Integration of Linear Programming from the Overall Equipment Effectiveness Machine Performance Evaluation to Maximize Uptime

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Abstract

According to a study on the Philippine Manufacturing Activities by the Board of Investments (BOI) in 2017, the Philippines is regarded as Asia's new manufacturing powerhouse; its top 1,000 corporations include 322 manufacturing firms and post gross revenues totaling Php 3.2 trillion. The manufacturing industry is a significant player in the economic sectors, generating both wealth and employment. However, many processes experience significant delays due to machine downtimes and erratic work schedules, resulting in low machine efficiency and product throughput. Through careful consideration, this research study focuses on a 3rd party logistics company specifically, the B-Mirk Enterprises. B-Mirk Enterprises is one of the premier providers of manufacturing, warehousing, logistics, and manpower services in the Philippines. The research study aims to evaluate the company's performance through the Overall Equipment Effectiveness (OEE) criteria and identify parameters that influence the outcomes of the company's production processes. The research study focuses on the company's newly implemented services within the labeling department which are also identified as the lowest in terms of its efficiency. A mathematical model is generated through the use of the Linear Programming technique, which is an analytical method of problem-solving and decision-making that is proven to be useful in the management of organizations. The overall study evaluated the company's overall production performance as a support in developing an LP algorithm which made use of LINGO Optimizing Software and Excel Solver and was able to maximize machine efficiency and uptime for 7 hours or 2.3 hours per shift for B-Mirk's Labeling Department.

Keywords
Manufacturing Industry, Machine Downtimes, BMirk Enterprise, OEE, Linear Programming

1. Introduction

The present industry is becoming extremely aggressive, bringing retailers to provide increased efforts in providing the consumers' needs and to ensure health safety as well as the well-being of the people (Aryapadi et al. 2020). Various manufacturing companies are struggling in meeting the (1) increasing customer demands and (2) daily production quotas, while balancing multi-production operations that encouraged businesses to resort to Business Process Outsourcing (BPO) and third-party logistics (3PL) (Ferruzzi et al. 2011). In-house productions are passed on to BPOs and 3PLs do the in-house productions that can greatly reduce the operating costs of the business that result in a significant increase in the profit (Mboga 2015). Now, BPOs and 3PLs are challenged to have flexible manufacturing to cater to different clients having different product specifications. All that being said, equipment, machines, and devices are vital elements for every manufacturing and production system (Kardas 2017; Jan, et. al, 2021). Modern production companies established multi-product production to enhance the production facility's effectiveness and one approach used to quantify the losses of the facility and its machines is the Overall Equipment Effectiveness (OEE) (Hao, et al. 2021). The purpose of OEE is the comparison of the actual utilization from the ideal utilization of the machine (Kardas 2017). The three components that constitute the OEE are (1) the availability, (2) the performance, and (3) the quality. It is inevitable to have inefficiencies during a production process, however, it must be avoided and prevented at all times (Peyrache and Silva 2019).

Machine downtime and failure produce substandard products and poor facility performance resulting in low reliability to the manufacturer (Ahmad, et. al, 2018). According to the research study entitled "Model to reduce waste in the production of labels in Peruvian companies of the plastic sector by applying Autonomous Maintenance, Kanban and Standardization of work," the three main causes of the high percentages of waste are (1) machine failure with 56.15%, (2) inadequate parameters of calibration and inappropriate utilization of personnel with 39.83%, and (3) inadequate planning of production and inadequate manipulation of the plastic material with 4.02% (Flores, et. al, 2020).

Labeling operation is one of the tasks under the production process that takes place on the latter part of the process. Intharak and Tharmmaphornphilas (2015) stated in their optimization study of a rotary type labeling machine that labeling machines are important devices for labeling operation during the packaging process. Throughout the research study, the labeling machine has produced numerous defects, which contributed to the concept of utilizing the labeling machines as the subject of study. These defects were categorized as overlapping defects, off-center label defects, and flipped label defects (Intharak and Tharmmaphornphilas 2015). Linear Programming (LP) is a widely used solution arc when it comes to inadequate planning of production, that Flores and his peers stated, is a main contributor to waste (Flores, et. al, 2020). It is a technique under operations research for optimal resource allocation in line with the company's practices (Woubante 2017).

