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Application of Operations Research in Steel Industry

[1]Ishika Sheth, [2]Garvit Chhabra, [3]Gaurav Agarwal, [4]Harsh Raka, [5]Iccha Saraf
Student, Anil Surendra School of Commerce, NMIMS Mumbai, India

Abstract:- In this paper, we have discussed the use of Operations Research in the steel industry and how they are used to tackle the production process problems, cost minimization problems, and transportation problems. Operations research has been used for decades to optimize business models and processes. The estimated demand for steel has risen by 7.2% in the year 2020 and experts see incessant growth for the Indian economy. Domestic manufacturers will intensively require to optimize their production process to keep up with the demand. Based on mathematical and statistical calculations, the paper aims to optimize the logical and systematic processes and approaches in one of the fastest-growing industries in India.

Keywords:- *Operations Research, Steel Industry, Simplex Method, Transportation by VAM, Optimizing, Queuing Theory, Just-in-Time Management.*

I. INTRODUCTION

Steel is one of the major foundations for the development of industries in the international economy. Industries like defense, transportation, energy, aeronautics, construction, etc. all have major requirements of steel. This industry has the potential to back the national economy of countries. China is the leading producer of steel (60%) in the world. Countries like Japan, the USA, and India have the next biggest share of the production.

Operations Research (OR) is the process of converting statistics, figures, and data into improved decision making. It comprises the application of various scientific and mathematical methods to solve challenging problems. OR has been used in several situations in the past. British scientists used OR to teach the militants about the newly developed radar to locate enemy aircraft. It was the start of the use of OR in military services in Britain and many other countries. After World War II, several British Operations Research workers moved to the National Coal Board, electricity and transport boards, and also to the Iron and Steel Research Associations.

OR in today's world is a bit different, more accurate, and very challenging. This is due to the developed techniques, type of data collection, new problems, and unique business situations. Operations Research has helped many businesses to solve different problems such as reduce costs, increase efficiency, etc. Costs like transportation, inventory storing and maintenance can be reduced by OR. Various OR techniques like Transportation Problems, Linear Programming, Interior Point Method, etc. help minimize these costs. It also aids better machinery setup and provides improved inventory management.

In this research paper the application of Operations Research in the Steel industry has been discussed in the following ways:

1. Transportation problems using VAM and the Simplex method have been used in optimizing the cost involved in transporting finished products to and fro from the processing plants.
2. Moreover, the problem of scheduling of the multiple trucks arriving at the warehouse has been tackled using the Queuing theory and Internet+.
3. Assignment problem helps in allocating the best route for transporting different steel products to different warehouses to obtain optimality in terms of cost and time involved.
4. The Just in Time theory of Inventory Management is used to schedule what quantity of raw material is required at what time. This helps in giving the business a competitive edge by reducing costs and uninterrupted production.
5. The structure of a factory has a great impact on its efficiency. The research paper includes an optimal floor plan layout to productively utilise all resources of space, machine, and manpower.

II. LITERATURE REVIEW

The steel industry faces numerous problems while optimizing their processes. This is mainly due to the size of their capital and the time required to process the metal. These are the fixed costs of the business that can be reduced sparsely. However, the variables costs involved can be manipulated and cut down more effectively. For example, the fee for the carriage of goods incoming and outgoing can be controlled and reduced. In this paper we have discussed some Operation research theories that can be implemented to curb these costs.

Das et al. take into consideration the fixed charge (like cost of renting a vehicle, landing fees in an airport, setup of machines in manufacturing environment etc.) capacitated in a nonlinear transportation problem with non-linear objective functions and linear constraints. Thereby establishing indigenous optimum conditions for the given problem and also establishing an algorithm for solving the transportation problem.

