Supply Chain Optimization with Two Echelons in a Small Medium Enterprise Printing Company

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***Abstract*—This paper shows an optimized supply chain of a Small-Medium Enterprise (SME) printing company. The methodology used was divided into two phases: phase I: identification of the current scenario and input analysis, and Phase II: implementation of the model with the application of Python, in which results were obtained from the optimization of the production plan, inventory plan, sales, plan and maintenance plan. With the validation of the software, a maximization was obtained with a profit of $598,113 per year. In addition to the modeling, it is possible to find the number of products to be produced in the following months of the year; that is to say, it is possible to foresee the number of inputs necessary to supply the company's demand.**

***Keywords*—optimization, supply chain, Python, process improvement**

I. Introduction

Currently, one of the main objectives of companies is not to be surpassed by their competition, so every day they seek to be better by delivering greater value to their customers by satisfying their needs (Sharma *et al.*, 2020) through efficient inventory management; this implies the proper management of the flow of inputs, raw materials, materials in process, finished products, etc. (Salas-Navarro *et al.*, 2019). Therefore, it is necessary to increase competitiveness through the optimization of processes, as this improves the use and allocation of resources throughout the supply chain to meet the program (Peña Felizzola, 2020). For all companies, including those in the graphics sector, it is important to achieve economic stability; therefore, they constantly improve their production process to meet the standards of quality, quantity, and response time of their products (Tordecilla *et al.*, 2021).

In addition, since it is known that the decisions made by organizations have an impact on the entire supply chain in small and medium-sized companies and that these are focused on techniques acquired with experience over the years and not always with some kind of methodology or forecast, in this research, the current situation of a printing company was analyzed, which did not have an optimized supply chain, because in several periods it did not have available inventory to meet its demand, which was variable and uneven. Thus, it can be said that the responsibility of the supply chain is to reduce uncertainty regarding demand, production times, and production capacity (Tordecilla *et al.*, 2021).

Good utilization of resources, information, and knowledge in the supply chain is a challenge for businesses (Manrique *et al.*, 2019). For this reason, several authors have considered that their optimization is of great importance; for example, Salas-Navarro *et al.*, (2017) express that effective management of supply chains in an organization proves to be a very effective mechanism to provide fast and reliable delivery of high-quality ducts and services. Likewise, by identifying the variables that influence the supply chain, it is possible to obtain solution proposals that guarantee its improvement through intervention in its processes and thus facilitate the achievement of its competitiveness (Sablón-Cossío *et al.*, 2021).

A supply chain is defined as a network of inputs, their transformation into finished products, and the distribution of the final product to the customers (Salas-Navarro *et al.*, 2018); that is, it is the relationship and dependence between its elements from their point of origin to their consumption. Also, considering that inventory management is defined as a set of cross-cutting, supply chain activities, connected to obtain efficient inventory management and control (Rau & Yupari, 2021), an adequate inventory plan must be carried out and correctly managed to prevent undesired consequences by reducing risks with production costs, and demand-supply variations

II. Literature Review

Different works use tools to optimize the supply chain according to the objective of each organization. Encarnación (2020) mentions the importance of optimization in supply chain processes as the key to a company's success. In addition, (Vinajera-Zamora *et al.*, 2020) advocate that properly managed supply chains provide competitive advantages and impact organizations by evaluating the performance of a company's production processes. Also, Van Foreest *et al.*, (2018) express that the supply chain is a system of organizations, people, resources, information, and activities that involve the transformation

Manuscript received May 12, 2023; revised July 21, 2023; accepted September 7, 2023.

of natural resources, raw materials, and components into a finished product that is delivered to the end customer. Likewise, according to Díaz *et al.* (2020) supply chains are a fragile link with breaking points due to their high variability in which methods can be developed to minimize their risk.