This research study revolves around the labeling operation of a local enterprise corporation specializing in process outsourcing. This research is of great importance because it provides an exceptional approach by systematically evaluating the company's machine downtime to prove that further improvement is necessary to attain the optimal downtime that is appropriate for the labeling production. The values would be solved through a designed LP algorithm that may determine the optimal downtime for the operation. B-MIRK is a group of companies and is currently the Philippines' premiere BPO (Business Process Outsourcing) company that provides third-party services such as manpower services, manufacturing, warehousing, logistics, etc. (B-Mirk, 1992). The labeling department is utilizing labeling machines which replaces the manual labeling operations and is currently experiencing a long period of machine downtime resulting in a high number of product rejects. The rate of output per unit of time is higher than the rate of consumption (demand) per unit of time. However, due to a lack of capacity, the output rate may be lower than the demand rate in some cases. Furthermore, consumption can only begin after a batch has been completed. In such cases, the annual demand cannot be met, resulting in shortages (Goyal et al. 1996).

1.1 Objectives

This research aims to (1) evaluate the machine performance and (2) propose an optimal machine calibration of B-Mirk's labeling machine. Overall Equipment Effectiveness is the tool that the researchers utilized to evaluate the current machine performance. The company provided the researchers the necessary data needed for the evaluation and the formulation of the Linear Program. MS Excel is the medium that will be used to evaluate the labeling machine with the guidance of OEE. LINGO and MS Excel are the software packages to be used in formulating the

Linear Programming.

2. Literature Review

The past few decades have been about the resurgence and dramatic evolution of the different production processes of each enterprise in the global market. Nowadays, manufacturing firms are more focused on improving production performance in terms of production output and machine performance in order to stay globally competitive; this is because high productivity performance is directly related to equipment efficiency and process control. (Azizi 2015). Production Equipment is becoming a primary focus of research due to its role as the backbone of industrial processes and a critical performance indicator of productivity (Tabikh 2014). According to Ahmad, Ali, and Hossen (2017), every manufacturing company's purpose is to produce goods profitably, which can only be accomplished with an effective maintenance strategy that maximizes equipment availability while avoiding unplanned machine downtime. Concentrating on this complex industry guarantees that machines are properly regulated and that resources are available when and where they are needed. Machine Availability, also known as uptime, is the percentage of time a machine is in operation (Christiansen, 2021). Over time, companies have realized that increased reliability and increasing machine uptime are nearly synonymous. In comparison, machine downtime is defined as the ratio of total production time lost due to non-operational equipment to total available time (Immerman, 2018). Additionally, it can be defined as an incident that costs a business not just financially, but also as an event that jeopardizes safety, undermines morale, and affects consumer reliability and satisfaction. In a study by Malardalen University in Sweden, the researchers conducted a web-based survey of Swedish companies with at least 200 employees. The main findings of the investigation show that the estimated downtime cost accounts for approximately 23.9 percent of the total manufacturing cost ratio and 13.3 percent of the planned production time. Furthermore, whether planned or unplanned, the hourly cost of downtime is relatively high. Several studies in literature show that small improvements in production will result in increased productivity, lesser unscheduled downtime, and a more robust supply chain. In other words, the higher the uptime, the higher the reliability of the machine. (Christiansen, 2021). According to one estimate from the International Society of Automation in 2019, factories lose between 5% and 20% of their productivity due to downtime. There are several potential issues that can impact a supply chain and cause delays, such as fluctuating raw material availability, customs hold-ups, adverse weather, staffing issues, political issues, procurement problems, changes in legislation, and so on. Mitigating and accounting delays through effective production planning is one way to safeguard the enterprise and avoid further repercussions along the way (Moss 2019).

