Model to increase the use of production capacity using Lean tools in the paint subsector

Garcia Contreras Allison Lizeth, Industrial Engineering Student[1], Leon Janampa Ronaldinho Joel, Industrial Engineering Student[2], and Maradiegue Tuesta Fernando, Industrial Engineering Professor[1]

[1] Peruvian University of Applied Sciences, Perú, U201710440@upc.edu.pe, pcinjmar@upc.edu.pe

[2] Peruvian University of Applied Sciences, Perú, U201723881@upc.edu.pe

Abstract– Currently, the contribution to the PBI of the construction sector has increased, which generates a greater demand for its products. Also, the production of paints fails to meet the demand generated, so the problem to be addressed in this article is the use of production capacity in a manufacturer of industrial paints with an annual turnover of approximately 80 million soles, which currently uses an average of 53.29% of its installed capacity, below the 69.7% average of the sector, generating large losses of money for the company. The case study was carried out so that it can be replicated with other companies with a similar context and generate added value to the sector, therefore an improvement model is proposed by applying the tools and methodology of Aggregate Planning, Autonomous TPM and SRM through the integrated application of the above mentioned providing an efficient production planning, an improved maintenance plan and the approval of suppliers. Validation of the tools was performed with case studies that presented similar problems. The proposed model implements and integrates the main techniques, managing to increase mill availability to 93%, reduce reprocesses and the percentage of error in the demand forecast by up to 1% and eliminate the stock-out of raw material, thereby increasing the use of production capacity. Finally, an increase of 16% is obtained for the use of production capacity, with an NPV of $68,732 and IRR of 45.54%, which indicate that the project is profitable and optimal for the company.

Keywords-- Production capacity, Lean tools, paint subsector, service level, Availability of milling.

I. INTRODUCTION

Production capacity is defined as the amount of production generated in an industry within a period and is used as a reference among companies in the same sector to assess if they are not meeting expectations and if it operates below the average performance of the sector. A study by MITINCI (2020) in Peru indicates that, according to the evolution of the percentage of use of production capacity in the paints subsector, it has varied throughout the period 2012-2022 and currently industries use on average 69.8% of their capacity. [1] However, manufacturing companies of intermediate non-primary goods in Peru have presented a decrease of 35.22% until 2020. This is because in recent years the capacity to meet their demand has been decreasing and because 60% of these companies do not use more than 90% of their installed production capacity. According to the studies reviewed, [2] the reasons for this problem may vary depending on the item and the operations they carry out, and it is mainly due to various factors such as unproductive times, mismanagement of information for the planning of raw materials, production stops caused by frequent failures of machinery, among others; so, these companies are in decline in the attention of their demand.

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LEIRD2022.1.1.118
ISBN: 978-628-95207-3-6 ISSN: 2414-6390

After evidencing the problem, the importance of proposing various methods or proposals for solutions within the case study is presented. To this end, an investigation was carried out of several success stories in which various authors proposed that their problems under study, the use of production capacity within companies is directly related to production stops, poor management of relationships with their suppliers and poor planning of requirement of raw materials and inputs because they do not carry out adequate control of these factors that are seen reflected and impact companies in various indicators. For example, generating cost overruns to repair machinery, reduction in their levels of service or productivity, longer production time due to downtime, non-compliance with their demand, among others, so it is important to propose new solutions or strategies that allow companies to stand out among their competitors and the labor market. [3] A success story raised by the authors Baitaneh and Al-Hawari in 2020, developed through the integration of Total Autonomous Preventive Maintenance and the 5S methodology a maintenance plan that works together with control and cleaning cards to reduce the number of failures found that affect the quality of the product and generate reprocesses for not complying with quality standards, in addition to generating that capacity is not used efficiently; resulting in a 13% increase in the availability of machinery and a 44% increase in the efficiency of the production line. [4] Another success story that justifies our research project is the case of the authors Hasanati and Permatasari in 2019, in which case the problem focuses on the number of hours stopped on a production line due to the constant breakdowns of raw materials due to the errors of quantity requested in the replenishment orders or on the dates that the request is made. Therefore, they propose, mainly, the improvement based on an improved aggregate planning method through the use of a system that allows to keep track of the inventories of raw materials and inputs, and this way estimate the quantities to be requested for future requirements; obtaining an 80% reduction of the planning errors of raw material orders and also reduce by 41% the delivery times of these finally increasing up to 87.5% of the company's productivity. [5] Finally, another success story that is identified very similar to the current situation of our case study is that of the authors Forkmann and Henneberg in 2019, in which they propose the study and analysis of the performance of the suppliers of a production company that constantly presents breaks in the deliveries of their requested request orders in an anticipated period to avoid delays or stock breaks. However, 60% of its suppliers miss their delivery dates. As a result of the proposed solution of the authors, homologation, and analysis of the level of service obtained by their suppliers, it is obtained that under the new guidelines and strategies proposed the on-time deliveries of raw materials are increased by 31% and that an increase of up to 75% in performance and level of service is obtained. [6] Since various solutions to the problem have been carried out - since there are differences in the realities of each case study - through the application and implementation of techniques and methodologies to improve the use of production capacity from its root causes, such as the planning of material requirements or also called MRP to reduce the number of delays within the production process, increase productivity and increase the availability of your machinery.[7] Given what has been presented, it is proposed to implement an innovative solution model to increase the use of capacity. This increase in utilization has a direct impact on the company's unmet demand.

