Original Article

# Environmental and economic evaluation of the household utility packaging process from the cleaner production approach

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**Abstract**

Waste generation in a process must be avoided for economic and environmental reasons, as waste is raw materials that did not become a product. In this sense, this work aims to evaluate opportunities for improvement through Cleaner Production (CP) to reduce the amount of BOPP packaging waste generated in the packaging process. Two packaging machines were studied (Flow Pack 84 and Flow Pack 07). From the on-site evaluation of the process in both machines, the main causes of waste generation were identified: breaking of the BOPP film, missing material, stuck material, misaligned material, and inadequate sealing. Flow Pack 84 also generated almost three times more packaging waste when compared to Flow Pack 07. Thus, CP actions were established to reduce or eliminate waste at the generating source. By installing a kind of a lung of the conveyor belt and two stop sensors in Flow Pack 84, it would be possible to eliminate waste generation from stuck materials. As for Flow Pack 07, the missing material does not depend on the machine, but on the quality of the material that is fed into it, so this problem must be resolved before the packaging process. The economic feasibility analysis showed that the investment made with these changes would be recovered in just over a year. Thus, packaging waste generation would be reduced by 63.4% in Flow Pack 84. In this way, the concept of CP shows that, with simple actions and without large investments, it is possible to minimize waste generation or even eliminate it at the generating source, even creating incremental innovations. It is extremely important to know the production process to evaluate the improvements. In this process, even by justifying that all waste generated is sold to recycling companies, this study showed that there is a greater economic and environmental return with the preservation of the raw material.

**Keywords:** Cleaner production; BOPP; Packaging process; Flow pack.

## 1 Introduction

The scarcity of natural resources, the pressure from society for companies to adopt measures to prevent negative environmental impact, and economic issues have increased the search for sustainable alternatives related to waste generation in the production process. In this context, there is an opportunity to develop Cleaner Production (CP) actions to reduce or even eliminate waste generation at the generating source. The CP has been an important means to systematically motivate waste reduction and product reuse [1]. Some authors stated that CP methods, as well as Environmental Management practices, aim at the efficiency of the production process, the use of inputs, and the non-generation of waste [2]. Chareonpanich et al. [3] showed that environmental assessment tools have been improved and adjusted to standards, laws, and regulations to improve the sustainability of products, processes, and services. Santos and Araújo [4] also demonstrated that the CP actions implemented in the studied process resulted in a substantial reduction in the use of resources and costs.

The diagnosis of the process is very important in CP, as it assists in knowing the production process and its structures and identifies points in the production chain where it is necessary to propose mitigation or minimization of impacts. This also enables the quantification of waste generation [5,6].

A common process in the packaging industry is the production of Bioriented Polypropylene (BOPP), a film widely used in the flexible packaging industry. This product is obtained through the biorientation of Polypropylene (PP) and has several advantages.

BOPP films used in the packaging industry are sold in the form of reels and may or may not have printing, which are drawings and texts produced through the flexographic printing process with specific ink made from organic solvents.

The generic packaging process works as follows: the BOPP is received in the form of reels that are manually inserted into specific equipment, the FlowPack-type wrappers, which carry out the product packaging process. There are

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several types of FlowPack wrappers. However, they all have the same principle: to close the packaging by heat-sealing, that is, by heating the BOPP film. The packaging process, as shown in Figure 1, begins with the product that will be packed, which is placed on the conveyor belt (automatically or manually) to be transported to the packaging area. The BOPP coils are placed on the rotating axis of the machine, which operates with three independent axes: one for advancing the film, one for traction of the feed chain, and the last one for activating the jaws. The film is continuously removed from the reel, wrapping the product like a tube. Afterward, rollers seal longitudinally and jaws seal and cut across the entire material, forming the package.

This process generates waste that equals economic losses and negative environmental impact since treatment and disposal costs are necessary. Therefore, reducing or eliminating waste generation has a great economic and environmental impact [8].

Alternatives based on CP that enable economic gains, as well as less environmental impact on physical, biotic, and socioeconomic means, are urgent needs. The authors also state that this improves the quality of the population's life by reducing environmental impacts, as well as helping companies reduce the loss of inputs in the form of waste [9].

Process management avoids unnecessary expenses, and CP approaches support this statement, showing that it is possible to link economic gains to environmental gains. For this purpose, companies should seek the application of clean technologies to reduce negative environmental impacts. The processes, on the other hand, must work, firstly, to prevent waste generation. If that is not possible, the reduction in generation can already bring good environmental and economic gains [10].

The commercialization of waste is a path followed by many companies. However, there is a greater economic gain with the conservation of raw materials than with the commercialization of recycled materials [10]. Orth et al. [11] state that avoiding waste generation by wasting material delays the acquisition of new materials, whose production, storage, and transportation processes also involve negative environmental impacts. Therefore, according to the authors, the company that avoids waste contributes to the reduction of negative environmental impacts, either by reducing waste generation or by reducing the acquisition of new materials.

