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Study on Implementation and Usage of Operations Research in Chilean Forestry Industry

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Abstract: ***This paper's focus was to understand the usage of various OR techniques and its consequent impact on the Chilean forest industry production and efficiency. It explains the importance of Chilean forest industry to the world's supply of timber and timber products, the problems it has faced during the 2000s, such as inefficient transport system and lack of proper allocation of machinery and labor, the different OR techniques and models implemented to solve these as well as their impact by looking into the revenue growth of the country's forestry sector. We found that usage of OR techniques which have been explained in our findings, has contributed to an astounding double-digit growth rate of the industry. Alongside this, during the research, there was an observation made of other problems that persist in the Chilean forest industry ranging from law to biological sustainability, further helping in understanding the industry as well how effective OR models can be. The models used have been implemented for over a decade now, and hence a proper assessment and assertion of their impact could be done. Furthermore, since revenue growth has occurred once they had been implemented, it's logical to assume that they've had a correlation and have contributed to the same.***

Keywords: ASICAM, OPTICORT, PLANEX, Chile, Forest Industry

1. Introduction

Forestry Plantations Chile is one of the top 10 countries in the world in terms of land dedicated to forestry plantations and the fifth in the Americas, with 2.9 million hectares (Christian Salas, 2016) One of the reasons why most of it is dedicated to Forest industry is due to the environmental conditions and geographical topography enabling a high output of timber. The large areas of pine and eucalyptus plantations in Chile have rendered it a major exporter of paper and wood products to overseas markets. Most Chilean wood products today are being exported as lumber, logs, and chips. In 2000, the forestry sector of Chile generated exports of $1.89 billion. Annually, 6 billion kilograms of wood are processed in Chile as sawed timber, pulp, and paper. The major markets for Chilean wood exports are Japan, the United States, South Korea, Germany, and Belgium, among a few others. (Sen Nag, April 26, 2017)(The World Bank, 2019)

Like most Latin American businesses based on the export of raw materials, Chile's forestry industry has enjoyed an extraordinary boom for much of this decade. In just five years, the value of its wood and wood pulp exports more than doubled from US$ 2.5 billion in 2003 to a record US$ 5.6 billion in 2008. But the global financial crisis has taken its toll. Timber exports have dwindled and, in August, market prices for wood pulp were still around 25% down on a year earlier. As a result, export revenues from forestry products fell 28% in the first half of this year compared to the first six months of 2008. That was the biggest year-on-year decline in over a decade and the Chilean Wood Corporation (CORMA), which represents over 200 forestry companies, predicts that for the full year, export revenues be around US$ 4.3 billion, down by US$ 1.3 billion in 2008. (Amcham Chile, 2015)

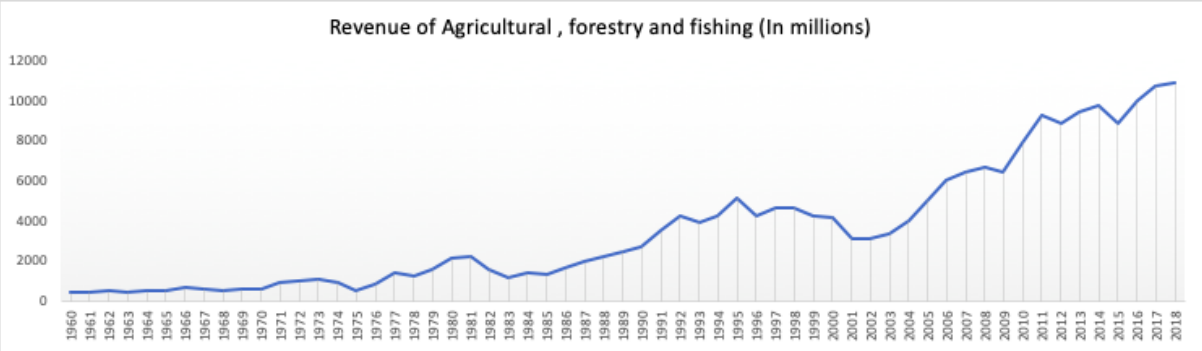
Operations research has a variety of uses, including: Scheduling and management, Urban and agricultural planning, Enterprise resource planning (ERP) and supply chain management (SCM), management, Network optimization and engineering, Packet routing optimization, Risk minimization. Etc. (Rouse, 2019)