In this study, the researchers chose to employ Overall Equipment Effectiveness (OEE) since OEE assists companies in identifying process bottlenecks and initiating continuous improvement projects. It can also track the impact of process changes and other improvement initiatives by measuring OEE improvement. Since measuring a company's OEE is only the first step towards an efficient production line, the researchers also employed a Linear Programming Formulation to maximize efficiency and cost-effectiveness. The goal of OEE is to locate losses. These losses can be classified into three categories: Availability, Performance rate, and output Quality rate. The maintenance function has an impact on all of the OEE constituting measures. Maintenance, for example, has a significant impact on availability. All planned shutdown and maintenance activities reduce equipment availability and, as a result, impact the company's OEE. By monitoring and optimizing manufacturing processes such as machines, cells, and production lines, OEE effectively quantifies downtime due to its simplicity (it condenses complex production data into minimally plausible metrics suitable for evaluating genuine manufacturing efficacy), functional, and robust characteristics (Kalsi and Tayal, 2020). OEE is utilized as both a benchmark and a baseline since it compares the performance of a specific production asset to industry standards and also allows for the tracking of progress toward eliminating waste from a given production asset over time. As for the Linear Programming part of the paper, The LP model is a structured set of mathematical relationships (e.g., equalities, logical conditions), representing an abstraction of the real problem under consideration (Abdul et al. 2017). It helps in determining an optimum assignment of interdependent activities, given the availability of resources. The LP model's objective function is a specification that outlines the contribution of each decision variable to the achievement of the objectives, whether it is an economical, ecological, or social goal. Constraints limit the options for decision variables, restricting the solutions to problems. This research study focuses on solving the given problem by calculating its OEE and then using a mathematical model such as linear programming to pinpoint precisely what process parameters could be further optimized, resulting in a maximized uptime for the company's labeling production.

3. Methods

The process begins by determining the variables that will be used to evaluate the machine's performance, specifically its availability, performance, and quality. Following that, pertinent data and information must be acquired from B-Mirk Enterprises in order to satisfy all necessary factors. The method is identical when forming an LP model, which requires the researchers to identify feasible restrictions as a necessary step prior to building the algorithm. By carrying out the essential procedures and assessing the performance of BMirk's labeling machines, the formulation of the LP algorithm may be carried out and evaluated, along with any other inconsistencies identified. Following that, the model developed to solve an optimal value can be applied to B-future Mirk's goals and its effectiveness in further improving their labeling production can be evaluated.

Throughout the study, the researchers utilized a research design of assessing the performance of B-Mirk Enterprises' labeling machines through the use of an Overall Equipment Effectiveness criteria that concludes the overall performance of machines and their downtimes. This assessment provides the avenue to conclude the need for an optimal machine downtime for B-Mirk's Labeling Department through the use of a mathematical algorithm such as Linear Programming. As the company is furthering its efforts in improving the new labeling production's machine efficiency, the researchers contributed through optimization as the best approach in addressing the current issues of machine downtime, delays, and manpower by maximizing the overall resources of production.

3.1 Overall Equipment Effectiveness (OEE)

An oral interview is to be conducted, which helps acquire information such as the number of SKUs of labeled bottles, the cycle time of each product, numbers of workers per shift, the frequency of maintenance practice, etc. This information will then be analyzed for machine performance and other analyses to conclude such factors that could affect the state of production. In fulfillment of measures for the Overall Equipment Effectiveness, the following equations were determined and solved. Loading time, Machine Availability, Performance Rate, Quality Rate, and Downtime of every shift of each SKU is solved which could be expressed in Equations ,

[1] **Loading Time** = Schedule Operating Time **–** Downtime
[2] **Machine Availability** = Actual Production Time / Planned Production Time
[3] **Performance Rate** = Current Production rate / Ideal Production Rate
[4] **Quality Rate** = Conforming Parts Produced / Total Parts Produced
[5] **Downtime (OEE based)** = Scheduled Operating Time **-** (Availability x Actual Production Time)

The operation of B-Mirk's Labeling production runs in two (2) 12-hr shifts per day with 1-hour machine maintenance for every first shift of the week, which reduces the total 12-hr shift to 11.5 hrs. The Overall Equipment Effectiveness scores are calculated and expressed with the use of the Equation (Table 1).

[6] **OEE** = Machine Availability **x** Performance Rate **x** Quality Rate

Table 1. Variables in solving Overall Equipment Effectiveness Equations

Variables	Definition
Scheduled Operating Time	12-hr shift (720 minutes), deducting 30-mins maintenance for 1st shift, thus 11.5-hr production run
Downtime	Total downtime occurred throughout 9 days B-Mirk's labeling production for May 2021.
Actual and Planned Production Time	Actual production refers to actual 720-min shift minus maintenance, break time, and total downtime occurred for each shift. Planned production is the 720-minute shift minus the break time of employees.
Cycle Time	Total duration (approximate) to fully label one bottle for all SKUs.
Current and Ideal Production Rate	Total output generated for each shift where Current refers to Actual

	Production number of labeled bottles per SKU and Ideal Production is the amount expected to be produced based on Planned Production Time over Cycle Time.
Conforming and Total Parts Produced	Conforming parts refers to the actual number of perfectly labeled bottles, and Total parts refers to the total production of labeling operations including rejected bottles.