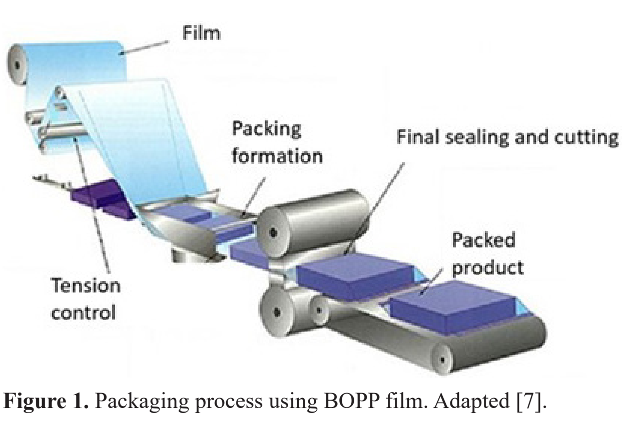


**Figure 1.** Packaging process using BOPP film. Adapted [7].

In this context, this work aims to diagnose the production processes of BOPP film, flexographic printing, and packaging. From this research, possible actions of CP in the packaging process will be pointed out, seeking to reduce waste at the generating source.

## 2 Materials and methods

### 2.1 Packaging process

In the packaging process, waste can be generated in two situations: in the case of the packaging being generated without any product inside (empty packaging) or when the packaging is outside the quality parameters, such as when it presents inadequate sealing, for example. In the second case, if the material inside the packaging has not suffered any kind of damage, it can return to the process to be packed again. Among the six machines in the company from the study, two were selected for this research: one manufactured in 1984 and the other in 2007. To facilitate identification, the machines were defined according to their year of manufacturing, that is, Flow Pack 84 and Flow Pack 07. The machines were chosen due to Flow Pack 84 being older generating more waste when compared to the others. As for Flow Pack 07, it was chosen because it can pack the same materials that are packaged in Flow Pack 84, thus enabling the comparison between both to be carried out under the same process conditions.

### 2.2 Materials

BOPP is produced from the biorientation process of PP film, carried out by a company (Alpha) from the metropolitan region of Porto Alegre / Brazil. After being produced, the film is sold in the form of reels to a company (Beta) located in the state of Santa Catarina / Brazil, which performs the flexographic printing process using inks made from a basis of organic solvents. After the printing process, the reels are sent to a company (Gama) that only performs the packaging process. During this process, there is the generation of packaging waste that, due to some factors, does not meet the quality standards and is therefore discarded. Figure 2 shows a representation of the generated waste.

However, it is important to highlight that this waste does not present any type of impression in order not to disclose the brand or the name of the company.

### 2.3 Evaluation of environmental aspects and impacts

The Environmental Aspects and Impacts Assessment (EIA) is a planning tool that provides a systematic and structured framework [12].

From a block diagram, a survey of environmental aspects and impacts was carried out based on the methodology used

**Table 1.** Evaluation Scale

| Grade | Severity | Definition |
|---|---|---|
| 1 | Low Impact | Environmental Impact is restricted to the place of occurrence. |
| 2 | Medium Low Impact | Environmental Impact is restricted to the company, reversible with mitigating actions. |
| 3 | Medium Impact | Environmental Impact is restricted or not to the company, reversible with mitigating or corrective actions. |
| 4 | Medium-High Impact | Environmental Impact is restricted or not to the company, reversible with corrective actions. |
| 5 | High Impact | Environmental Impact is restricted or not to the company, with irreversible consequences even with corrective actions. |

**Source:** Adapted [14].

**Figure 2.** BOPP waste.

by Stalter et al. [13], which used the Leopold Matrix as a base. In this methodology, the environmental aspects associated with the possible impacts caused on soil, water, air, natural resources, and health were listed and inserted in a table. Afterward, an association was made between aspects and impacts, and a score from 1 to 5 was assigned [14], according to Table 1.

## 2.4 Economical evaluation

The economic feasibility study was carried out with the premise of measuring the invested capital versus the gain obtained in implementing improvements aimed at reducing BOPP waste generation. The indicator used in this assessment was Simple Payback, which shows the number of periods necessary to recover the business investment. Balarine [15] states that it is a simple and initial mechanism for project analysis.

To calculate Simple Payback, when equal and successive returns occur, the initial investment is divided by the gain in the period: SPB (Simple PayBack) = P (Initial Investment) / VPT (Value of periodic tickets).

The result corresponds to the number of periods elapsed from the initial investment until its recovery, that is, it is the moment in which the cash balance becomes positive [16].

If the PayBack time is greater than the PayBack amount, the project is rejected; if this time is shorter, the project is accepted [17].

## 3 Results and discussion

The block diagram in Figure 3 shows the inputs and outputs of the three processes: production of the BOPP film, flexographic printing process, and packaging process.

In the production process of the BOPP film, waste is generated from cutting the sides of the film, the burrs. However, this waste is milled and returned to the production process as a raw material. The emissions generated in this step are due to the corona treatment that activates the surface of the film through an electrical discharge, causing a chemical reaction that breaks some bonds and releases ozone. This treatment is necessary because, without it, the impression does not adhere to the film.

The flexographic printing process in BOPP films uses inks with organic solvents and works as a stamp: the ink wets a roller with the relief of the drawing and the roller presses the relief onto the film, printing on it. In this process, the largest waste generation is linked to ink consumption, through the disposal of packaging and dregs, in addition to the vaporization of organic solvents. The generation of film waste can also occur when printing is not performed properly.