2. Overview of the Industry

Chile has a strong forest sector based on plantations of exotic species and an extensive area of temperate rainforests with unique ecological features and a wealth of biodiversity. Although this is one of the most important economic activities of Chile, management between exotic species plantations and natural forests is asymmetric. Highly intensive silviculture is applied to plantations of Pine and Eucalyptus, but only limited silviculture is applied to natural forests. (Christian Salas, 2016)Political efforts should focus on developing sustainable forest management for plantations and natural forests with public funding for research in natural forests and private funding for forestry plantations. The declining enrolment in forestry schools is a result of an oversupply of professional foresters, which results in unemployment and low salaries. The main challenges to the Chilean forest sector can be summarized as follows:(a) Forest fires and other natural environment problems such as climate change (b) to promote the silvicultural management of natural forests; (c) to enhance the potential of natural forest for climate change adaptation and ecosystem services; (d) to develop a high-value wood market for native species; (e) to reduce the allowable size and maximum slope for clear-cutting; (f) to improve or create laws and regulations to address these challenges (g)The traditional transport systems used in the Chilean forest industry are inefficient and poorly organized there were no well-defined schedules. (h)proper planning of allocation of labor and machinery (Christian Salas, 2016).

Use of systems has led to annual savings of at least US $20 million a year. This amount is significant given the size of the firms. Due to the use of three OR systems, Bosques Arauco reports total savings of $8 million a year over a total annual timber production worth $140 million. The systems have also had an important impact on management organization, given a strategic competitive advantage and

have contributed to environmental protection. This work has been recognized in other countries: South Africa and Brazil have implemented some of these systems, and New Zealand has expressed interest in them.



(The World Bank, 2019)Forestry exports have risen continuously, resulting in a positive trade balance. Exports in 2008 totaled USD 5,454 Million, representing a growth of approximately 16% over the last 6 years. Over this period, the export market has diversified, with the wood produced in Chile now reaching up to 115 countries. The forestry sector is Chile's second largest exporting industry, behind large-scale mining. It generates direct and indirect employment for approximately 400 thousand people and represents approximately 7.3% of GDP. The industry's products are exported to more than 115 countries, with China and the US being Chile's main export markets, followed by Japan and Mexico. (The Chilean Forestry Sector and associated risks- (Fernando Raga Forest Development Manager of CMPC (Paper and Cardboard Manufacturing Company))

Before the implementation of OR, (pre-1998) the financial crisis of 1997 which lasted till 1999 and caused global slowdown, pushed the revenue down by a higher % than the crisis during 2008. Implementation of OR helped alleviated losses for the industry

Overall, We see that after the implementation of these or techniques from 1999, the revenue did drop on account of external factors however just a year after that we see that the revenue started growing exponentially till 2008, after which again it fell due to the financial crisis but picked up soon after, showing that the OR techniques over the years has enabled the production to keep rising and support expansion, increase in number of products available and transport effectively, alongside other variables, except during the times of low demand, during which too, it has helped curb losses.

The main factors affecting long-term global demand for wood products include:

1) Demographic changes: The world's population is projected to increase from 6.4 billion in 2005 to 7.5 billion in 2020 and 8.2 billion in 2030.
2) Continued economic growth: Global GDP increased from about US$16 trillion in 1970 to US$47 trillion in 2005 and is projected to grow to almost US$100 trillion by 2030
3) Regional shifts: Developed economies accounted for most of the GDP in the period 1970–2005. The rapid growth of developing economies will swing the balance significantly in the future.
4) Environmental policies and regulations: More forests will be excluded from wood production.
5) Energy policies: The use of biomass, including wood, is increasingly encouraged. (FAO, 2019)

3. Research Objectives

1) To understand and study the changes in management and operations research that this group brought along to the forestry firms functions daily.
2) To understand the old systems, how they operated and how they were inefficient in comparison to the newer ones put into place, we focused on outlining the implementation, operations and output of the new systems to arrive at a differential result. The systems studied were:
   a) Daily truck scheduling
   b) Location of harvesting machinery
   c) Short term harvesting
3) Since suboptimal performance in these 3 areas was extremely commonplace in the Chilean Forestry industry, we decided to direct our focus on these. The extent to which they were addressed and rectified will the analyzed and ascertained through the findings of this report.
4) In a nutshell, our objective undertaking this assignment was to study the existing systems, identify the variables that could use improvement and understand how these new systems helped with the improvement, the to outline reasons these changes were needed, along with the implementation of new systems and to elaborate and present the results and procedures in the form of a comprehensive report.