3.2 Mathematical Model Formulation

The model for solving for the optimal machine downtime takes the form of an LP algorithm. Provided by the linear formulations below, the model's objective is to minimize machine downtime and maximize uptime by solving the best and optimum machine downtime for the labeling production of B-Mirk Enterprises. Data that the Company provided is composed of the following information: Date, Total Output, Total Reject, Total Workhours, Breaktime, Downtime, Machine Efficiency, Manpower Usage, and Remarks on Downtime. With this data, the researchers were able to classify and quantify the total downtimes of the Company per SKU. Also, average uptime was calculated using six shifts of the Labeling Production in the Company per SKU. The researchers only worked around the overall 18 (shifts) from the daily production report of the company which only ran for nine (9) days, allotted to six (6) shifts per SKU; thus constrained the study on working on a wider range of the labeling production which then brought more focus on the available reports provided by the company. In order to examine the effects of production processes on uptime per SKUs, a linear programming (LP) tool using the LINGO Optimization software (LINGO) and Excel solver were utilized. LINGO was used to model the problem to generate the optimum value and the decision variables. At the same time, Excel Solver was used to indicate the acceptable downtimes as expressed by the mathematical formulation. The analysis for the different downtimes of the Company is clustered into D1 - D5. The Company has five classifications of downtimes, and each process parameter does not have a fixed schedule. The downtimes are classified into:

[1] **D1 =** Downtimes due to Preparation and Set-up Time
[2] **D2** = Downtimes due to Machine Set-up from one SKU to another
[3] **D3** = Downtimes due to Changing Label Sticker
[4] **D4** = Downtimes due to Cleaning Area
[5] **D5** = Downties due to Adjustment (Crumpled, Sensor, Misalignment, Bubble)

The objective function aims to minimize downtimes observed by the company using the company's current uptime in the form of the three SKUs produced in the labeling department. These are:

X1 = total current uptime for 55ml bottle
X2 = total current uptime for 250ml bottle
X3 = total current uptime for 500ml bottle

The mathematical model used in this formulation is shown below:

$$\textbf{Maximize } \mathbf{Z} = 7.61\mathbf{X1} + 7.7\mathbf{X2} + 5.6\mathbf{X3}$$

Subject to:

$$\begin{array}{ll} D1 & 1.81X1 + 0.88X2 + 1.08X3 < 3.77 \\ D2 & 1.65X1 + 3.50X2 + 1.75X3 < 6.9 \\ D3 & 0.83X1 + 2.17X2 + 3.21X3 < 6.21 \\ D4 & 0.75X1 + 0.5X2 + 0.42X3 < 1.67 \\ D5 & 1.58X1 + X2 + 0.25X3 < 1.83 \\ & X1, X2, X3 >= 0 \end{array}$$

4. Data Collection

In order to fully perform the necessary procedures to evaluate the machine performance of B-Mirk Enterprises Corporation and to generate the proposed model Linear Programming algorithm successfully, the researchers requested the company to tabulate and gather the parameters and decision variables that are essential for evaluation and formulation. From the data gathered, the researchers then considered the overall production run of 12 hours per shift and the varied machine downtimes to set up the equations. The objective of the production problem presented in this section is to evaluate the current production state of B-Mirk's Labeling Department through its machine performance and to use the said evaluation as a basis for the need to formulate a robust algorithm in the form of Linear Programming that would maximize machine uptime and determine optimal machine downtime values for the company's labeling production. The approaches used in providing optimal values would be through Lingo and Excel Solver.

The first phase of the problem is solving the production's OEE scores, comprising the machine's Availability, Performance, and Quality that considers the varying labeling machine downtime per shift and SKU.