As authors of this research project, we are motivated to carry out a detailed study of the problem identified to mitigate the reasons and root causes that will allow us to propose a comprehensive solution to the case study by reviewing the literature from various sources, success stories and tools correctly supported for the development of our proposal. This article proposes an improvement plan to increase the use of paint production capacity through lean tools such as Aggregate Planning, Autonomous Maintenance and SRM in a manufacturing industry in Lurin that provides the case study with an integral solution of the causes found so that the solution has a greater scope ensuring the maintenance and development of a culture and continuous improvement. It is proposed to implement an innovative solution model to increase the use of capacity and reduce the number of stops caused by equipment failures so that companies can meet demand. [8]

This article consists of 5 parts. Firstly, the state of the art for the development of research is presented, secondly, the contribution of the research is described, thirdly, the proposal to be implemented and the steps to be followed to provide a comprehensive solution are explained, fourthly, the solution proposal is validated and finally the results and conclusions of this research are detailed.

II. STATE OF THE ART

A. Analysis of the problem

The use of production capacity turns out to be decisive in factors such as customer satisfaction, delivery compliance, market share and quantities sold. [9]

Due to this importance, some authors mention that the causes of low capacity are related to delays and inefficiencies within the production process, so it is recommended to analyze the bottleneck of the company and identify the root causes to later improve the process. [10] Likewise, according to Fernández (2020), some of the main causes that lead to a low production capacity are the poor connection of the information of the materials to conduct their planning and related causes in the production line such as machinery failures or the inadequate use of resources. [11]

Performing an analysis in our research, the articles in this category are directly related to support the relevance and impact of the problem, as well as attacking the reasons for the low use of production capacity such as: the reduction of defects in products and reprocesses during the production flow. For example, for the articles [12], [13] these factors were reduced by 82.94% and 66%, being percentages that allow to visualize and evidence an improvement in the face of the problem. Likewise, this is related to the articles[14], [15] that are focused on the support of the relevance and impact both economic and in the customer service that causes the problem in different case studies, uses two tools as an application of simulations, support tools such as the 5S, among others, which allowed to carry out the diagnosis in the companies and provide different types of solutions. Together, in the aforementioned areas, results were obtained mainly in the increase in productivity and efficiency, increase in the use of production capacity by 11.2% and 96.7% respectively, as well as favorable results in various factors that cause this impact on them.

B. Impact of TPM for improvement in production lines

First, we have the implementation of Total Productive Maintenance – TPM, where he observed in many studies this can be integrated with other methodologies such as the Material Requirements Planning or also known as MRP within the environments and production sectors. For example, the authors Wang . 2019, propose that by developing an integrated methodology it is possible to obtain a planning of 96.63% and increase the use of production capacity up to 90.45%. [16] Likewise, authors such as Ribeiro et al. 2019, indicate that it is necessary that prior to any implementation the processes within the company under study must be standardized, which will guarantee that after elaborating and carrying out the action plan with the TPM methodology it will end up reflecting great results such as mitigating the root cause, as in their study that obtained an 86% reduction in the number of machine failures and an increase in capacity. of production up to 97%. [17] However, it is important to mention that for such implementation to be successful, development policies must also be known, such as the delegation of maintenance tasks to operators, and their evaluation.

C. Increased use of production capacity through MRP

The Material Requirements Planning it is defined as a technique that allows to determine the quantity and time of purchase of articles of demand necessary to satisfy the needs of the Master Program of Production[18], which was also designed to support the manufacturing industries in the management of inventories with dependent orders and programs the replenishment of materials. Even some authors such as Kholil et al., 2019 mention that this tool provides us with reliable and accurate results for the correct replenishment of raw materials and inputs and maintains optimal safety stock levels so that it does not generate many maintenance costs or stock breaks that could lead to production stops.[19]

In the context that the low use of production capacity is due to downtime due to maintaining a low level of inventories, the author mentions that the planning of your requirements can be improved through an MRP, which accelerates the sourcing process to an operational level. Therefore, he designed a material control model that can respond to uncertain demands. [20] Other authors who present the same problem of poor planning given that they began their operations in the middle of the pandemic where the level of availability was low which generates a great uncertainty of what was planned with the amount to be produced, so they implement a design based on an MRP that provides them with an adequate supply prioritizing the materials that it really requires at the time of production. [21]