Waste generation in the packaging process occurs in three situations: when the film does not turn into packaging, when the film reel runs out and only a hard paper core remains, and when the product to be packed is not within the quality specifications.

## 3.1 Environmental aspects and impacts assessment

Figure 4 shows the evaluation of the aspects and the respective environmental impacts of the BOPP film production processes, the flexographic printing process, and the packaging process. The biggest negative impacts are associated with the flexographic printing process since it uses inks made from organic solvents, which are responsible for airborne emissions, generation of contaminated lees, and packaging.

Figure 4 shows that 100% of the impacts of the BOPP production process, as well as the flexographic printer process, have a higher score in Environmental Impacts. This shows the importance of seeking alternatives to reduce waste at the source.

Contamination of the soil and water resources was the item with the highest incidence in the worksheet for

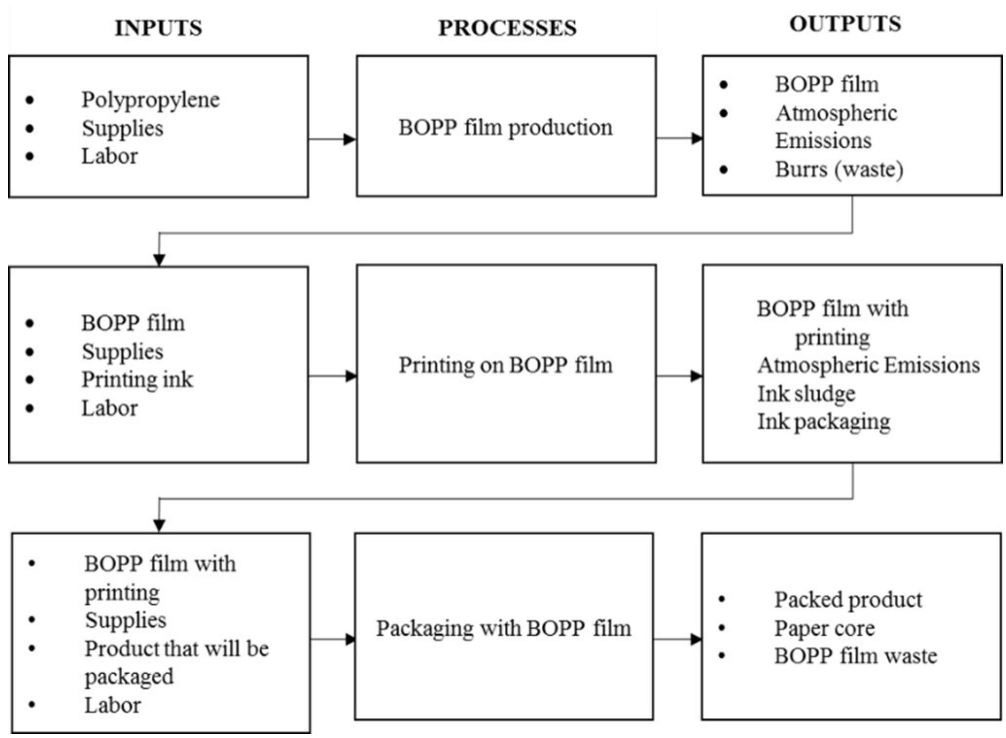


**Figure 3.** Block Diagram.

| | Impact | | | | | |
|---|---|---|---|---|---|---|
| | Physical | | | | Anthropic | |
| | Soil | Water | Air | Natural Resources | | |
| Aspects | Soil contamination | Contamination of water resources | Air pollution | Consumption of renewable or non-renewable resources | Health | Total |
| Polypropylene consumption | 1 | 1 | 1 | 5 | 3 | 11 |
| Water consumption | 1 | 1 | 1 | 5 | 1 | 9 |
| Electric power consumption | 1 | 1 | 1 | 3 | 1 | 7 |
| Printing ink consumption | 5 | 5 | 5 | 5 | 5 | 25 |
| Evaporation of organic solvents | 5 | 5 | 5 | 2 | 5 | 22 |
| Burr generation | 1 | 1 | 1 | 5 | 1 | 9 |
| Ink sludge generation | 5 | 5 | 5 | 2 | 5 | 22 |
| Ink packing generation | 5 | 5 | 5 | 2 | 5 | 22 |
| Paper core generation | 1 | 1 | 1 | 3 | 1 | 7 |
| BOPP films waste generation | 1 | 1 | 1 | 5 | 1 | 9 |
| Oil consumption used in machinery | 5 | 5 | 2 | 5 | 5 | 12 |

**Figure 4.** Adaptation of the Leopold Matrix Environmental Aspects and Impacts Assessment.

surveying environmental aspects and impacts. It is mainly present in the packaging process. This item is associated with waste generation and, represents the loss of reserves and results in environmental degradation [18].

Atmospheric pollution is present in the first two processes through ozone and volatile organic compound (VOC) emissions. VOCs can aggravate stratospheric ozone degradation and contribute to the greenhouse effect, so it is important to control and minimize the emission of them, which react in the presence of light. Ozone, in the lower layers of the atmosphere, is harmful to plants, animals, and humans, even in low concentrations. The author also points out that ozone acts as an agent that inhibits plant photosynthesis and damages the human lung structure [19].