By this research, we can solve non-linear transport issues by taking price reductions, price breaks into consideration, which would help identify more accurate costs of transport and eventually lower them by the choosing of the optimum solution from the available alternatives. (Das, 2013)

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Furthermore, Jha et al., Operations Research Applications in Steel Industry use replacement theory for transportation and operations research optimization. The transportation model is advantageous to the steel plant to develop a strategic plan to reduce transportation costs. The replacement cost theory assists a steel company in replacing a truck that transports raw materials to improve efficiency. Because of the deteriorating property, failure or breakdown of certain equipment, the replacement theory is required. This would help in providing solutions in terms of cost reduction, selecting the most relevant solution for the given problems and finally executing it. He offers a contingent plan on how to best execute it in case the problem goes awry and the company has to find a substitute to help them commute their goods. (Jha, 2018)

Ascertaining the utmost significance of the utility of transportation problems across sectors, the above research papers used various methods to minimize the transportation costs, the applicability of which has substantial significance in steel industry. On a mathematically experimental basis, Rekha Joshi, a researcher, computed the Transportation Problem using North West Corner Method (NWCM), Least Cost Method (LCM), Vogel Approximation Method (VAM), and Modified Distribution (MODI) method for three variable problems to determine the most economical and optimal routes of transportation. Other papers employed VAM to compute the initial solution to minimize the transportation cost, following which, the MODI method was employed to calculate the improved optimal solution further scaled down the cost. Ablordeppey, illustrates transportation problems of the brewery using quantitative manager in the paper. (Ablordeppey, 2012) (Joshi, 2013)

In the paper by Askerbeyli, a case study based on a specific steel company in Turkey is used to minimize the cost of transportation of various steel products to different regions with the help of Operation Research techniques. These methods proved to be highly efficient across different industries while numerically concluding the MODI method as the best way to solve transportation problems, pertaining to its ease in computation of the optimal solution in lesser time. (Askerbeyli, 2020)

Zhang et al. in his research paper highlights the ineffective scheduling of the inbound and outbound operations of steel plates in shipyards. He points out the high costs involved due to inefficiency and formulates a method to find proper storage locations during the in-steel stage thereby reducing costs during the steel-out process. The ‘Greedy Algorithm’ is a simple algorithm based on the concept of intuition used for optimizing problems. As it tries to find the overall best solution to the problem, the algorithm takes the best decision at each phase. Zhang et al has worked on the data of an actual shipyard to validate the effectiveness of the ‘Greedy Algorithm’ used. (Zhang, 2013)

Sharma et al., suggested that the transportation problem be solved with the help of dual simplex. and two-phase method. This method starts with an infeasible solution which is optimal and works towards feasibility. The author refers to the Albert David Company, which functions with 3 plants across India with 14 depots. In an integrated steel plant, the factory has many aspects and features. From loading and unloading from docks of steel coils to processing and slitting machines. In specialized and large-scale businesses, they have their in-house processors. They use tech-savvy machines such as a slitting machine, a decoiler, and a shearing machine. For optimal usage of the capital, the companies use planning and research. Sometimes it is easy to work up from an infeasible solution to a relevant one. (Sharma, 2012)

Another method used is the Big M method. The process is known as the "common sense approach" too. It aims to make the artificial variables in the main objective function extremely unprofitable, this pseudo cost makes any real outcome far more feasible, as compared to the original impossible feasible solution. The inflating of values can be understood as charging a penalty, a penalty so exorbitant that it cannot be a part of the ultimate solution. If the objective function (Z) is to be minimized, then a very large positive price (penalty, M) is assigned to each artificial variable and if Z is to be minimized, then a very large negative price is to be assigned. The penalty will be designated by +M for minimization problem and by –M for a maximization problem and also M>0.

Dutta and Fourer, Mihailor, who focuses on 34 papers, provides an outline of how linear programming models in steel plants can be used. Gercuk focused on composition charges, optimal equipment loading, and equipment transportation in a non-mathematical overview of linear programming and some of its applications. The economical use of machines and materials is the maximisation of many. The economical use of machines and materials is the maximisation of many variables. An example of the said variables would be market prices, the grade of steel, and the processes it has to go through. While considering the scrap value of steel, the work of Fabian (1958), who designed a cost minimisation in the linear programming model and that model had four subparts. 1. Iron-making. 2. Steelmaking. 3. for shop loading for rolling operations. 4. Finishing operations.

The models of various stages of production are interconnected to form a "Master Model" of an integrated steel plant. (Fabian., 1958) (Goutam Dutta), (Fourer, 1997), (Gercuk, 1961).