D. *Contribution and impact of SRM in improving production times*

Finally, we rely on the contribution of Supplier Relationship Management, which is a methodology that provides us with improvements in the mechanisms with suppliers. Its purpose is to improve communication with different suppliers in commercial and information terms so that they optimize the supply processes. Likewise, this methodology is used to control the purchases of raw materials, the acquisitions of goods, outsourcing of tasks and other activities. In addition, for an effective SRM system, strategies and procedures must be included during the procurement processes to commit the supplier to developing a policy of cooperation and integration. [22] On the other hand, there are also communication problems that delay the correct supply of materials, such as some authors who mention that after an inefficient relationship with your suppliers you can have very long lead times of materials that do not benefit your production, so they perform a supplier management (SRM), where their delivery capabilities are considered, operations with the company and the latest lead times of supply. [23] Likewise, another author mentions that in recent years companies are concerned with optimally managing their suppliers and by applying a methodology such as SRM, it is directly influencing to obtain greater performance and improves the behavior of their suppliers in the deliveries of materials. [24]

E. *Successful Cases*

Within the success stories reviewed in the state of the art, we have a compilation of the main articles that thanks to their results and contributions give us a greater viability for the development of research.

Among these we have the articles [17], [25] that use the TPM methodology supported with the 5S tool, so it shows the complementation of the strategies where an increase of 20% of the performance and 3% of the increase in the use of the production capacity respectively was obtained. As for the intermediate products manufacturing sector, the biggest problem related to the low use of capacity is due to problems in the production line such as machinery stops or excessive rework, so they propose to develop the TPM methodology, considering pillars such as autonomous maintenance, planned maintenance and training, so that the entire production process is duly documented with action plans for machinery failures. [26] In India it is assumed that adding equipment can increase the use of capacity, however, the authors Thorat & Mahesha, 2020, analyzed the usefulness of the application of TPM to increase the production of a manufacturing company, where 2 pillars of the TPM were developed, autonomous and scheduled maintenance, through documented activities and fault identification processes it was possible to control excessive stops by 6% and increased the productivity of the machine. [27] In addition, improvements in the reduction of reprocesses and times between maintenance (MTTR) can be evidenced. Likewise, the articles use the TPM methodology with the aim of reducing machine downtime and giving greater continuity to the production process. When comparing the articles, we obtain reductions of 6%, 5 hours on average and 12% of the stops that cause downtime [28], [29] and increased use of production capacity.

On the other hand, in the success stories for the main methodology of MRP, the support is evidenced in secondary tools that complement its application. The article results in a reduction in inventories that represents 45% of total assets[30]. Also, in a very similar way is the case of the articles[18], [31] that use the MRP with support tools such as the material boom where they manage to reduce costs by 40% and planning errors by 80% respectively. Additionally, No. 33 also achieves the increase in raw material received against consumption from 67% to 82%. On the other hand, it is also very important to highlight that in success stories such as articles [19], [32], [33] during the implementation of MRP, unlike the articles, they integrate this tool with the use of forecasts, simulations and statistical analysis tools that allow greater visibility to the requirements and costs related to the storage of these inputs that the case studies will have. allowing to obtain more exact results.

Finally, the success stories allow us to support the SRM, one of the main tools to attack the problem, given that its application manages to increase the use of production capacity by improving the performance of suppliers as is the case of articles where results are obtained of increase in 24% of capacity use[34], [35] and an improvement in the performance of the supplier in 75.5% respectively. Finally, the authors of these sources of information agree that a good organization is needed and carry out an adequate implementation plan to add value and improve in the case studies more efficiently.

After the presentation of the reviewed literature where the importance of the problem was analyzed with different case studies that describe a direct relationship between production capacity with machinery problems, supplier delay, errors in demand forecasting among other causes according to the case study analyzed. Authors use lean tools such as MRP, TMP, among other tools that are optimal for their case study. Based on the literature reviewed, we are at a higher technical and tactical level to optimally address by evaluating the root causes of the problem and relating it to the tools required to provide an innovative solution.

Within the limitation of the state of the art, other sources of research such as conferences and theses related to the subsector were not considered, due to the few previous studies in the research subsector specifically. In addition, information from scientific articles older than 3 years was not considered.

III. METHODS

A. Fundaments

As a result of the analysis of the problem we can show the importance of the use of capacity when the demand for orders is greater than what is produced generating a mismatch in the supply chain. The causes of the problem in question are due to a bottleneck due to paralyzed machinery, reprocessing, poor management with suppliers and poor material planning. For this reason, according to the revised literature, the authors claim that, after using valuable tools that manage to solve these root causes, they managed to increase their production capacities. Likewise, the limitations and suggestions of various authors who applied these management models are considered. Therefore, a model is proposed to increase the use of production capacity through 3 main tools that were linked to the identified root causes that will be shown in Fig. 1.

Three basic causes were identified, as shown in Figure 1 and as a proposed solution for each of them, the implementation of the following tools has been proposed: Autonomous Maintenance Application (TPM) that will directly impact machinery shutdowns and excessive rework; aggregate planning (MRP) that will increase the efficiency of production planning and replacement of materials; and finally, Supplier Relationship Management (SRM) whose objective is to improve the delivery times of suppliers' materials.