This study is focused only on the packaging process, in which not all impacts were critical. However, each discarded package carries a load of critical environmental impacts from the processes that precede it.

### 3.2 Packaging process, generation causes description, and priority causes identification

Flow Pack 84 generated a higher amount of packaging waste when compared to Flow Pack 07 and in-depth monitoring was carried out to identify the causes of waste generation. The need to quantify this waste was also identified. Therefore, it was established that each of the causes would be associated with two other parameters: machine downtime and quantity of discarded packaging. The process in both machines was monitored from April to May 2017, for ten minutes, twice a day. Thus, it was possible to observe the behavior of the machines in different shifts with different operators. The observations were carried out during the morning and afternoon shifts. The maximum packaging capacity of the machines is 75 pieces/minute in Flow Pack 84 and 175 pieces/minute in Flow Pack 07, which means that, every 10 minutes, around 750 pieces were packed in Flow Pack 84 and 1750 pieces in Flow Pack 07.

As previously explained, the sample size calculation was performed with the support of the G * Power statistical analysis software v. 3.1, developed by Faul et al. [20]. An average effect size to be detected (w = 0.3), a significance level of 10%, and an estimated power of 95% were considered to assess the association by the Chi-Square test with 4 degrees of freedom between the machines and the types of failures. The number of 4 degrees of freedom was established because it is an analysis of a contingency table with two machines and 5 different types of problems, observed in a pilot sample with 10 repetitions of 10 minutes of observation on each machine. For this, a minimum size of 176 problems/failures was obtained. As explained previously, 80 timeframes were collected, with 220 failures observed in the two machines in total.

Thus, it was possible to survey the main process differences between the machines, as well as observe opportunities for improvement aimed at reducing waste generation.

The data were organized with the aid of contingency tables and the Pareto diagram was used to identify the variables that most negatively impact the process.

### 3.3 Improvement opportunities

Bhupendra and Sangle [21] state that strategies that seek non-generation should be the first to be implemented to achieve financial advantages and mitigate risks. In this context, CP takes a preventive approach to optimize raw materials, water, and energy.

The reduction of waste generation at the source is integrated into the processes through the replacement of raw materials, technological changes, good operating practices, and changes in products [10]. Table 2 shows two actions that are part of the scope of CP's level 1 actions, that is, reduction at source.

Based on the actions presented in Table 2, the possibilities of reducing waste generation were evaluated at the generating source, that is, in the packaging process.

### 3.4 Flow Pack machines and waste generation causes

This item will describe the failures that occur in the process and that cause the generation of packaging waste on both machines.

#### 3.4.1 Missing material

Flow Pack 07 has a 17-meter-long belt, which acts as the lung of the packaging process, and two stop sensors, which have the function of interrupting the process if there is missing material. One of these sensors checks the alignment of the pieces at 60 cm before the packaging area and the other detects the material missing on the lung conveyor, in order to keep it filled all the time, avoiding missing material in the packaging area. Thus, there is no generation of packaging waste due to missing material or misaligned material. On the other hand, in Flow Pack 84, if the operator does not feed the conveyor, the machine

**Table 2.** Actions to reduce waste at source. Adapted [10,22]

| Action | Examples |
|---|---|
| Product Change | Changes in composition, type of packaging, and product lifespan. |
| Change in the Process | Replacement of raw material Use of less polluting raw materials and supplies with a longer lifespan |
| Technological Change | Improvement in process automation, replacement of equipment, and processes. |
| *Housekeeping* | Changes in procedures, management, and training of employees. |

will continue the process and generate empty packages that will be discarded as waste. Missing material can also occur in Flow Pack 07, because, due to quality problems, the materials may not be fed to the conveyor and cause the machine to stop due to missing material on the lung conveyor. However, in this case, it is a problem before the packaging process.

### 3.4.2 Misaligned material

In Flow Pack 07 there is a sensor, about 60 cm before the packaging area, that detects if the materials are aligned. If any of them is misaligned, the machine interrupts the process. In this way, it prevents the packaging from being sealed over the materials, which could lead to loss of material and packaging. As Flow Pack 84 does not have this sensor and the feeding is done by the operators, the materials can be misaligned on the conveyor, causing them to be improperly packaged. This generates packaging waste and possible loss of materials. Once the packaging is sealed over the material, it must be discarded.

### 3.4.3 Stuck material

This is similar to the misaligned material failure. However, in this case, the material also interrupts the passage of others. If the material gets stuck in Flow Pack 07, the stop sensor will identify the missing material and interrupt the process. In Flow Pack 84, as there is no stop sensor, the material will be stuck, preventing the passage of the others, while the machine continues the process, generating empty packages. In Flow Pack 07, the material gets stuck due to the high speed of the machine, which can cause the materials to overlap and, consequently, get stuck at some point. In the case of Flow Pack 84, the material gets stuck in the packaging area due to dimensional problems. If the operator feeds materials with dimensions larger than the standard (Figure 5), they can be stuck, preventing the passage of others and, consequently, generating empty packaging.