Singh and Verma (2018) establish inventory management as a continuous and planned process in the supply chain whose objective is to organize the goods and materials required by companies ensuring a balance between demand and supply. Dadouchi and Agard (2018) express that the field of supply chain study is consistent and that many of its tools are successful; however, these sometimes have difficulties that can be solved by executing an adequate demand forecast to maintain a convenient stock. Equally important, Gupta *et al.* (2022) show that applying modeling as an optimization tool makes it possible to analyze and estimate good inventory management by making waste invisible and not having a zero or excessive stock, but a balanced one. Darom *et al.* (2018) defend that to avoid an insufficient stock, the most relevant parameters should be evaluated in the face of possible supply events. Thus, Asan *et al.* (2016) argue that one of the difficulties in inventory management planning is uncertain demand; therefore, parameters are usually assumed considering environmental variables in uncertainty scenarios to forecast demand.

Martínez and Osorio (2018) mention that there is currently no systematization that keeps track of inventories; however, companies work with a periodic review system through software that can plan and optimize resources decreasing the loss in production times. Taboada-González *et al.* (2016) demonstrate that it is possible to optimize the supply system, of the supply chain, using software that manages to build projections and inventories suitable for companies. For example, Zapata-Ruiz and Oviedo-Lopera (2019) employed a simulation tool, to optimize productivity, in a computational replica of the current situation of the company and found bottlenecks by modeling the processes and thus managed to reallocate resources. In addition, Giraldo-García *et al.* (2019) developed a model by simulating the impact of production with supply chain planning processes considering that acceptable indicator levels must be reached. A model that integrates simulation, it aims to improve the efficiency and effectiveness of a company by prioritizing solutions based on defined criteria that allow for optimizing the operations (Pérez *et al.* 2019).

III. Methodology

The research was carried out in a Small-Medium Enterprise (SME) belonging to the manufacturing printing sector with fourteen direct employees. The production plan of the printing company followed an empirical method, without using any technological or demand-based projection system, which generated a lack of inventory for several periods. A Pareto Diagram (Fig. 1.) was made considering the demand for the products for the years 2020 and 2021 to know the main products of the company, which were referral guides, business forms, stickers, flyers, labels, sales slips, receipts, personal cards, invoices, and orders.

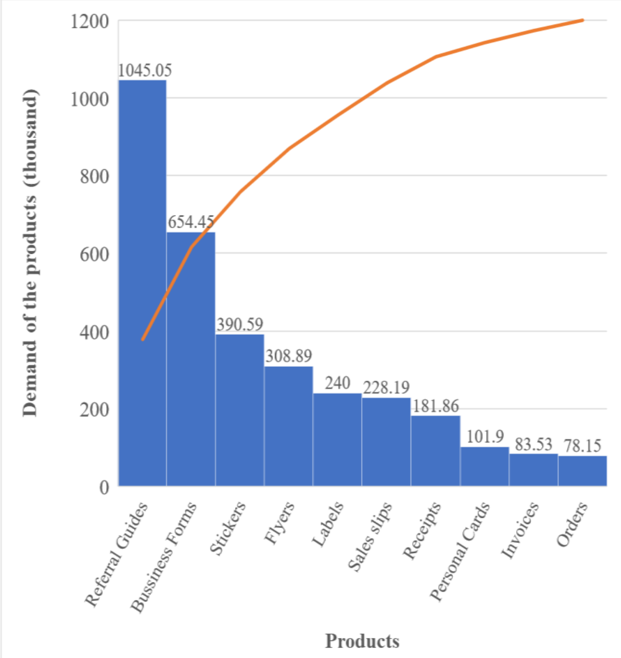

Figure 1. SME products Pareto diagram

Then, the industrial machines involved in the production process of the ten main products in Fig. 1. were identified.

- One CTP (Offset Plate Burner)
- One Heidelberg Sormz (large format offset printing press)
- One Heidelberg GTO (small format offset printing press)
- Two plasticizing machines (laminating machine)
- Two guillotines (Cutting machine)

A. Phase I: Diagnosis

The present research study was focused on creating an optimal production plan since this can increase the company's profitability (Campo *et al.*, 2020). An experimental methodology with the evaluation of scenarios was applied and developed in three phases to optimize the supply chain of a printing company. First, the company's current scenario was identified: the company's demand for the main products (Table II), the machines in the productive area of the factory (Table I), and the production time per product on each machine. Then in Table III, the indexes, meters, constraints, objective, and decision variables used in the modeling were established. Subsequently, a two-echelon supply model was carried out using Python software in which the results of the optimization of the production plan, sales plan, inventory plan, and machine maintenance plan in the company's supply chain were obtained. (Williams, 2020), the modeling code can be obtained at. https://bit.ly/3H8mPNC.