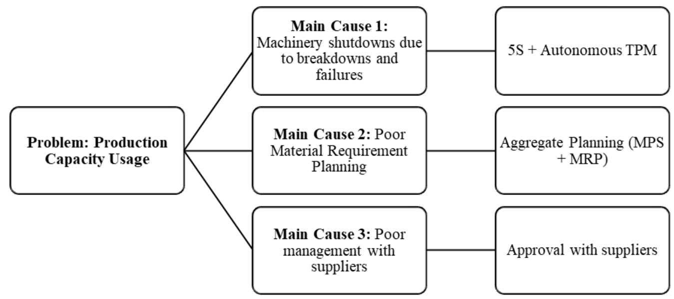


Fig. 1. Linking the problem with the causes and proposed solution tools. For the selection of tools to be used for the development of the research project, a comparison was made between the techniques and tools that meet the needs and objectives set, resulting in those previously exposed.

B. Proposed model

The proposed model consists of 3 phases that are diagnosis, tools execution (5S application and autonomous maintenance plan, demand analysis with MRP and MPS, and homologation of suppliers) and monitoring.

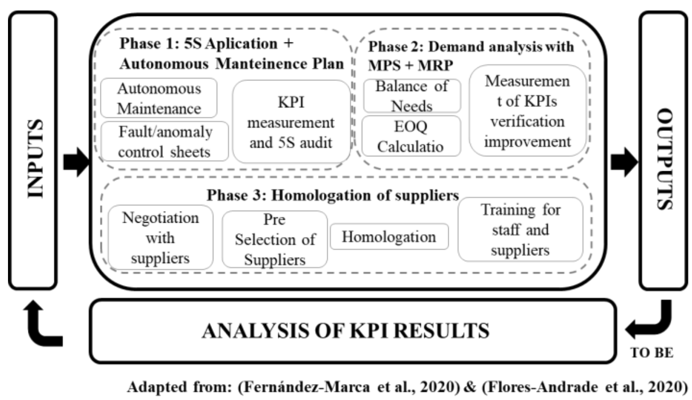


Fig. 2. Proposed Figure Model. *Adapted from Implementation Model, Fernández-Marca et al., 2020.* The design of the model presented is divided from the input of data to the output of these after going through the 3 phases developed. As well as the improvement of the indicators chosen for improvement, monitoring and measurement is shown.

C. Model Detail

The proposed model is made up of 3 phases in which resources such as lean tools, technological resources, the Arena Simulator, among others, will be necessary. First, the use of the linear regression method to develop the most accurate demand forecast for the company. Secondly, the analysis of the company's current OEE was developed, which will allow us to develop a much more effective maintenance plan. Finally, the analysis of incidents of suppliers focused on those who provide the company with the "A" classification materials used in the grinding process (bottleneck) which will allow us to give way to the conditions under which the company must really work with its suppliers.

Based on the scientific articles that use this model, either focused on a single tool mentioned or a hybrid of tools has been integrated to propose an improvement within the case study. It is considered that this model is the closest and focused on our problem because it uses demand forecasting in the same way. Inputs, outputs, general steps within the preparation, implementation and generalization are presented, so these details are adapted to our integration of tools in the final design. [6]

The three components of our proposed model are detailed below:

Component 1. Implementing the stand-alone TPM

In the development of component 1, concepts of Autonomous Maintenance and 5S are integrated, the latter being a support tool that gives us an improvement in working conditions and staff orientation. It begins with the training of the tools to employ the operators involved. An initial 5S audit is carried out to know the current situation, which indicates greater deficiencies in cleaning and standardization. We proceed to apply the classification and order the Grinding area. It is then cleaned with red and yellow card formats. Standardization and discipline is carried out with control formats in the area. Then, the OEE of the Grinding area is measured, which is 58%. The control of failures and anomalies is carried out through weekly formats and with it the development of periodic self-maintenance with standard cleaning formats to the Grinding machinery. Finally, a measurement of KPIs and final audits.

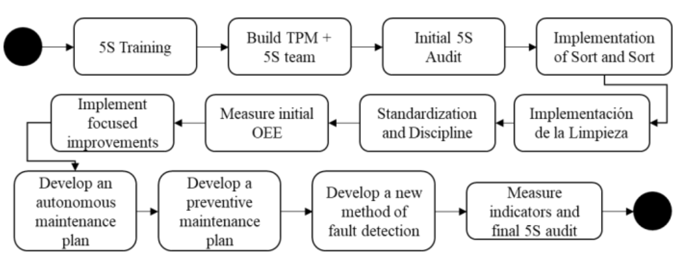


Fig. 3. Autonomous maintenance implementation flow. It was taken into consideration that based on the general model it will be implemented in 3 phases, however, in this part of the research it is developed in a specific way.