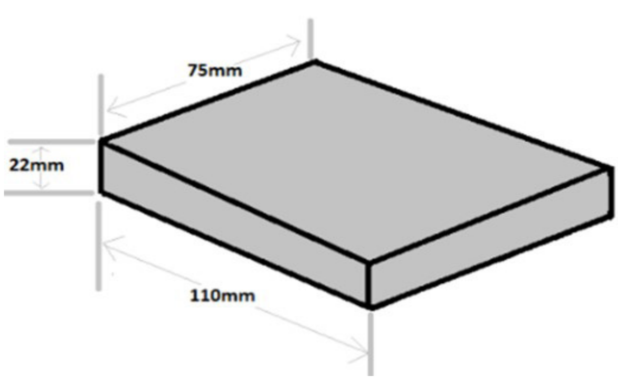


**Figure 5.** Pattern dimension of materials.

### 3.4.4 Breaking of the film

The friction coefficient is one of the quality tests performed on BOPP films. It serves to assess the relative sliding difficulty between two surfaces [23]. If this coefficient is outside the specification range, the film may not slide properly and then break due to tension. Whenever the film breaks, the machine must be stopped so the operator can replace the film on the rotating axis system and readjust it to the process.

### 3.4.5 Inadequate sealing

Inadequate sealing usually occurs each time the machine stops since, as this happens while it is hot, the jaws remain warm throughout the process. If the machine stops, the film will remain in contact with the jaws, which will heat it to the point of degrading it and there will be waste generation.

## 3.5 Statistic assessment

### 3.5.1 Assessment of the association by contingency table

The contingency table (Table 3) was evaluated using Pearson's Chi-Square test, showing a significant result at the level of 10% (Chi-Square = 9,049, gl = 4, p-value = 0.06, estimated power of the test = 92.4%). The complementary waste analysis indicated a significant association between Flow Pack 07 and the failure due to missing material and Flow Pack 84 and the failure due to stuck material. No other relevant associations were found related to the other failures at the same level of significance. The item 'nothing observed' indicates that the process was evaluated, but, in that period, no problems were observed. That is, the process did not stop and did not generate packaging waste.

Flow Pack 07's significant association with the item 'missing material' can be explained by the machine's feeding system. When a material is out of dimensions or even crooked, it does not enter the lung conveyor, and, if it does, it ends up being expelled after going through the cameras' evaluation. Thus, if there are many materials out of the specifications, this will cause the process to stop, in order not to feed the

**Table 3.** Contingency Table

| Problem | *Flow Pack 84* | *Flow Pack 07* |
|---|---|---|
| Missing material | 38 | 51 |
| Misaligned material | 23 | 20 |
| Stuck material | 24 | 9 |
| Breaking of the BOPP film | 7 | 6 |
| Inadequate sealing | 16 | 18 |
| Nothing observed | 5 | 3 |
| **Total** | **113** | **107** |

lung mat. In Flow Pack 84, on the other hand, the feeding is done manually by the operators and the machine has a lower speed, so the item 'missing material' showed lower values.

Flow Pack 84 showed a significant association with the 'stuck material' item since the machine does not have an automated quality assessment system or a stop sensor that interrupts the process when a material is stuck. This process is done by the operators, who do not always have the sensitivity to assess the dimensions.

When this occurs in Flow Pack 07, the camera system identifies the material and expels it, whereas in Flow Pack 84 it goes on to be packed and can end up stuck in the machine, preventing the passage of others; thus, generating empty packages. The other problems showed no significant difference, so they cannot be associated with the type of machine.

### 3.5.2 Priority causes identification

Among the causes of packaging waste generation, the Pareto diagrams show those that are more relevant, and, as such, must be treated with priority by the CP program.

The Pareto diagrams shown in Figures 6, 7, and 8 show the problems that must be prioritized. In Flow Pack 84, the items missing material, stuck material, and misaligned material are responsible for almost 80% of incidences (Figure 6A). As for Flow Pack 07, the items missing material, misaligned material, and inadequate sealing correspond to just over 85% of incidences (Figure 6B). In this case, according to the analysis through the contingency table, in Flow Pack 84, missing material and stuck material are significant; in Flow Pack 07, only the missing material is significant. Thus, these are the items that should be prioritized in terms of incidence.