Afterward, the second phase is done through the use of the LINGO Optimizing Software. LINGO is mathematical programming software that is used to build optimization models efficiently and to support decision-making in areas such as production, distribution, marketing, and finance. A drawback in using a complex language such as LP is the generation of an optimal solution. However, LINGO helps cut off the development time and allows the researcher to formulate linear, nonlinear, and integer problems quickly and in a highly readable form. As a result, LINDO's solution will never deviate more than 2% from the true optimal solution. (*LINDO User's Manual*, 2003)
The next phase is performed through the use of Excel Solver. Excel solver is an add-on tool that solves optimal values in both maximization and minimization problems. The process performed in utilizing this tool allows the researcher to identify the optimal parameters for an optimized algorithm for more production improvements for the company.

5. Results and Discussion

The study was carried out within the B-Mirk Manufacturing company, mainly under the labeling department, producing three (3) SKUs of a specific brand having a volume of 55 mL, 250 mL, and 500 mL labeled bottles. The results were obtained from the May 2021 daily production report provided by B-Mirk for nine (9) days, running on two (2) shifts per day. The machine performance was assessed through the continuous production run of six (6) shifts and three (3) days for a single type of SKU. The regular adjustments and machine maintenance of the operations occur during the first shift of the week for an hour which automatically affects the overall 12 hours running time of the said shift. In order to determine the efficiency and performance of a single machine or a production like, the most efficient tool such as OEE is utilized, which uses availability, performance rate, and quality as the measures in determining equipment losses (Nakajima, 1988).

In order to examine the effects of production processes on uptime per SKUs, a linear programming (LP) tool using the LINGO Optimization software (LINGO) and Excel solver were utilized. LINGO was used to model the problem to generate the optimum value and the decision variables. At the same time, Excel Solver was used to indicate the acceptable downtimes as expressed by the mathematical formulation.

5.1 Numerical Results

Aligning the obtained values to this research's objectives, which are to maximize machine utilization and minimize downtime, these parameters can affect the performance of the labeling department of B-Mirk Corporation. Observing the values obtained for the Machine Availability, Performance Rate, and Quality Rate for a single SKU (55 mL), the fifth batch has produced the lowest values. Machine Availability can be maximized by minimizing the gap between the planned production time and the actual time that is used in the labeling department. As for the Production Rate, underlying factors could directly affect the current number of total outputs produced, such as a shortage in resources and workforce (Halturina et al., 2015). This will then result in a lower ratio between the Current Production Rate and the Ideal Production Rate that the company wants to achieve. As for the Quality Rate, regardless of the Production Rate obtained for the shift, it depends on the total number of outputs and the total number of rejects produced on that particular shift. Looking at the fourth shift, which produced a Performance Rate of 49.76%, it still produced the highest Quality Rate out of the six (6) shifts for 55 mL SKU with a value of 96.95%. Thus, Machine Availability can be maximized, and to maximize the Quality Rate, the production of rejects must be minimized (Tble 2, table 3, and table 4).

Calculations for Machine Availability, Production Rate, and Quality Rate used for the next two (2) SKUs are the same as those shown above.

Table 2. Computed Availability (%) with measures of Actual and Planned Production Time for all shifts of SKU 55mL

	Shift	Actual Production Time (minutes)	Planned Production Time (minutes)	Machine Availability
55 mL	1	408	615	66.34%
	2	605	675	89.63%
	3	600	675	88.89%
	4	635	675	94.07%
	5	115	675	17.04%
	6	570	675	84.44%

Table 3. Computed Performance Rate (%) with measures of Current and Ideal Production Rate for all shifts of SKU 55mL

	Shift	Current Production Rate (units)	Ideal Production Rate (units)	Performance Rate
55 mL	1	10,260	12,300	83.41%
	2	12,312	13,500	91.20%
	3	12,312	13,500	91.20%
	4	6,718	13,500	49.76%
	5	1,026	13,500	7.60%
	6	12,312	13,500	91.20%

Table 4. Computed Quality Rate (%) with measures of Conforming and Total Parts Produced for all shifts of SKU 55mL given the corresponding Number of Rejects per shift

	Shift	Conforming Parts Produced (units)	Total Parts Produced (units)	Quality Rate	Number of Rejects
55 mL	1	10,260	11,206	91.56%	946
	2	12,312	12,864	95.71%	552
	3	12,312	12,896	95.47%	584
	4	6,718	6,929	96.95%	211
	5	1,026	1,184	86.66%	158
	6	12,312	13,574	90.70%	1262

The OEE scores for SKU 55mL were computed using the Machine's Availability, Performance Rate, and Quality Rate as expressed in Equation [6] and shown in Table 5 of the paper. For SKU 55mL, the fifth shift had the lowest OEE score, which brings an alarming production issue that needs to be addressed by the company. The majority of the downtime factors affected the fifth shift's OEE score, which came from its Availability and Performance Rate.