Having referenced multiple research papers, we focus on elaborating on new and efficient ways a steel processing plant can optimize their operations and maximise its profit. We consider better ways of managing inventory, faster ways to transport their materials and coils, optimal use of machines such as slitting and decoiling machines and more. We have understood the above methods and will use operations research to enunciate further how to mathematically optimize a business.

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III. APPLICATION OF OPERATION RESEARCH IN STEEL INDUSTRY

Objective

The objective is to understand the use of few OR methods like Transportation Problems using VAM and Simplex Method to minimize transportation costs in the Iron and Steel Industry. A transportation problem is a form of linear programming problem in which the object is to reduce the cost of transporting a product from multiple sources to various destinations.

Transportation by VAM

The Vogel approximation method is an iterative procedure for calculating a basic feasible transportation solution. Because the initial basic viable solution provided by this method is either ideal or extremely close to the optimal solution, it is chosen above the NWCM and LCM.

Transportation problem by VAM can be used to minimize the transportation cost in the iron and steel industry. In paper, they used a problem-based in Turkey to minimize the transportation cost by using VAM. There were 6 products which were to be transported to 6 regions according to the demand of each region. The problem was solved using the demand and supply quantities of each product supplied to each region, and the transportation cost of each route. Using VAM the best routes were selected and the optimal solution was determined. The total transportation cost was minimized. (TC=3514619)

Table 1: Step 1, Verify if AD = AS

STEP 1:	VERIFY IF AD=AS	
AD:	24443+10958+9000+6000+4000+34108	88509
AS:	17440+29057+21904+6608+8000+5500	88509
AD = AS		

Table 2: Step 2, IBFS by VAM

STEP 2: IBFS BY VAM

THE TRANSPORTAION METHOD

PRODUCTS		KOCAELI	ISTANBUL	ANKARA	IZMIR	SAMSUM	KARABUK	SUPPLY AMOUNT
STEEL BILLET PRODUCTS - 1	UNITS	2539	0	0	901	0	14000	17440
	PRICE	51	65	43	85	70	17	
STEEL BILLET PRODUCTS - 2	UNITS	0	10958	9000	5099	4000	0	29057
	PRICE	51	65	43	85	70	17	
STEEL BILLET PRODUCTS -3	UNITS	21904	0	0	0	0	0	21904
	PRICE	51	65	43	85	70	17	
REBAR PRODUCTS - 1	UNITS	0	0	0	0	0	6608	6608
	PRICE	41	55	33	75	60	7	
REBAR PRODUCTS -2	UNITS	0	0	0	0	0	8000	8000
	PRICE	41	55	33	75	60	7	
REBAR PRODUCTS -3	UNITS	0	0	0	0	0	5500	5500
	PRICE	41	55	33	75	60	7	
DEMAND AMOUNT		24443	10958	9000	6000	4000	34108	**88509**

Step 3: Calculate Total Cost

Total Cost: $(51 \times 2539) + (85 \times 901) + (17 \times 14000) + (65 \times 10958) + (43 \times 9000) + (85 \times 5099) + (70 \times 4000) + (51 \times 21904) + (7 \times 6608) + (7 \times 8000) + (7 \times 5500) = \mathbf{3514619}$.

The Simplex Method

The Simplex Method is the first solution algorithm for linear programming problems that were created. It is a method for solving a set of linear equations quickly and efficiently. The simplex method moves from one extreme point to one of its neighbouring extreme points. The simplex algorithm is commonly used to determine the best combination of ingredients at the lowest cost (the goal).

Simplex Method is a means to find the optimal solution of an optimization problem in this case being the high transportation cost of finished products from the steel factory. In the paper, the programming language R has been used to facilitate the Simplex algorithm. R is a statistical computing, graphics programming language and a free Software environment. It is used to create statistical software and analyse data. Through that software, the number of units supplied to different locations using various routes has been established and the optimal solution has been found. The TC using the Simplex Method was TC=3514619. Using both the Transportation problem by VAM and the Simplex Method the TC was found to be the same, which was TC=3514619. (Askerbeyli, 2020)

It is suggested to minimize transportation cost in the steel industry using TP by VAM method over the SIMPLEX method. The VAM method is easy to use and the solution is close to the optimal solution. The SIMPLEX method has a technique that is very complicated, difficult to adopt, and has too many steps, therefore it is hard to learn and perform. VAM is systematic, takes less time, and gives the best possible cost of every route. Therefore, VAM is preferred over the SIMPLEX method.