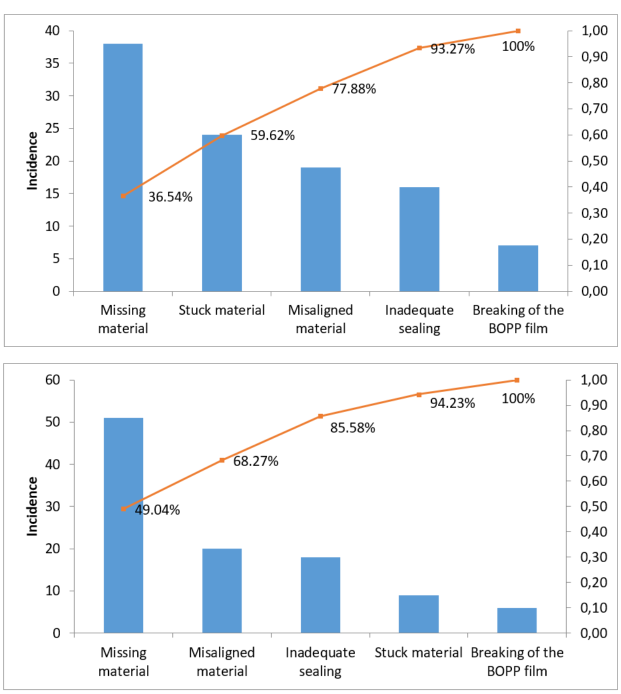


**Figure 6.** (a) Process Problem x Incidence – Flow Pack 84 (b) Process Problem x Incidence – Flow Pack 07.

As shown in Figure 7A, 100% of the problems with *Flow Pack 84* are due to the *breaking of the film* and *stuck material*. As for *Flow Pack 07*, the main problems are *missing material* and *breaking of the film* (Figure 7B).

Figure 8B shows that, in *Flow Pack 07*, 100% of packaging waste generation is due to the breaking of the

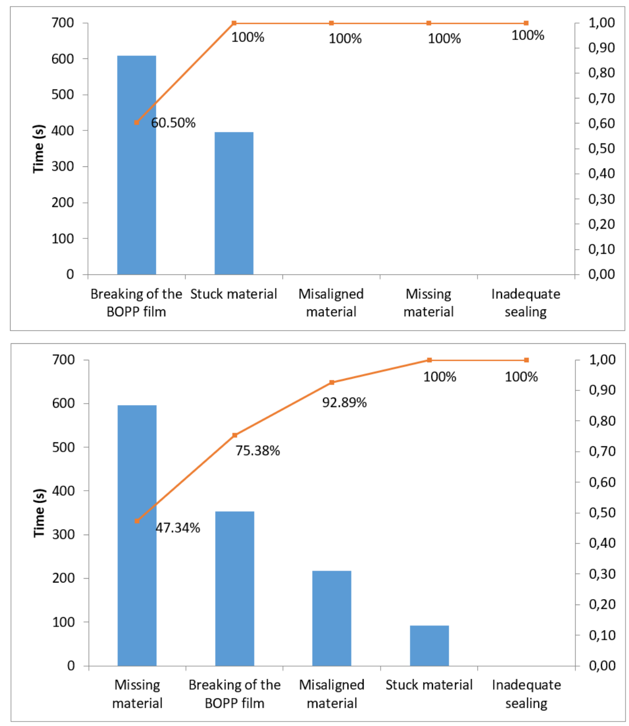


**Figure 7.** (a) Process Problem x Time – Flow Pack 84 (b) Process Problem x Time – Flow Pack 07.

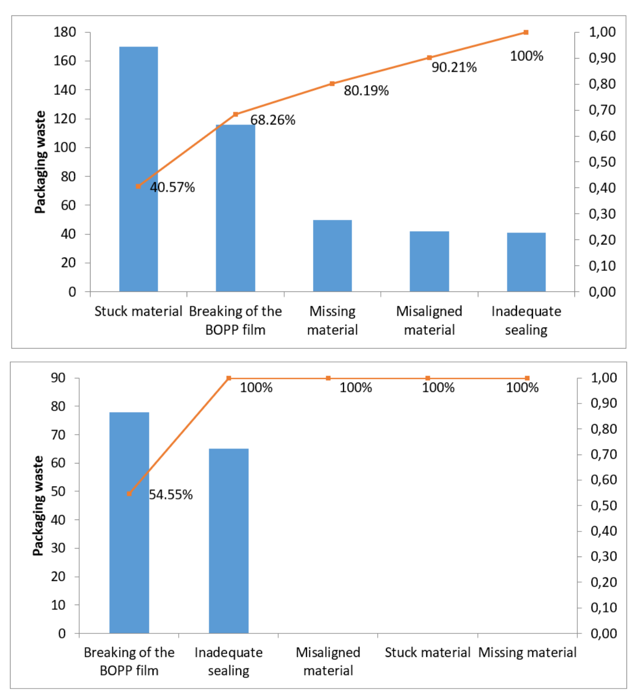


**Figure 8.** (a) Process Problem x Discarded packaging – Flow Pack 84 (b) Process Problem x Discarded packaging – Flow Pack 07.

**Table 4.** Main problems associated with the type of machine

| | Incidence | Time | Discarded packaging |
|---|---|---|---|
| **Flow Pack 84** | Missing material/ Stuck material | Stuck Material | Stuck material/ Missing material |
| **Flow Pack 07** | Missing material | Missing material | Breaking of the film |

film and inadequate sealing. However, none of these showed significance through the contingency table. Figure 8A shows that the items: stuck material, *breaking of the film*, and *missing material* are responsible for 80% of the causes of packaging waste generation in *Flow Pack 84*. Of these three, *stuck material* and *missing material* present significance, according to the contingency table.

From the Pareto diagrams and the contingency table, Table 4 was created. The table shows that missing material and stuck material are the main problems in Flow Pack 84. The *breaking of the film* was identified as an issue related to the quality of the film itself. As for Flow Pack 07, missing material and breaking of the film presented themselves as the main problems.