TABLE I. MACHINES REQUIRED

	Prod1	**Prod2**	**Prod3**	**Prod4**	**Prod5**	**Prod6**	**Prod7**	**Prod8**	**Prod9**	**Prod10**
Contribution margin	1.03	1.05	0.80	0.98	0.75	1.20	1.20	0.89	1.32	1.13
CTP	0.007	0.007	0.007	0.007	0.007	-	-	0.007	-	-
Heidelberg Sormz	-	0.003	-	0.006	0.007	-	-	-	-	-
Heidelberg GTO	0.008	0.02	0.005	-	0.005	0.005	0.008	0.005	0.008	0.008
Laminator	-	-	-	-	0.003	-	-	0.002	-	-
Guillotine	0.0003	0.007	-	0.005	0.003	0.003	0.0003	-	0.0003	0.0003

Prod1=Referral slips, Prod2=Business forms, Prod3=Stickers, Prod4=Flyers, Prod5=Labels, Prod6=Sales slips, Prod7=Receipts, Prod8=Personal cards, Prod9=Invoices, Prod10=Commands

TABLE II. DEMAND FOR PRODUCTS YEAR 2021.

	Prod1	**Prod2**	**Prod3**	**Prod4**	**Prod5**	**Prod6**	**Prod7**	**Prod8**	**Prod9**	**Prod10**
Jan-21	1,200	63,250	3,500	8,000	10,000	7,950	2,700	2,500		11,000
Feb-21	3,250	45,400	0	4,000	3,200	12,250	1,000	1,000	1,300	1,000
Mar-21	2,300	10,050	0	10,000	0	7,800	1,000	1,000	1,400	0
Apr-21	1,350	3,750	121,000	2,000	4,020	3,850		1,000		11,000
May-21	1,100	13,650	550	0	2,500	9,150	35,250	4,000	2,050	3,000
Jun-21	2,350	600		6,060	0	8,525	34,000	5,000	2,050	2,000
Jul-21	3,150	3,000	1,036	3,000	5,000	17,350	2,000	7,000	33,650	1,000
Aug-21	1,550	37,250	10,000	0	0	15,350	6,550	5,000		0
Set-21	1,050	61,500	0	0	2,000	3,350	21,500	7,000	850	5,000
Oct-21	600	18,150	0	0	7,800	6,850	8,500	1,000	3,350	0
Nov-21	1,200	29,300	1,000	16,000	1,000	2,550	21,150	3,000	550	1,050
Dec-21		20,000		1,100	0	1,200	0	2,350	5,230	3,000

Prod1=Referral slips, Prod2=Business forms, Prod3=Stickers, Prod4=Flyers, Prod5=Labels, Prod6=Sales slips, Prod7=Receipts, Prod8=Personal cards, Prod9=Invoices, Prod10=Commands

TABLE III. MODEL PARAMETERS

Indices, Parameters, and Decision Variables		**Definition**
Indexes	Months (t)	Number of months
	Products (p)	Number of products
	Machines (m)	Number of machines
Parameters	hours_per_month	Time (hours/month) available on any machine monthly.
	maximum_inventory	A maximum number of units of a single type of product that can be stored in inventory in a given month.
	maintenance_cost	Monthly cost (USD/unit/month) of holding one unit of any type of product in inventory.
	target_shop	Number of units of each type of product to be held in inventory at the end of the planning horizon.
	profit p	Profit (USD/Unit) of product p.
	installed	Number of machines of type m installed in the plant
	low_reqm	Several machines of type m to bear e scheduled for maintenance at some point in the planning horizon.
	time_reqm,p	Time (in hours/unit) required on machine m to manufacture one unit of product p.
	max_salest,p	Maximum number of product units p that can be sold per month t
Decision variables	market,p	Several units of product p to be manufactured in month t.
	story,p	Number of units of product p to be stored in month t
	salt,p	Number of units of product p to be sold in month t.
	repairs,m	Several machines of type m are scheduled for maintenance in month t.