4. Research Methodology

Through our research, we have come across many published research papers and articles online that stated both general solutions as well as definitive ones to the problems faced by forestry firms in the Chilean rainforest. Our paper is based off our understanding and interpretations of the findings, procedures, implementations, results, advantages, limitations and comparatives stated in these papers and picking out methods that were best suited to present.

We utilized research papers that that gave us a good overview of the Chilean Forests, in terms of their positioning with respect to their competitors, the revenue they make and how big of a contributor it is to both the Chilean and global

economy and insight to the current problems that they are facing like the potential risks faced both by the firms and the forest due to current and probable economic instability, social issues faced due to local communities directly affected by these firms operations, and the extent to which these issues are detrimental (not only to the forests, but for the people that depend on said forests to support themselves)(Rosamel Milaman, 2016). These papers emphasized on the rich forest resources of Chile and the extent of which is owned and managed by large forestry firms, the current progress of silviculture and forestry research in the area. These also focused on the existing social and policy problems faced by the industry and how they can be amended. These were for our primary understanding and helped us ascertain which areas to specifically investigate keeping in mind the parameters in place and where to dig deeper to get a clearer picture of what we're up against.

Once we came to a consensus, we started looking into solutions that are both practical and efficient. For this we referred to papers that state general OR techniques, the processed and circumstances under which they are used in the forestry industry for optimization purposes and the constraints they operate under (the materials and methods they use and strategies they employ at different levels, the constraints they operate under, how environmentally friendly they are, etc.).

After attaining a general know- how on said OR techniques, we researched specific sources that work exceptionally well for the Chilean forestry industry and present a perfect solution to the current situation forestry firms operating there. We paraphrased our understanding of the working of these systems through the findings of this report.

5. Literature Review

Simulation:
Simulation modelling solves real-world problems safely and efficiently. It provides an important method of analysis which is easily verified, communicated, and understood.

Simulation enables experimentation on a valid digital representation of a system. Unlike physical modelling, simulation modelling is computer based and uses algorithms and equations. Simulation software provides a dynamic environment for the analysis of computer models while they are running, allowing to view them in 2D or 3D.

The uses of simulation in business are varied and it is often utilized when conducting experiments on a real system is impossible or impractical, often because of cost or time. Across industries and disciplines, simulation modelling provides valuable solutions by giving clear insights into complex systems.

The ability to analyze the model as it runs sets simulation modelling apart from other methods. By being able to inspect processes and interact with a simulation model in action, both understanding and trust are quickly built.
(The Anylogic Company, n.d.)

Linear Programming with Column Generation
Column generation or delayed column generation is an efficient algorithm for solving larger linear programs.

The idea is that many linear programs are too large to consider all the variables explicitly. The premise is that most of the variables will be non-basic and assume a value of zero in the optimal solution. Because of this, only a subset of variables needs to be considered in theory when solving the problem. Column generation leverages this idea to generate only the variables which have the potential to improve the objective function—that is, to find variables with negative reduced cost.

The problem is split into two: the master problem and the subproblem. The master problem is solved—from this solution, one can obtain dual prices for each of the constraints in the master problem. This information is then utilized in the objective function of the subproblem. The subproblem is solved. If the objective value of the subproblem is negative, a variable with negative reduced cost has been identified. This variable is then added to the master problem, and the master problem is re-solved, which generates a new set of dual values, and the process is repeated until no negative reduced cost variables are identified. The subproblem returns a solution with non-negative reduced cost, one can conclude that the solution to the master problem is optimal.
(Wikipedia, 2019)

Hueristic Methods:
Heuristics are a problem-solving method that uses shortcuts to produce good-enough solutions given a limited time frame or deadline. They are a flexibility technique for quick decisions, particularly when working with complex data. Decisions made using a heuristic approach may not necessarily be optimal, but they facilitate timely decisions. Analysts in every industry use rules of thumb such as intelligent guesswork, trial and error, process of elimination, past formulas and the analysis of historical data to solve a problem. These methods make decision making simpler and faster through short cuts and good-enough calculations.
(Chen, 2019)

GIS System:
Geographic Information Systems (GIS) can be used to display spatial data and to solve problems that involve spatial factors. GIS is particularly useful for relating, integrating, and analyzing information from these different layers of spatial information. Therefore, anything that can be placed on a map is a candidate for GIS, and so the variety of uses are quite extensive.