### 3.5.3 Downtime assessment and discarded packaging

Tables 5 and 6 show the sum of downtime and discarded packaging on each of the machines, from April to May 2017. Flow Pack 84 had a total of 1005 seconds (16.75 minutes) of added downtime, while Flow Pack 07 had 1259 seconds (20.98 minutes). This is around 20% more than the stop time of Flow Pack 84. Regarding the number of discarded packaging, Flow Pack 84 had 427, while Flow Pack 07 had 143. This means that only 33% of the waste generation was from Flow Pack 07.

Flow Pack 84 showed less downtime and more generation of discarded packaging, while Flow Pack 07 had more downtime and less generation of discarded packaging. This can be explained by the presence of the stop sensor, as it prevents the machine from continuing the process without material in the packaging area and, thus, does not generate waste. Flow Pack 07 has this sensor and, therefore, stopped for longer, but generated less packaging waste when compared to Flow Pack 84, in which there is no sensor.

### 3.6 CP proposals of level 1

As identified from the Pareto diagrams, Flow Pack 07 had missing material, responsible for the highest incidence and the longest downtime, and the breaking of the film, responsible for the greatest generation of packaging waste, as its main problems.

Missing material is not directly linked to the packaging process, but rather to the previous belt feeding process, as the feeding is automated. From observing the process, it was identified that the main cause is the feeding of the materials (Figure 9), that is, due to process problems, they end up bending. This prevents the material from being able to enter the lung conveyor and, when it enters, it ends up being expelled when going through the evaluation of the cameras.

**Table 5.** Flow Pack 84

| Problems | Addition of downtime (seconds) | Addition of quantity of discarded packaging |
|---|---|---|
| Missing material | 0 | 51 |
| Misaligned material | 0 | 50 |
| Stuck material | 397 | 170 |
| Nothing observed | 0 | 0 |
| Breaking of the film | 608 | 116 |
| Inadequate sealing | 0 | 40 |
| **Total** | **1005** | **427** |

**Table 6.** Flow Pack 07

| Problems | Addition of downtime (seconds) | Addition of quantity of discarded packaging |
|---|---|---|
| Missing material | 596 | 0 |
| Nothing observed | 0 | 0 |
| Misaligned material | 218 | 0 |
| Stuck material | 92 | 0 |
| Breaking of the film | 353 | 78 |
| Inadequate sealing | 0 | 65 |
| **Total** | **1259** | **143** |

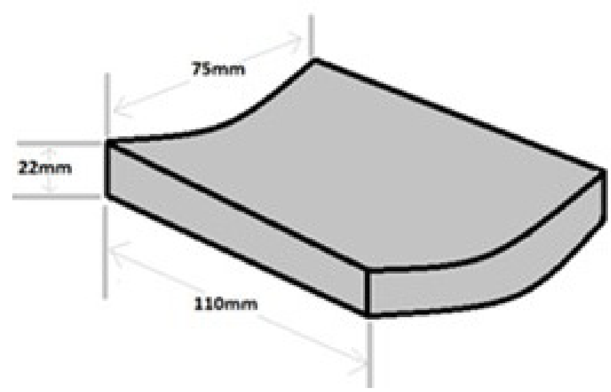


**Figure 9.** Deformed material.

The breaking of the film was identified as an issue related to the quality of the film itself. There is a quality control parameter for the coils that is very important for the process: the coefficient of friction (COF). The COF is the film's ability to slide on a surface, that is, a measure of the difficulty of sliding between two surfaces. The variation in COF accounts for large volumes of rejections during the process, as well as customer returns due to difficulties in use, as this parameter interferes with the performance of the film during the process [24]. If this parameter is out of the specification range, the film does not slide continuously, causing the tension to increase and, consequently, the film to break. In this case, the solution would be to discuss with the supplier so they can improve their process to avoid sending materials outside the specification range, as this results in waste generation.

In Flow Pack 84, the greatest incidence was the missing material. This can be explained by the fact that the feeding and the quality control of the materials are performed manually by the operators, unlike Flow Pack 07, in which it is done through cameras. Since the process is fast and operators need to evaluate the materials to be packed and feed the conveyor, missing material is a recurring problem and generates empty packaging. In this case, the installation of an automatic feeder, a quality control system by cameras, a lung conveyor, and a stop sensor would help with this matter.

This sensor, in addition to stopping the machine when there is no material in the packaging area, would also assist in the item that presented the greatest generation of packaging waste: stuck material. Thus, whenever a material was stuck, or there was no material in the packaging area, the machine would stop, avoiding the generation of empty packaging. Therefore, the sensor would also assist in eliminating waste due to misaligned material failure, interrupting the process if any material was misaligned on the belt before entering the packaging area. With these changes, this process would start to look similar to the Flow Pack 07 process, which does not generate waste for these parameters. Thus, the generation of packaging waste for the same parameters in Flow Pack 84 would be eliminated. Waste would be reduced by 63.4%.

The breaking of the film is one of the problems that demands the longest downtime and can be solved by controlling the COF of the coils. In this way, the coil does not get stuck, thus avoiding the film breaking, which requires the machine to stop and generates waste.