Component 2. Implementation Aggregated Planning using MPS and MRP

Component 2 is made up of the implementation of the MRP tool for material requirement planning. This in order that the company has a correct planning of material requirement, and an adequate planning of its production based on its demand in a certain period First of all, the use of MS Excel allows us to evaluate and forecast the demand within the company. After the forecast is made, the production planning will be calculated, as well as the requirement of materials based on demand, and the calculation of the economic order batch. For this, the analysis has been carried out based on the data and real conditions with which the company currently works. The templates represent each of the steps to follow for the implementation of the MRP tool and the following steps must be followed to provide an integrated planning plan to the company that will serve to analyze their requirements, thus reducing the % absence of raw material caused by poor planning.

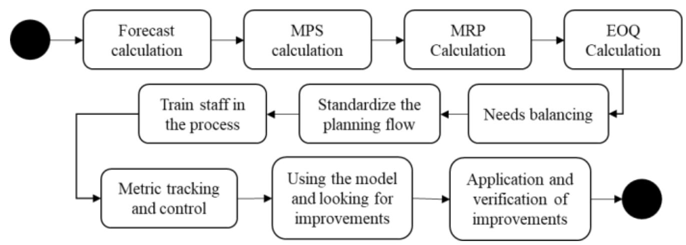
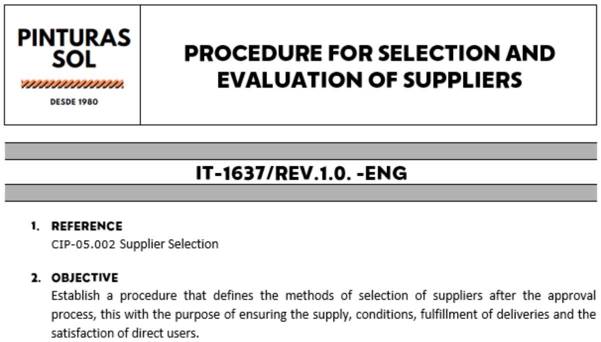


Fig. 4. MPS and MRP Implementation process flow. This figure presents the step by step to be developed to eliminate the deficient planning of requirements for your daily production.

Component 3. Implementation of Supplier Approval

In this implementation, the critical products are identified based on the ABC classification and the calculation of the lead time to work with the suppliers is carried out based on the current demand of the company. [36] Then, we move on to the negotiation stage between the company and the suppliers to achieve shorter delivery times. We proceed with all those who have accepted the terms and conditions. This stage is the pre-selection and therefore the homologation stage carried out by a third party. The objective of this implementation focuses on improving the relationship and compliance of suppliers with the company. Likewise, ensure the replacement of inputs and raw materials so as not to affect production or impact on the use of production capacity.


PINTURAS SOL
DESDE 1980

PROCEDURE FOR SELECTION AND EVALUATION OF SUPPLIERS

IT-1637/REV.1.0. -ENG

1. REFERENCE
CIP-05.002 Supplier Selection

2. OBJECTIVE
Establish a procedure that defines the methods of selection of suppliers after the approval process, this with the purpose of ensuring the supply, conditions, fulfillment of deliveries and the satisfaction of direct users.

Fig. 5. Procedure for homologation of suppliers proposed for the company Pinturas Sol S.A. The figure is the sections developed to carry out the homologation of suppliers such as guidelines, requirements, and others.

IV. VALIDATION

This section presents the validation of the project, where the viability and suitability of the operation and the economic impact will be evaluated with the aim of supporting and certifying that the proposal described will work and be feasible at an economic level for our Stakeholders. It is important to bear in mind that we have worked with a confidence level of 97.5% and a margin of error of 10% to be able to determine the results of the p_value in the Chi-square and Kolmogorov-Smirnov tests to have a valid sample to be used in the Arena software for the analysis of the simulation.

A. Functional Validation

For the functional analysis, a simulation of the production process of industrial paints has been developed within the case study. In addition, it is known that the company worked under the "make to order" of gallons to produce, considering that it presents various types of reprocesses caused by non-compliance with quality specifications, as well as machinery stops due to poor planning of the company, non-compliance of the supplier and stops due to failures or breakdowns in the mill machinery (identified bottleneck).

For the simulator, the total time of 6,336 hours corresponding to a working year in the company was configured. Therefore, it started running the system with a few 30 replications.

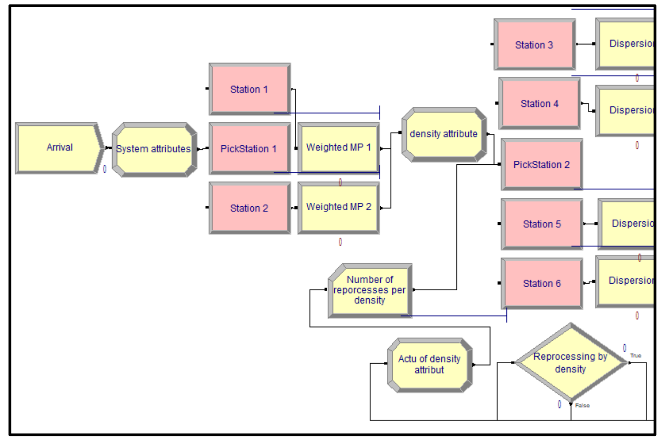


Fig. 6. Representation in the Arena simulator. The figure shows the simulation design in the Arena software with a working time of 365 days.