Common uses of GIS include inventory and management of resources, crime mapping, establishing and monitoring routes, managing networks, monitoring and managing vehicles, managing properties, locating and targeting customers, locating properties that match specific criteria and managing agricultural crop data, addressing public health concerns, mapping wildfire risk and preparedness, modelling hazmat risk, first response, and mapping, monitoring, or mitigating invasive species.

(Mapasyst, 2019)

Mixed Integer Linear Programming:
An integer programming problem is a mathematical optimization or feasibility program in which some or all the variables are restricted to be integers. If some decision variables are not discrete the problem is known as a mixed-integer programming problem.

Production planning-
Mixed integer programming has many applications in industrial production, including job-shop modelling. One important example happens in agricultural production planning involves determining production yield for several crops that can share resources (e.g. Land, labor, capital, seeds, fertilizer, etc.). A possible objective is to maximize the total production, without exceeding the available resources.

Scheduling-
These problems involve service and vehicle scheduling in transportation networks. For example, a problem may involve assigning buses or subways to individual routes so that a timetable can be met, and to equip them with drivers. (Integer Programming, 2019)

6. Findings

1. ASICAM: Simulation and Transportation
The traditional log-transport systems used were inefficient because they were poorly organized. Truck drivers had no well-defined schedules, leading to failures to meet demand, long waiting times, aggression among drivers, long workdays, suboptimal utilization of equipment, and poor coordination within house operations at the mills. All this led to the urgency to develop a more efficient system in log transportation in Chile.

The objective of this system is to satisfy demand while minimizing transportation costs within technical, policy, and labor constraints such as; (1) The origins from which to transport product to satisfy each demand, (2) What trucks and cranes are needed at origins and destinations to satisfy all demands, (3) The work schedule for trucks and cranes.

Forestry firms also considered a few of the following variables while making their scheduling system: (1) The characteristics of trucks, (2) The arrival time of trucks at destinations (which determines the number of cranes needed for deliveries of logs) (3) The income of truck drivers, (4) The starting and ending points of each truck's daily route.ASICAM is based on a centralized administrative system that schedules and controls all trips, and a **simulation model** for generating such decisions and an administrative body.

(Rafael Epstein Department of Industrial Engineering, University of Chile, Republi'ca 701—Santiago, Chile, Ramiro Morales Department of Industrial Engineering, University of Chile, Jorge Sero´n Bosques Arauco Los Horcones s/n, Concepcio´n, Chile, Andres We, 1999)

Simulation enables experimentation on digital representation of the system A software allows the analysis of computer models while they are running, allowing to view them in 2D or 3D.The uses of simulation modelling provide valuable solutions by giving clear insights into complex systems like this one. The ability to analyze the model and inspects processes as they run (The Anylogic Company, n.d.) is what works exceptionally well for ASICAM. As this requires the programmers to visualizer and predict optimal truck routes to minimize transportation costs that will be used in OPTICORT.

2. Opticort: Mixed Integer Linear Programing and Column Generation
Traditionally, an experienced planner did short-term harvest planning manually. However, matching timber with product demand turned out to be difficult, which led to losses as mismatches led to harvesting more timber than was really needed and to the degradation of the excess. It also led to less than optimal use of machinery which led to the development of OPTICORT

After implementing ASICAM, for three months, demands for timber products are estimated and for of harvesting decisions, forests are divided into homogeneous stands, similar mainly in tree age, site quality, and management state.

Transportation costs used in OPTICORT are based on different origin-destination pairs. OPTICORT is based on an **LP model** with a **column-generation procedure**. The main decisions the model covers are which stands to harvest among those with mature trees ready for harvesting that are accessible by existing roads, what type of machinery to use, what volume to cut each period, and what product should be delivered to different destinations.

(Rafael Epstein Department of Industrial Engineering, University of Chile, Republi'ca 701—Santiago, Chile, Ramiro Morales Department of Industrial Engineering, University of Chile, Jorge Sero´n Bosques Arauco Los Horcones s/n, Concepcio´n, Chile, Andres We, 1999)

Column generation or delayed column generation is an efficient algorithm for solving larger linear programs many linear programs are too large to consider all the variables. The problem is split into two: the master problem and the subproblem and a conclusive solution is arrived at through a series of complex steps that follow. (Wikipedia, 2019)

OPTICORT makes use of this to make short term harvest plans by considering several constraints, especially transportation costs developed by ASICAM's routes.