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Queuing Theory

Several times, due to a lack of scheduling, multiple trucks arrive at the same warehouse at the same time, and one of them must wait. There are times when the time between two trucks arrivals is so long that the warehouse and loading equipment sit idle.

The goal of selecting optimal routes and timetables is to reduce truck operating costs while carrying all units of steel to the designated destination within the specified time period. To arrive at the best scheduling solution, all viable schedules for each warehouse and route are obtained, and the least costly schedules for each truck is picked.

This theory describes a system for predicting the optimal number of truck loading/unloading stations needed in a factory site to satisfy future traffic levels. The technique is based on the assumption that the number of loading/unloading stations may be expanded as long as the marginal cost of stations (building and maintenance) is less than the waiting truck delay charges. The number of waiting trucks and average truck delays was calculated using the "queuing hypothesis."

The queuing theory is used in conjunction with warehouse infrastructure and activities to calculate the optimal number of loading stations at a warehouse. The goal is to avoid over-and under-building by accident. The station movements should be evaluated first in this technique. The waiting time of trucks outside the loading station and in line is estimated using the queuing model in question. Cost estimate studies, including station and waiting truck costs, are conducted for economic reasons. Lastly, the optimum number of loading stations is decided to obtain the minimal cost.

The amount of time a truck must wait at the loading warehouse is determined by how many other trucks must use the same warehouse, how many trucks are prepared for loading, and how quickly a truck can load once it arrives at the factory. The length of time the truck is engaged with loading/unloading is determined by the truck's type and size, the warehouse's capabilities, and the type of ore to be loaded/unloaded.

Internet+

Internet + is used to integrate the use of Internet and traditional industries to improve production factors and modernise businesses using Internet information technology. As a result, this study proposes to employ "Internet +" technology to create a logistics information platform for the warehouses where the iron/steel is dispatched, where the container central warehouse dispatcher and trucks may exchange information. According to the volume and time requirements of container trucks, the status of loading and unloading equipment, to reserve the truck's arrival time, which not only guarantees the quantity of container demand for collection and distribution operations, but also effectively reduces truck waiting time in the factory, and realizes the maximum efficiency of seamlessness. On the basis of sharing the truck's anticipated arrival time, a logistical information platform is developed. (Qi, 2020)

Using Assignment Problem for optimizing transportation

Assignment Problem helps in optimizing the transportation of the Iron and Steel Industry by minimizing the cost and time involved. Here, A to F represents the warehouses involved in the transportation. There are 6 products involved in the problem. The numbers in the cell represent the cost of transportation.

This is the original cost matrix:

Table 3: Original cost matrix

	A	B	C	D	E	F
Product 1	**51**	**65**	**43**	**85**	**70**	**17**
Product 2	**51**	**65**	**43**	**85**	**70**	**17**
Product 3	**51**	**65**	**43**	**85**	**70**	**17**
Product 4	**41**	**55**	**43**	**75**	**60**	**7**
Product 5	**41**	**55**	**43**	**75**	**60**	**7**
Product 6	**41**	**55**	**43**	**75**	**60**	**7**

We subtract the row minimum from each row:

Table 4: Subtract row minima

	A	B	C	D	E	F	
Product 1	**34**	**48**	**26**	**68**	**53**	**0**	**(17)**
Product 2	**34**	**48**	**26**	**68**	**53**	**0**	**(17)**
Product 3	**34**	**48**	**26**	**68**	**53**	**0**	**(17)**
Product 4	**34**	**48**	**36**	**68**	**53**	**0**	**(7)**
Product 5	**34**	**48**	**36**	**68**	**53**	**0**	**(7)**
Product 6	**34**	**48**	**36**	**68**	**53**	**0**	**(7)**

We subtract the column minimum from each column:

Table 5: Subtract column minima

	A	B	C	D	E	F
Product 1	**0**	**0**	**0**	**0**	**0**	**0**
Product 2	**0**	**0**	**0**	**0**	**0**	**0**
Product 3	**0**	**0**	**0**	**0**	**0**	**0**
Product 4	**0**	**0**	**10**	**0**	**0**	**0**
Product 5	**0**	**0**	**10**	**0**	**0**	**0**
Product 6	**0**	**0**	**10**	**0**	**0**	**0**
	(34)	**(48)**	**(26)**	**(68)**	**(53)**	

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There are 6 lines required to cover all zeros:

Table 6: Cover all zeros with lines

	A	B	C	D	E	F	
Product 1	0	0	0	0	0	0	X
Product 2	0	0	0	0	0	0	X
Product 3	0	0	0	0	0	0	X
Product 4	0	0	10	0	0	0	X
Product 5	0	0	10	0	0	0	X
Product 6	0	0	10	0	0	0	X

Because there are 6 lines required, the zeros cover an optimal assignment:

Table 7: Optimal assignment

	A	B	C	D	E	F
Product 1	0	0	0	0	0	0
Product 2	0	0	0	0	0	0
Product 3	0	0	0	0	0	0
Product 4	0	0	10	0	0	0
Product 5	0	0	10	0	0	0
Product 6	0	0	10	0	0	0

This corresponds to the following optimal assignment in the original cost matrix:

Table 8: Optimal assignment in original cost matrix

	A	B	C	D	E	F
Product 1	51	65	43	85	70	17
Product 2	51	65	43	85	70	17
Product 3	51	65	43	85	70	17
Product 4	41	55	43	75	60	7
Product 5	41	55	43	75	60	7
Product 6	41	55	43	75	60	7

The optimal value equals 301.

Costs of Inventory Management

Inventory management is a crucial aspect of any business, inadequately managing inventory could lead to higher storage costs, higher carriage costs, and could also lead to lost opportunities that might come a business' way. The costs associated with keeping the inventory account for almost a quarter of the value of the inventory. Applying operations research techniques for inventory management would give a business a comparative edge over its contemporaries.

What Is Just-in-Time (JIT) in Inventory Management?

JIT, is a system that ensures that the business is working closely with its suppliers, so that raw materials are transported at the scheduled time, hence production remains unhindered. The goal is to have the minimum amount of inventory on hand to meet demand. The said method involves a detailed understanding of what to order, the quantity to order, and when to order. If one master this, they may be able to optimize the costs related to buying and storing without interrupting the flow of the business.

Different methods to handle Inventory Management

Having a system for counting the inventory is a prerequisite for ordering inventory promptly. The 'Periodic System', as the name suggests, is checking on the inventory at regular intervals. It might be daily, weekly, or monthly. However, this isn't very effective for JIT.

Another method would be the two-bin system, its simple method, there's two containers or two racks of raw material and as soon as the first bin is empty, the order is placed for the next.

Perpetual Inventory Method is a system that keeps track of removals of inventory continuously thus monitoring the current levels of each item, an example would be bank account balance, it shows accurate amount left in the account.

A business could also use the Universal Bar Code system, it keeps track of all the information of the steel, and whenever the inventory leaves the warehouse, it would automatically reduce and update the inventory.

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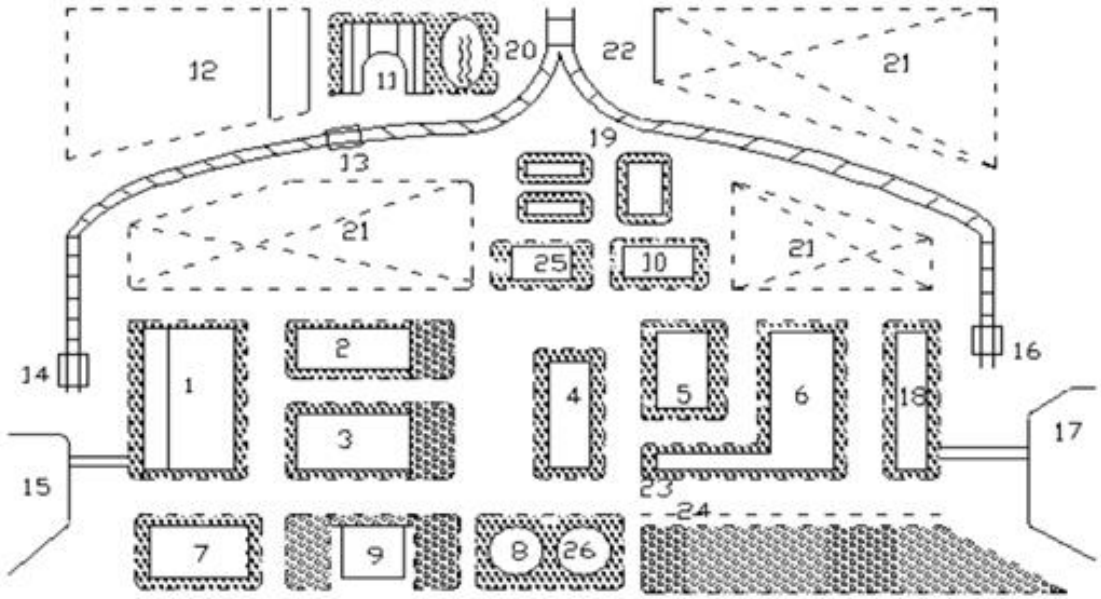
Figure 1: Optimizing the steel plant factory layout