Availability shows the comparison within the machine's actual production time and as well as the scheduled time it takes to label each unit (N. Ahmand et al., 2017). Given that Availability takes into account downtime loss (A. Talya et al., 2021) by multiplying Actual and Planned Production time, one of the aspects that resulted in the low Availability of the shift came from its low Actual Production Time of 115 minutes, indicating that the said shift had a significant amount of downtime of 700.41 minutes out of the production run of 720 minutes for the whole shift.

On the other hand, the performance also indicated a low value of Performance Rate, which is affected by having a low production output, due to high duration of downtime giving less time for production. Based on the B-Mirk's daily production report, the fifth shift for SKU 55mL had the least production and most significant duration of downtime; the majority of the delay originated from the bottle waiting to be labeled, change over setup for the 55mL SKU, and as well as the machine setup. The rest of the downtimes for the said shift also consisted of bottle preparation, various validations, adjustment delay due to crumple, bubble, and misalign of the bottle within the labeling machine.

SKU 250mL obtained low OEE scores, where the computations showed the first shift having the lowest OEE score of 67.20%, majorly affected by its Availability and Performance Rate. Same as explained through the OEE score resulted in the SKU 55mL, providing a low availability rate given a significant amount of downtime, which correlates with a low value of Performance Rate due to low production output.

Given a low computed OEE score for SKU 55mL and 250mL, the 500mL, on the other hand obtained a better and consistent performance in terms of its Quality Rate, as shown in Table 5. According to Feng (2017), if there is efficient stock production, it is due to higher demand and a shorter cycle time. SKU 500mL has a higher number of labeled goods and less number of rejects, which states an efficient production run, which therefore brings to an assumption that the labeling operations for SKU 500mL have a lower cycle time of 1.5 seconds. The first and fifth shift had the lowest OEE scores of 14.84% and 25.24% respectively. These values were affected by the low Performance Rates and as well as a high duration of downtimes. Given the average OEE rate for manufacturing plants of 60% (A.K. Gupta, 2012), shifts 2, 3, and 4 fairly had a value within the 60% average value. All shifts for the SKU 500mL achieved a high value of Quality Rate while the Availability and Performance varied in low performance which was also due to the high duration of downtime.

The OEE scores obtained and the corresponding values from its measures should be fully maximized in order to execute improvements on the labeling machine's performance fully. It is a cutting-edge approach to maintenance that aims to improve equipment efficiency, reduce breakdowns, and improve fully independent maintenance performed throughout production (N. Ahmand et al., 2017). Gupta and Gargio, in 2012, mentioned that measurement is a crucial component of any continuous improvement strategy. Having the objective of reducing B-Mirk's labeling machine downtime, OEE paved the way for measuring the current performance of the machine and further assessing what level of performance it is currently on. Through the OEE scores solved, the company would have an idea of what level of performance their production is currently at; it may allow the organization to impose different aspects of improvements in handling their maintenance schedule, unscheduled adjustments, labeling process, or in terms of machine scheduling (Table 5).

Table 5. Computed OEE (%) scores for all SKUs at varied shifts

	Shift No.	Shift (h)	Availability	Downtime (min)	Performance	Quality Rate	OEE (%)
55 mL	1	12	66.34%	389.33	83.41%	91.56%	51%
	2	24	89.63%	177.74	91.20%	95.71%	78.23%
	3	36	88.89%	186.67	91.20%	95.47%	77.40%
	4	48	94.07%	122.63	49.76%	96.95%	45.39%
	5	60	17.04%	700.41	7.60%	86.66%	1.12%