B. Model Evaluation – TO BE System

After applying the proposed Lean tools such as autonomous maintenance, 5S, MPS, MRP and supplier approval, it is expected to improve in the following aspects:

- Increase in the availability of machinery.
- Reduction in production downtime due to breakdowns or milling failures.
- Reduction of rework.
- Reduction in downtime due to poor raw material planning.
- Reduction of the stock-out of raw material due to non-compliance of the supplier.

TABLE I
COMPARISON OF RESULTS BETWEEN INITIAL VS THE THREE PROPOSED SCENARIOS

		Proposed Scenario		
Ratio	**As Is**	**Pessimistic**	**Conservative**	**Optimistic**
Annual production capacity	988,733.57	988,733.57	988,733.57	988,733.57
Total production	526,901	578,000	616,000	685,000
Use of production capacity	53.29%	58.46%	62.30%	69.28%

Based on the simulation carried out and the results on Table I previously exposed and, according to an optimistic result, the use of production capacity can be increased to 69.28%, so the functionality of the proposal can be validated since applying it increases the use of production capacity. Also, considering that at some point the company works under a pessimistic to conservative scenario, this would reach up to 62.30% above the goal of the use of production capacity at the company level, this being favorable for the case study.

C. Economic Evaluation of the Proposal

For economic validation, cash flows are made with sales forecasts of 5 years. To make this projection, the growth trend of the construction sector of 5.1% was considered according to figures from the INE (INEI, 2020). Therefore, based on whether this figure is projected to be an annual growth of 5%. The cost of the project is $ 61,600 and making a 5-year loan is presented in detail the balances of the loan that was built from a TEA of 12% and a TEM of 0.95%. Likewise, to justify the viability of the investment, the calculation of different financial indicators such as the Net Present Value (NPV) and the Internal Rate of Return (IRR) will be carried out in the three scenarios presented in the results of the simulator. To do this, a CPPC cut-off rate of 12% is considered as data for all three scenarios.

TABLE II
RESULTS OF ECONOMIC SENSITIVITY ANALYSIS FOR EACH SCENARIO

Scenario	VAN	IRR vs CPPC
Pessimistic	$10,514 > 0	18.33% > 12%
Conservative	$68,732 > 0	45.54% > 12%
Optimistic	$181,827 > 0	88.02% > 12%
Conclusion	***It's cost-effective***	***It's cost-effective***

From the Table II previously exposed, for the economic analysis of the project, the CPPC cut-off rate of 12%, net present value (NPV) and the internal rate of return were calculated where it can be evidenced that for the three scenarios the project is profitable at financial levels and the return of money that the company was losing due to the problem under study is achieved.

V. CONCLUSIONS

We have studied the processes of maintenance management, supplier management and material planning management to demonstrate that optimizing these variables can increase the use of production capacity in a paint manufacturing company. The evidence presented above shows that it has been possible to optimize machine downtime, the error in the demand forecast and the shortage of the main raw materials due to supplier default and reprocesses, generating an increase in the operating time of the bottleneck, i.e., the milling area, and thus reducing the costs associated with a production stoppage.

In this case study a simulation was used, in the Arena Simulation software, where the inputs were the variables already mentioned and the information outputs show the improvements in the management indicators and the main result indicator which is the use of the production capacity increases to 69% equaling the technical gap of the Peruvian sector.

In addition, the investment cost of the project is $ 61,600, and according to the cash flows calculated in the 3 scenarios, the NPV value is greater than zero and the IRR is greater than the cut-off rate, which shows that the project will not have financial losses and is economically viable.

To achieve the optimal use of production capacity, some general actions are suggested. The reasons for the low production must be identified, considering factors such as bottlenecks, supply, suppliers, quality, maintenance, among other variables, depending on the case study. The methodology used can be replicated in companies that present the causes, but it is advisable to review more sources of information that complement the reasons not mentioned in this case study. Finally, it is recommended that the company comply with an investment plan in critical processes that involve machinery with excessive downtime, with the aim of not completely wearing out its parts, since they cause a critical fall that impacts on their efficiency and, to be able to extend their useful life without incurring excessive costs of repairing the machinery.

REFERENCES

[1] MITINCI, “SUBSECTOR 2422: PINTURAS, BARNICES Y REVESTECIMIENTOS EN PERÚ 2020,” 2020.

[2] INEI, “Evaluación del Año 2020,” 2021.

[3] K. Flores-Andrade, R. Guardia-Miranda, P. Castro-Rangel, C. Raymundo-Ibañez, and M. Perez, “Production management model through MPS and line balancing to reduce the non-fulfillment of orders in lingerie clothing MSEs in Peru,” *IOP Conf Ser Mater Sci Eng*, vol. 796, no. 1, 2020, doi: 10.1088/1757-899X/796/1/012018.