B. Phase II: Model Implementation

First, following the example of Williams (2020), the demand of the year 2021 was considered to perform the modeling. Then, to create the model in Python, the necessary modules were imported, and all the input data with their variables were read from an Excel file; that is, for each of the 10 products in each month, variables were created for the number of products to be manufactured, stored, and sold in the printing plant. Also, for each month and each type of machine, there is an upper limit on the quantity of each product that can be sold.

Subsequently, for the balance restrictions shown in Table IV, the quantity of the product in storage in the previous month was considered, and the quantity manufactured was equal to the quantity sold for each product in the current month. Similarly, with the capacity restrictions, it was possible to limit the time required by the products in each machine (no more than their availability). On the other hand, for correct optimization, if the machines are out of service, their maintenance is carried out so as not to affect production. Finally, the results of the production, sales, inventory, and maintenance plans were obtained.

TABLE IV. MODEL PARAMETERS

	Objective function and constraints
Target function	Maximizes the total profit (soles) of the planning horizon. Maximize Z = $\sum_{t\in \text{Months}} \sum_{p\in \text{Products}} (profit_p * sell_{t,p} - holding\_cost * store t_p)$
Restrictions	Opening balance. For each product p, the number of units produced must be equal to the number of units sold plus the number in stock (in units of product). makeJan,p = sellJan,p + storeJan,p
	Balance. For each product p, the number of units produced in month t previously-stored must be equal to the number of units sold and stored in that month (in product units). storet-1,p + maket,p = sellt,p + storet,p
	Inventory target. the number of units of product p held in inventory at the end of the planning horizon must reach the target (in units of product). storeJun,p = store_target
	Machine capacity. total time used to manufacture any product on machine type m cannot exceed its monthly capacity (in hours). $\sum_{p\in Products} time_{m,p} * make_{t,p} \leq hours\_per\_month * (installed_m - repair_{t,m})$
	Maintenance. The number of m-type machines scheduled for maintenance must meet the requirement. $\sum_{p\in Months} repair_{t,m} = down\_req_m$

IV. RESULTS

The following tables present the results obtained. Table V shows the production plan, which determines the quantity of each product to be manufactured per month in each planning period; for example, product 9, is forecast to produce 32629 invoices for the month of July. It is observed that, concerning the other products, product 3 is the one with the highest production for the month of April. In this research study, we sought to optimize the supply chain of a printing company using Python. A maximization was obtained with a profit of $598,113 for the year 2022; in addition, in the results of the production plan, the number of products to be manufactured for the following months of the year was found; that is, it is possible to foresee the number of inputs needed to supply the demand. In the work done by Peña and Felizzola (2020) the methodology of the present research is based on phases in which the current scenario was identified, the indices, parameters, and decision variables were analyzed, and finally, the model was implemented. In both cases, process optimization and an increase in production capacity were obtained.

On the other hand, in the work of Zapata-Ruiz and Oviedo-Lopera (2019), the input data were collected randomly from five companies in the same industry, and a computational simulation. In this case, the research collected data from a single company to model through Python and optimize the supply chain. Both investigations used an experimental design to build a model with real data. On the other hand, Taboada-González *et al.* (2016) obtained company data such as daily sales information, inventory levels, etc. to make projections and estimates.

TABLE V. PRODUCTION PLAN

	Prod1	Prod2	Prod3	Prod4	Prod5	Prod6	Prod7	Prod8	Prod9	Prod10
Jan-22	1,200	6,953	3,500	8,000	10,000	7,950	2,700	2,500		11,000
Feb-22	5,550	9,088	0	4,000	3,200	17,250	2,000	2,000	2,700	1,000
Mar-22	0	0	0	10,883	0	0	0	0	0	0
Apr-22	1,350	0	51,390	1,117	0	3,850		1,000		11,000
May-22	0	0	0	0	0	9,150	35,250	0	2,050	4,981
Jun-22	2,350	0		6,060	0	8,525	34,000	5,000	3,071	
Jul-22	0	0	243	3,000	0	17,350	0	7,000	32,629	0
Aug-22	1,550	7,993	10,000	0	0	15,350	6,550	5,000		0
Set-22	1,050	4,753	0	0	2,000	3,350	21,500	7,000	850	5,000
Oct-22	600	10,308	0	0	7,800	6,850	8,500	1,000	3,350	0
Nov-22	1,200	7,733	1,000	16,000	1,000	2,550	21,150	3,000	550	1,050
Dec-22	1,200	12,153	1,750	2,100	1,000	2,200	1,000	3,350	6,230	4,000