	6	72	84.44%	238.67	91.20%	90.70%	69.85%
250 mL	Shift No.	Shift (h)	Availability	Downtime (min)	Performance	Quality Rate	OEE (%)
	1	84	41.48%	603.85	20.03%	86.67%	7.20%
	2	96	82.96%	255.41	35.44%	99.52%	29.26%
	3	108	52.30%	535.39	32.36%	85.13%	14.40%
	4	120	86.67%	213.00	52.39%	94.47%	42.89%
	5	132	47.11%	570.19	40.06%	93.34%	17.62%
	6	144	85.19%	230.19	40.45%	96.60%	33.29%
500 mL	Shift No.	Shift (h)	Availability	Downtime (min)	Performance	Quality Rate	OEE (%)
	1	156	56.10%	466.46	26.54%	99.66%	14.84%
	2	168	82.96%	255.41	67.40%	99.54%	55.66%
	3	180	62.96%	452.41	72.16%	99.90%	45.38%
	4	192	82.96%	255.41	81.60%	99.82%	67.58%
	5	204	65.93%	426.63	75.91%	99.34%	49.71%
	6	216	76.30%	327.07	33.83%	97.80%	25.24%

5.2 LINGO Results

According to the findings from the LINGO optimization software, by adjusting the downtimes to have a value lesser than the recorded downtime for the month of May, gave the values, X1= 0.2576, X2 = 0.4674 and X3 = 0.2623, these constitute that when downtimes are transformed by the company, uptime per SKU will increase. Also, the overall uptime of the labeling production was maximized by 7.0256 hours in 3 shifts or 2.3419 hours per shift. Machine Uptime is a metric that measures the efficiency and availability of a company's manufacturing machinery.

Table 6. Excel Solver Results

	X1	X2	X3	OFV (Z)		
Solution	0.259	0.466	0.263	7.03		
Obj. Coeff	7.6	7.7	5.6			
				Excel Solver		
D1	1.81	0.88	1.08	1.16	<=	1.26
D2	1.65	3.5	1.75	2.52	<=	2.52
D3	0.83	2.17	3.21	2.07	<=	2.07
D4	0.75	0.5	0.42	0.54	<=	0.56
D5	1.58	1	0.25	0.94	<=	0.94

From the results in the Excel Solver shown in Table 6 Downtime classification D1 and D4 could still be further optimized. It is important to note also that these activities were oftentimes repeated and weren't allotted a specific time frame to accomplish. These downtimes consist of Preparation or Setup time and Cleaning Area. The LP formulation claims that when the company makes necessary adjustments regarding downtimes D1 and D4, they could save as much as 2 hours per shift as shown from the optimal solution.

5.3 Proposed Improvements

Based on the results, in order to improve the current labeling production, what can be proposed is to fully assign schedules for each process parameter. Brief observation concluded that minuscule downtimes are due to preparation and set up, as well as cleaning area. Though constituting only small increments in downtime, when accumulated, it results in decreased overall uptime for the Company. Heavy equipment is a large investment in terms of value for the Company; therefore, this asset must be managed correctly and with proper management. Having only (1) labeling machine in the production which also came overseas, it is considered a struggle for the company to reach out to manufacturers in case of machine malfunctions. To avoid these, training for proper machine handling should be given to machine operators for chances of machine breakdown. Provided that the maintenance of a machine is critical in achieving organizational objectives, it is insufficient to only run a 30-minute machine maintenance once a week for a 12-hr shift, therefore it is to be proposed to invest in Preventive Maintenance (PM) to reduce machine downtime and the likelihood of failure after maintenance has been applied for a set period of time. Inadequate maintenance leads to higher levels of asset failure and penalty costs (Ilangkumaran, 2010). PM schedules include cleaning, adjustments, repairs, servicing, oil changes, parts replacement, etc. In the case of the Company, where the application of PM may be inadequate, the production rate may suffer, resulting in lost production. The researchers suggest that instead of a one (1) hour machine maintenance per week, the Company could employ it three (3) times per week for 30 minutes each period. This is to balance out the frequency of machine maintenance and guarantee that the machines are well maintained to ensure the availability and operational output of the equipment.

5.4 Validation

The validation was extracted from results of the study, specifically the results from the applied Linear Programming Model. The data record of the cost and revenue of the B-MIRK's labeling operations was acquired in order to have a basis for the adjustment and validation of the study. The given data consists of Manning, Machine Cost, Electricity Consumption and Rejection Cost (Table 7). A statistical analysis was not used for this validation; instead, the comparison and improvement of cost and benefit was analyzed to provide a validation for the study.