It also makes use of mixed integer LP; it is a mathematical optimization or feasibility program in which some or all the variables are restricted to be integers. And is used for harvesting plans and scheduling (Integer Programming, 2019)

Using OPTICORT they were able to make better use of timber to satisfy demand and reduce timber degradation. Along with savings in transportation costs, it has proven

useful in evaluating plans for each season and in estimating the likelihood of satisfying the demand for coming seasons. This is the first system developed that optimizes detailed short-term harvesting decisions.

3. PLANEX: GIS System and Heuristic Methods

Traditionally, planners allocated machines manually by analyzing topographical maps, which allowed evaluation of a limited range of options and was laborious. Not satisfied with the existing systems, academicians and forestry firms developed PLANEX. It deals with the optimal location of harvesting equipment and access roads. It allocates machinery and design the road network to reach that machinery. The main decisions in planning involve: (1) which areas to harvest by skidders and which by towers, (2) where to locate the landings for towers (3) what area should be harvested by each tower, (4) what roads to build, (5) what volume of timber to harvest and transport.

Chilean forests are mountainous areas and the design of harvesting systems is complex. It must take into account a variety of constraints like: (1) Locating the landings for towers according to topographical conditions, (2) Locating each tower to comply with its range of reach, depending on the type of tower, operating conditions, and the characteristics of the terrain (for example, ensuring that the reach of the cable for logging is not interrupted by a river), (3) Ensuring that topographical conditions permit skidder operations, (4) Building roads with appropriate characteristics, including acceptable slope and minimum radius of turn for trucks, (5) availability of equipment.

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Information provided by the **GIS** that each firm has developed, is incorporated by PLANEX. The system designs an optimal allocation of machinery with the objective to harvest the maximum profitable volume while minimizing costs, which comprise of installing and operating towers, operating skidders, road building, and transportation through **heuristic methods**.

Geographic Information Systems (GIS) can be used to display spatial data and to solve problems that involve spatial factors. Anything that can be placed on a map is a candidate for GIS, and so the variety of uses are quite extensive.
Common uses of GIS include inventory and management of resources, establishing and monitoring routes, managing networks, monitoring and managing vehicles, managing properties, locating and targeting customers, locating properties that match specific criteria and managing agricultural crop data (Mapasyst, 2019). All of this is used in PLANEX as it involves extensive mapping, planning and coordination between factors of production.

Heuristics are a problem-solving method that uses shortcuts to produce good-enough solutions given a limited time frame or deadline. They are a flexibility technique for quick decisions, particularly when working with complex data.(Chen, 2019)Since PLANEX is operated by a forest engineer. With its use, the planner can spend more time analyzing different scenarios instead of generating maps. The heuristic graphical interface allows the planner to analyze modifications to solutions in a simple and visual way.

7. Conclusion

The primary mathematical problems that affected the performance of the Chilean forest industry were that of transportation, proper allocation of machine and labor, and lack of optimal harvest planning, for which the three frameworks implemented have had a significant effect on the firms and have prompted saving funds in the organizations as well as drive growth in supply, allowing for a double digit growth. ASICAM, OPTICORT, and PLANEX, have been pioneering efforts in the forestry-management field and one of the reasons of why the Chilean forest industry has been able to grow and profit. OR techniques have helped the Chilean forest industry grow faster at times of expansion and alleviate losses when the demand goes down.

8. Limitations

1) Broad scope of the subject: As academics who have recently been introduced to the intricacies of operations research, we found it challenging to pick out a niche topic to focus our research on as there are a plethora of topics with great potential.
2) Little prior knowledge: It was an endearing task to take on with little prior knowledge of this subject. Being aware of how vastly complex it's practical uses are, and of the fact that we had little exposure to the technicalities that come into play, which was a drawback on our part. As a result, learning of the systems and variables that are a part of our paper was a task we had to undertake in order to increase our understanding of the subject and build up confidence in our work.
3) Difficulty finding data: Scouring the internet for published, credible sources of material, making sure the material was fitting and relevant, and finding facts and statistics to back up our claims was without a doubt one of the bigger setbacks we faced as it took a big chunk of the time allotted to us to complete the assignment.

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