that MF is now better protected against possible and unexpected inefficiencies.

**Table 5 – Situation after efficiency improvement**

<table>
<thead>
<tr>
<th></th>
<th>Extrusion</th>
<th>M. Finishes</th>
<th>Washing</th>
<th>Sorting</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESP</td>
<td>1,148</td>
<td>1,352</td>
<td>2,736</td>
<td>1,294</td>
</tr>
<tr>
<td>AGLO</td>
<td>791</td>
<td>1,018</td>
<td>1,824</td>
<td>1,180</td>
</tr>
<tr>
<td>Total</td>
<td>1,939</td>
<td>2,370</td>
<td>4,560</td>
<td>2,474</td>
</tr>
</tbody>
</table>

In conclusion, it should be noted that by changing the system constraint to another stage, it is also observed that the process overall capacity increases. In the first table, Table 2, where the initial situation is represented, the capacity of the process was limited by MF and thus was 1,526,667 stoppers. On the other hand in the last table, Table 5, the capacity is limited by Extrusion, meaning a new capacity of 1,938,745 stoppers. Then it can be concluded that the implementation of the Theory of Constraints is effective in improving manufacturing processes, resulting in an increase of capacity of 412,078 cork stoppers. This variation means an increase in capacity of 27%. Thereby reflecting the increased capacity registered in economic terms a final calculation was performed. By doing the multiplication of the capacity variation, the number of working days and the average price per stopper, it is possible to obtain as results a potential increasing sales of about 1,545,293 euros in a year.

4.5: if the constraint has been broken, go back to step 1 to prevent inertia to become the next constraint.

Theory of Constraints is a continuous improvement philosophy and therefore the methodology in Figure 2 is represented as a cycle. Thus after elimination of the identified constraint one must return to the first step of this methodology. It is important to note that in a system there will always be a constraint. By returning to the starting point it is ensured the identification of the new restriction and its improvement are performed.

Before ending this cycle it was decided to do a final analysis to know what the limit of efficiency that MF could have was. These values are especially important for those in charge of this factory, in order to make an effective process control. The calculations were made and the values are represented in Table 6. These values were calculated for both groups of stoppers: ESP group has an efficiency limit of 64%, while for AGLO group the efficiency should not be less than 58%.

**Table 6 – Limit values of efficiency for MF**

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>ESP</th>
<th>AGLO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>64%</td>
<td>58%</td>
</tr>
</tbody>
</table>

5. Conclusion
To conclude this paper it should be pointed out that the objective initially proposed to improve the process and the consequent increase of its capacity has been reached. To accomplish
this, the methodology shown in Figure 21 that represents the TOC was followed. In the first step Mechanical Finishes was identified as the constraint of the process, a process which had a production capacity equal to 1,526,667 cork stoppers per day. In the second step alternatives have been suggested and implemented to improve this stage. These alternatives were focused on three main issues: improvement of supplying system, a better machines allocation and an improvement of efficiency. The third and fourth steps due to the type of suggested alternatives and to its success were not implemented. As result, the elimination of Mechanical Finishes as the constraint was possible. By achieving that an increase of capacity to 1,938,745 stoppers per day was achieved, this equals a 27% increase in capacity. With this result it is concluded that the stated objective was successfully attained.

It is also relevant to note that in Delgado (2014) a second cycle using the proposed methodology was applied to this same process. In this second cycle Extrusion, as it is illustrated in Table 5, was identified as the new constraint. By studying this new constraint it was possible to suggest improvements to eliminate it.

As for future studies, Equipar should continue with the application of TOC to this manufacturing process. During this study Equipar collaborators were always helpful and interested, demonstrating why Corticeira Amorim is the leader in the cork industry. And if they continue to implement TOC, this company could follow a philosophy of continuous improvement.

6. References