Table 7. Cost and Revenue Based on LP Results

		Based on LP Results		
Monthly Cost Using Labeling Machine	Original Data	55mL	250mL	500mL
I. Manning	₱90,923.27	₱90,923.27	₱90,923.27	₱90,923.27
II. Machine Cost (Monthly Depreciated)	₱33,333.33	₱33,333.33	₱33,333.33	₱33,333.33
III. Electricity Consumption	₱10,791.04	₱10,791.04	₱10,791.04	₱10,791.04
IV. Rejection Costs:	₱5,221.13	₱5,248.97	₱5,287.26	₱5,242.01
Total Cost (Monthly Based)	₱140,268.77	₱140,296.61	₱140,334.90	₱140,289.65
Outsource Piece Work				
Monthly Produce (Apple to Apple Capacity):	417,690.00	419,917.68	422,980.74	419,360.76
Unit Cost Per Piece:	0.50	₱0.50	₱0.50	₱0.50
Total Cost / Month:	₱208,845.00	₱209,958.84	₱211,490.37	₱209,680.38
Cost Reduction / Revenue / Month:	₱68,576.23	₱69,662.22	₱71,155.47	₱69,390.73
Cost Reduction / Revenue / Year:	₱822,914.76	₱835,946.68	₱853,865.58	₱832,688.70

Based on the table 8 given, the original revenue of the company is at ₱822,914.76 on a yearly basis and as the Linear Programming was applied from each respective SKU, the revenue evidently increased. In order to arrive at the revenue, the company based the operation with a labeling machine from their past operation which involves outsourcing work. The reason behind the increase in revenue is from the increased capacity which is presented on

Table 7. The Linear Programming is only significant to the rejection cost and the capacity yield. Manning, Machine Cost, and Electricity consumption remains as it is. The capacity increment from a minute has evidently improved the capacity yield in a day and since the labeling is a machine operation, an 85% efficiency is applied. The original data operation states that it only produced 417,690 monthly. As the Linear Programming is applied, the monthly yield of each SKU increased from 419,917.68 yields for the 55ml, 422,980.74 yields for the 250ml and 419,360.76 yields for 500ml.

Table 8. Capacity Based on LP Results

		Based on LP Results		
Capacity	Original Data	55mL	250mL	500mL
Capacity/Minute	15.00	15.08	15.19	15.06
Capacity/Hour	900.00	904.80	911.40	903.60
Capacity per Day	18,900.00	19,000.80	19,139.40	18,975.60
@85% Efficiency	16,065.00	16,150.68	16,268.49	16,129.26
Monthly Produced (26 days)	417,690.00	419,917.68	422,980.74	419,360.76

6. Conclusion

The study was conducted to further assess the production downtime of B-Mirk's labeling machine. The labeling production from a third-party logistics such as B-Mirk Corporation became the focus of this research through the motivation of a new production process emerging amidst the COVID-19 pandemic and the specific hurdles that needed to be addressed. These hurdles influenced the need to provide greater improvements in terms of productivity in overall labeling production. The production reports provided by the company were analyzed, and Overall equipment effectiveness (OEE) was utilized to perform an in depth assessment of the machine performance, which revealed that the downtime is a critical factor in the machine's availability and performance rate, which affects the production output. As seen in Table 5, the availability and performance rate was one of the causes which affected the overall OEE score of 1.12%, which indicates that having a considerable duration of downtime corresponds to a decrease in the actual production time. In manufacturing, actual production time is the overall duration that the machine is working, which therefore also affects the machine's performance, resulting in a decrease in the production output for the said shift. This decrease in the actual production time was also influenced by the 1-hour maintenance, given that a considerable amount of downtime occurred for the said shift. This study proved that it is possible to reduce downtime through evaluation of production time and output, and allows the focus of improvement on specified characterized downtime that had a major contribution to the decreased machine efficiency. The optimization model was also solved with the use of the software tools such as LINGO and Excel solver, which exhibited a maximized uptime for a single shift for each of the SKUs. From the optimized values obtained from the LP model, uptime was maximized by 7.0256 hours for the three consecutive shifts representing each SKU. This constitutes an uptime of 2.3419 for each shift. Results obtained from the excel solver indicate as well that classified downtime, D1, and D4 could still be further optimized through the company's focus on improving efforts in having a fixed time for Preparation, Set-up, and Cleaning Area, respectively.

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