1-Raw Materials; 2-Sintering; 3-Coking; 4-Iron; 5-Steel; 6-Rolling; 7-Thermal; 8-Oxygen; 9-Gas; 10-Transmission; 11-Total Area; 12-Residential and Commercial Areas; 13-Terminal; 14-Raw Material Station; 15-Entrance Port; 16-TransStation; 17-Export Terminal; 18-Finished Products; 19-Sports; 20-Artificial lake; 21-Development Reserve; 22-Railway; 23-Lawn; 24-Bush; 25-Residue Field; 26-Water Station.

The figure above has been taken from the research report of *Ermin Zhou, Kelou Chen, and Yanrong Zhang, titled 'Overall Layout Design Of Iron and Steel Plants Based on SLP Theory.* (Zhou, 2011)

It depicts the optimal Layout Design of Iron and Steel Plant to increase the overall efficiency of the plant by optimally utilizing available land and reducing wastage in terms of time and cost.

IV. LIMITATIONS

The study's conclusions must be seen in the light of the following limitations:

- Not having extensive information on primary data collection, it was very difficult to find access to real-world data but still, our finding is reliable and valid despite this limitation.
- The research would have been more accurate if ground research would have been conducted, but do to covid restrictions it couldn't be done.

V. RECOMMENDATIONS

With the world around us evolving at a fast pace there lies abundant techniques that could be used to improve the operations at an iron and steel plant. From this vast pool of opportunities Internet of Things and Blockchain technology certainly would have a vital impact on the operation processes.

The adoption of the Internet of Things in an Iron and Steel plant would exponentially reduce the costs and time required to complete a certain task, as with the help of this technology proper timings of arrival and departure of logistic vehicles could be ascertained, thus helping in assigning them appropriate loading dock, further leading to a decrease in the waiting time and speeding up the loading and unloading process. (Reis, 2021)

The Internet of things would be very well complemented by blockchain technology and smart contracts. As it would make the whole supply chain management much more efficient by recording all the transactions on the distributed ledger and executing smart contracts and making the whole operations process transparent. Which would lead to a reduction in human intervention further reducing the time required for such activities, thus making the operations process much faster. (Stefan, 2020)

Along with digitizing the sector, the steel industry tackles various problems that we are not able to understand due to the lack of understanding of the advanced machinery used to process the steel. Efficiency and systematic timing are required to ensure optimum usage of each machine, cutter, and slitter. Also, the planning for the assembly line is another problem that would require the help of operations research techniques. These are just a few areas where one could apply the knowledge of operations management and research. (Cao, 2020)

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VI. CONCLUSION

The paper helped us understand that Operations Research is universal. Every aspect of production in the Iron and Steel industry can be optimized using techniques of OR. Several methods like the Transportation problem using VAM, Simplex method and Assignment problem helped us in optimizing the transportation of finished goods from various warehouses. The Just in Time theory was useful in guiding the factory managers on the level of inventory required at all times thereby reducing their working capital requirements. Lastly, an optimal floor plan layout was derived to increase overall production efficiency. These mathematical and statistical methods pertaining to OR have improved our understanding of how a business canput it

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