[4] O. Bataineh, T. Al-Hawari, H. Alshraideh, and D. Dalalah, “A sequential TPM-based scheme for improving production effectiveness presented with a case study,” *J Qual Maint Eng*, vol. 25, no. 1, pp. 144–161, 2019, doi: 10.1108/JQME-07-2017-0045.

[5] N. Hasanati, E. Permatasari, N. Nurhasanah, and S. Hidayat, “Implementation of Material Requirement Planning (MRP) on Raw Material Order Planning System for Garment Industry,” *IOP Conf Ser Mater Sci Eng*, vol. 528, no. 1, pp. 0–8, 2019, doi: 10.1088/1757-899X/528/1/012064.

[6] S. Forkmann, S. C. Henneberg, P. Naudé, and M. Mitrega, “Supplier relationship management capability: a qualification and extension,” *Industrial Marketing Management*, vol. 57, pp. 185–200, 2019, doi: 10.1016/j.indmarman.2016.02.003.

[7] W. N. Cahyo, W. A. Khaeruzzaman, and F. W. Hasibuan, "Improving the performance of an assembly line to increase production capacity using value stream mapping: A study case," *IOP Conf Ser Mater Sci Eng*, vol. 598, no. 1, pp. 1–9, 2019, doi: 10.1088/1757-899X/598/1/012053.

[8] I. M. Ribeiro, R. Godina, C. Pimentel, F. J. G. Silva, and J. C. O. Matias, "Implementing TPM supported by 5S to improve the availability of an automotive production line," *Procedia Manuf*, vol. 38, no. 2019, pp. 1574–1581, 2019, doi: 10.1016/j.promfg.2020.01.128.

[9] A. Amrani and Y. Ducq, "Lean practices implementation in aerospace based on sector characteristics: methodology and case study," *Production Planning and Control*, vol. 31, no. 16, pp. 1313–1335, 2020, doi: 10.1080/09537287.2019.1706197.

[10] W. N. Cahyo, W. A. Khaeruzzaman, and F. W. Hasibuan, "Improving the performance of an assembly line to increase production capacity using value stream mapping: A study case," *IOP Conf Ser Mater Sci Eng*, vol. 598, no. 1, 2019, doi: 10.1088/1757-899X/598/1/012053.

[11] J. M. Fernandez Mozo, "Análisis del modo y efecto de fallas (AMEF)," *Universidad Privada del Norte*, Sep. 2019.

[12] A. Amrani and Y. Ducq, "Lean practices implementation in aerospace based on sector characteristics: methodology and case study," *Production Planning and Control*, vol. 31, no. 16, pp. 1313–1335, 2020, doi: 10.1080/09537287.2019.1706197.

[13] E. J. H. Lamprea, Z. M. C. Carreño, and P. M. T. M. Sánchez, "Impact of 5s on productivity, quality, organizational climate and industrial safety in caucho metal ltda," *Ingeniare*, vol. 23, no. 1, pp. 107–117, 2019, doi: 10.4067/s0718-33052015000100013.

[14] W. N. Cahyo, W. A. Khaeruzzaman, and F. W. Hasibuan, "Improving the performance of an assembly line to increase production capacity using value stream mapping: A study case," *IOP Conf Ser Mater Sci Eng*, vol. 598, no. 1, pp. 1–9, 2019, doi: 10.1088/1757-899X/598/1/012053.

[15] L. V. P. Ariza and H. A. F. Jimenez, "Optimizing production capacity in a food company using discrete event simulation," *Ingeniare*, vol. 28, no. 2, pp. 277–292, 2020, doi: 10.4067/S0718-33052020000200277.

[16] L. Wang, Z. Lu, and Y. Ren, "A rolling horizon approach for production planning and condition-based maintenance under uncertain demand," *Proc Inst Mech Eng O J Risk Reliab*, vol. 233, no. 6, pp. 1014–1028, Dec. 2019, doi: 10.1177/1748006X19853671.

[17] I. M. Ribeiro, R. Godina, C. Pimentel, F. J. G. Silva, and J. C. O. Matias, "Implementing TPM supported by 5S to improve the availability of an automotive production line," *Procedia Manuf*, vol. 38, no. 2019, pp. 1574–1581, 2019, doi: 10.1016/j.promfg.2020.01.128.

[18] N. Hasanati, E. Permatasari, N. Nurhasanah, and S. Hidayat, "Implementation of Material Requirement Planning (MRP) on Raw Material Order Planning System for Garment Industry," *IOP Conf Ser Mater Sci Eng*, vol. 528, no. 1, pp. 0–8, 2019, doi: 10.1088/1757-899X/528/1/012064.

[19] M. Kholil, Hendri, and S. Munajat, "Analysis of inventory control planning for P-200 chip (semi dull) using material requirement planning (MRP) method at Pt. Indonesia toray sinthetic," *Proceedings of the International Conference on Industrial Engineering and Operations Management*, vol. 2019, no. MAR, pp. 3131–3143, 2019.