Prod1=Referral slips, Prod2=Business forms, Prod3=Stickers, Prod4=Flyers, Prod5=Labels, Prod6=Sales slips, Prod7=Receipts, Prod8=Personal cards, Prod9=Invoices, Prod10=Commands

The following table, inventory plan, shows the amount of final product in the printing plant's warehouse for each planning month; as shown in Table VI, for the month of May an inventory of 1981 units of product 10 (orders) was left; however, for the last month of the period, there was a stock of 1000 units of each of the products for the following period.

Finally, according to the results of the maintenance plan in Table VII, it is recommended to carry out a maximum of one repair per year so as not to affect production.

TABLE VI. INVENTORY PLAN

	Prod1	Prod2	Prod3	Prod4	Prod5	Prod6	Prod7	Prod8	Prod9	Prod10
Jan-22	0	0	0	0	0	0	0	0	0	0
Feb-22	2,300	0	0	0	0	5,000	1,000	1,000	1,400	0
Mar-22	0	0	0	883	0	0	0	0	0	0
Apr-22	0	0	0	0	0	0	0	0	0	0
May-22	0	0	0	0	0	0	0	0	0	1,981
Jun-22	0	0	0	0	0	0	0	0	1,021	0
Jul-22	0	0	0	0	0	0	0	0	0	0
Aug-22	0	0	0	0	0	0	0	0	0	0
Set-22	0	0	0	0	0	0	0	0	0	0
Oct-22	0	0	0	0	0	0	0	0	0	0
Nov-22	0	0	0	0	0	0	0	0	0	0
Dec-22	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Prod1=Referral slips, Prod2=Business forms, Prod3=Stickers, Prod4=Flyers, Prod5=Labels, Prod6=Sales slips, Prod7=Receipts, Prod8=Personal cards, Prod9=Invoices, Prod10=Commands

TABLE VII. MAINTENANCE PLAN

	Maq1	Maq2	Maq3	Maq4	Maq5
Jan-22	0	0	0	1	1
Feb-22	0	0	0	0	0
Mar-22	0	0	1	0	0
Apr-22	0	0	0	0	0
May-22	1	1	0	0	0
Jun-22	0	0	0	0	0

Maq1=CTP, Maq2=Heidelberg Sormz, Maq3=Heidelberg GTO, Maq4=Plasticizer, Maq5=Cutting Machine

To identify their most important products, Taboada-González *et al.* (2016) used the ABC classification, while in this study they were classified using a Pareto diagram. Thus, both want to improve their inventory policy to meet their demand. Finally, it is considered that, despite having obtained an optimization in the supply chain, more years were not considered to expand and have greater precision in the input data.

V. CONCLUSIONS

With the two-echelon supply model through the Python program, it was possible to optimize the supply chain of the printing company, which previously did not have forecasts of demand, the quantity of product in stock, sales, and machine maintenance. Also, the indexes (months, products, and machines) that influenced the supply chain were identified through the data obtained from the company. In addition, the modeling was designed and validated in the program, with the indexes, demand, parameters, decision variables, and restrictions. Additionally, the results of the modeling can be implemented by the printing company in the current supply chain to optimize the economic benefit of the company and improve its profitability. It was also noted that the present study could have considered scenarios such as increasing the maximum limit of products in inventory or evaluating the number of inputs needed for the machines.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Betsy Cardenas conducted the research for the literature review. Shirley Gárate collected and prepare the information from the company. Both implemented the model, obtained the results, and wrote the paper. José Antonio Taquía helped with optimization programming, reviewed, and approved the final version.

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