Industrial solid waste is one of the main factors responsible for the degradation of the environment. Thus, reducing its generation means acting directly to prevent environmental degradation.

The use of alternatives based on CP can bring environmental benefits (reduction of the generation of solid waste, effluents, and atmospheric emissions), as well as economic, as the reduction of waste generation implies not only in the reduction of negative environmental impacts, but also of expenses related to the waste generated [9,11].

Technology change is one of CP's Level 1 actions that aim to reduce waste generation at the source. In this context, the adoption of newer and cleaner technologies does not always produce the expected results. In some situations, the global environmental costs may be much higher due to the load of old equipment to discard and the production of a new one [25].

The changes made in a process with the objective of reducing or eliminating waste generation can be made through the adaptation of equipment and processes [26]. As for the changes, these can be through changes in the production process, automation, changes in process conditions (production temperature, pressure, humidity used), physical rearrangements of the production, and modifications in the equipment.

Therefore, the actions proposed here, which aim to reduce waste generation at the generating source by modifying the technology of a machine, are in line with CP and the reduction of environmental impacts generated by packaging and the packaging process.

### 3.7 Economical evaluation

When a company chooses to reduce waste generation at the source, it invests in its production process [10]. On the other hand, if the option is to recycle or treat, the investment ends up being in waste management. In this way, the improvements suggested in this research are in line with the authors' idea; we suggest investing in improvements in the production process to reduce waste generation.

Evaluating the Flow Pack 84 packaging process, it was found that not only a stop sensor, but also a lung conveyor would be enough, since the point where operators feed the machine and the packaging area are very close. Therefore, an investment of R$ 17,850.00 was projected for a 5-meter-long belt and two sensors: one on the lung belt, to identify missing material, and the other 60 centimeters before the packaging area, to identify misaligned materials.

### 3.8 PayBack

For the economic feasibility analysis of the improvements in Flow Pack 84, some important data were raised, which are shown in Table 7.

According to Table 6, the total generation of packaging waste caused by the two failures highlighted is 271 units. Considering that each package weighs an average of 2.12g, there is a total of 574.52g of packaging waste generated in 43 observations of 10 minutes each. Since the total packaging waste in Flow Pack 84 was 427, it can be estimated that 63.4% of waste generation is due to the three failures shown in Table 6 (missing material, stuck material, and misaligned material).

The 43 10-minute observations are equivalent to 7.16 hours of machine operation. Considering that the packaging waste generation was constant and that the machine works 24 hours a day, at the end of 24 hours, there are 1431 units of packaging waste generated, which is equivalent to 3.03 kg. Considering 26 working days, a total of 78.89 kg of waste is generated in one month.

**Table 7.** Data for statistical analysis

| Item | Data for calculation |
|---|---|
| Conveyor belt + two stop sensors + labor | R$ 17,850.00 |
| Average mass / packaging | 2.12g |
| Price / kg BOPP film | R$ 15.47 |
| Number of observations made | 43 |
| Packaging waste generation from missing material | 51 units |
| Packaging waste generation from stuck material | 170 units |
| Packaging waste generation from misaligned material | 50 units |
| Return with the sale of waste | R$ 0.30/kg |

BOPP coils have different masses and are sold per kilogram; currently, their price is R$ 15.47/kg. Thus, there is a loss of R$ 1,220.43 monthly and R$ 14,645.13 annually for the generation of packaging waste. Currently, this waste is sold to recycling companies at a cost of R$ 0.30/kg. So, at the end of a year, the company has a profit of only R$ 284.00. Discounting this profit from the total cost of raw material that becomes waste, the company has an annual loss of R$ 14,361.14.

The calculation of the financial return on investments using the Simple PayBack method is as follows (Equation 1). For projects developed in the company, the return on the amount invested must be recovered in a maximum of 3 years.

$$\begin{array}{l} \text{PayBack} = \dfrac{17{,}850.00}{14{,}361.14} = \\ 1.2 \text{ years} = 1 \text{ year} 2 \text{ months} 12 \text{ days} \end{array} \tag{1}$$

The PayBack time of the investment is within the limit established by the company, which means it is an economically viable proposal. Considering that the waste generated is raw material that has not been transformed into a product, based on the proposed improvements, the company stops spending R$ 14,645.13 on the purchase of new raw materials. These are values that, together with the PayBack value, economically justify the investment in the improvements proposed here. It should be noted that the energy gains resulting from the reduction of failures and issues related to labor were not considered.

## 4 Conclusion

This study confirms that, with simple actions and without large investments, it is possible to minimize or even eliminate waste generation at the generating source, which is in line with the level 1 actions of CP.

This study also showed the importance of knowing the production processes, equipment, and raw materials used. These were important points so improvements could be aimed at reducing waste generation.

Unlike what a first glance might suggest, changing an entire machinery may not be necessary, as demonstrated in this study, as some less costly adjustments and improvements can bring positive results.

The statistical analyses used were also an important tool. Through them, it was possible to identify every important element in this research, from the ideal sample size to the causes of waste generation that should be prioritized, thus allowing greater certainty in decision making. Although it could be justified that all the waste generated is sold to recycling companies, this study showed that there is greater economic return by preserving the raw material and transforming it into a product than by selling the waste generated.

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