[20] P. Utomo, P. Hartoyo, and N. I. Arvitrida, "Design and Implementation of Mrp-Jit Hybrid System," pp. 1–12, 2020.

[21] I. Alvarez-Placencia, D. Sánchez-Partida, P. Cano-Olivos, and J. L. Martínez-Flores, "Inventory management practices during COVID 19 pandemic to maintain liquidity increasing customer service level in an industrial products company in Mexico," *Advances in Science, Technology and Engineering Systems*, vol. 5, no. 6, pp. 613–626, 2020, doi: 10.25046/AJ050675.

[22] R. Wahyudi, V. Stephani Bangun, and I. Muda, "Implementation of supplier relationship management on MSMES in Indonesia," *Industrial and Manufacturing Engineering*, vol. 2, pp. 435–437, 2021, doi: 10.2307/41165933.

[23] A. Adesanya, B. Yang, F. W. Bin Iqdara, and Y. Yang, "Improving sustainability performance through supplier relationship management in the tobacco industry," *Supply Chain Management*, vol. 25, no. 4, pp. 413–426, Mar. 2020, doi: 10.1108/SCM-01-2018-0034.

[24] R. Wahyudi, V. Stephani Bangun, and I. Muda, "Implementation of supplier relationship management on MSMES in Indonesia," *Industrial and Manufacturing Engineering*, vol. 2, pp. 435–437, 2021, doi: 10.2307/41165933.

[25] E. J. H. Lamprea, Z. M. C. Carreño, and P. M. T. M. Sánchez, "Impact of 5s on productivity, quality, organizational climate and industrial safety in caucho metal ltda," *Ingeniare*, vol. 23, no. 1, pp. 107–117, 2019, doi: 10.4067/s0718-33052015000100013.

[26] G. Pinto, F. J. G. Silva, A. Baptista, N. O. Fernandes, R. Casais, and C. Carvalho, "TPM implementation and maintenance strategic plan - A case study," in *Procedia Manufacturing*, Jan. 2020, vol. 51, pp. 1423–1430. doi: 10.1016/j.promfg.2020.10.198.

[27] R. Thorat and G. T. Mahesha, "Improvement in productivity through TPM Implementation," *Mater*

Today Proc, vol. 24, pp. 1508–1517, 2020, doi: 10.1016/j.matpr.2020.04.470.

[28] R. Thorat and G. T. Mahesha, "Improvement in productivity through TPM Implementation," *Mater Today Proc*, vol. 24, pp. 1508–1517, 2020, doi: 10.1016/j.matpr.2020.04.470.

[29] L. Li, Y. Wang, and K. Y. Lin, "Preventive maintenance scheduling optimization based on opportunistic production-maintenance synchronization," *J Intell Manuf*, vol. 32, no. 2, pp. 545–558, 2021, doi: 10.1007/s10845-020-01588-9.

[30] P. Sundharesalingam, M. Mohanasundari, and P. Vidhyapriya, "Application of productivity enhancement tools in RIGS manufacturing industry: ABC and MRP," *International Journal of Scientific and Technology Research*, vol. 8, no. 12, pp. 1900–1905, Dec. 2019.

[31] R. Hencha and D. S. Verma, "Study of material requirement planning processes and its analysis and implementation a case study of automobile industry," *International Journal of Scientific and Technology Research*, vol. 8, no. 8, pp. 648–653, 2019.

[32] A. P. V. Acosta, C. Mascle, and P. Baptiste, "Applicability of Demand-Driven MRP in a complex manufacturing environment," *https://doi.org/10.1080/00207543.2019.1650978*, vol. 58, no. 14, pp. 4233–4245, Jul. 2019, doi: 10.1080/00207543.2019.1650978.

[33] J. Padron-Cano, J. R. Coronado-Hernández, W. Caicedo-Torres, N. Mercado-Caruso, and F. V. Ospino-Vadiris, "Materials requirements planning through an application based on particle swarm optimization," *Espacios*, vol. 38, no. 14, 2018, Accessed: Sep. 25, 2021. [Online]. Available: https://www.researchgate.net/publication/316005657_Materials_requirements_planning_through_an_application_based_on_particle_swarm_optimization

[34] S. Forkmann, S. C. Henneberg, P. Naudé, and M. Mitrega, "Supplier relationship management capability: a qualification and extension," *Industrial Marketing Management*, vol. 57, pp. 185–200, 2019, doi: 10.1016/j.indmarman.2016.02.003.

[35] M. Beatrice and P. Mulyungi, "Role of Supplier Relationship Management on Procurement Performance in Manufacturing Sector in Rwanda: A Case of Skol Breweries Rwanda Limited," *International Journal of Science and Research*, vol. 8, 2019, doi: 10.21275/ART20198266.

[36] K. Mahmood, M. Rehman, and C. Abdul Rehman, "Improving Supply Chain Performance through Supplier Relationship Management: A Moderating Model of Knowledge Management Practices in Automobile Sector of Pakistan," *Orient Research Journal of Social Sciences*, vol. 5, no. 2, 2020.