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Application of Operations Research in the supply chain management of wineries

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ABSTRACT

Supply chain management is a procedure of further developing the business' supply chain, making them stronger, spryer, and therefore, more competitive. This paper is an endeavor to study the contributions of operations research to the operational, tactical, and strategic planning of wineries and to maximize the efficiency of the supply chain in the winery field. The central points looked at in this research paper are distinguished through the knowledge gauged from informational websites and published papers. The overall goal is to recommend some subjective and quantitative methods from the field of OR for the different issues identified. The issues examined are the major inconvenience of spraying with capacity limitations in viticulture, finding how to optimally schedule the work in wine grape harvesting, and maximizing the processing and storage of wine in the minimal time possible. It is important to consider all the possible underlying implications to the suggested method and solution before finalizing it.

Keywords— *Optimization; supply chain; wineries; operations research; grape harvesting; viticulture; crushing*

1. INTRODUCTION AND OVERVIEW

Today's times are marked by proliferation and cut-throat competition; the inclusivity of supply chain management has become more necessary than ever before as the standing of a company in the industry is heavily dependent on its supply chain. From a more enhanced perspective, the supply chain is the coalescence of all the activities that contribute to the acquiring of raw materials to the contriving of the final products as well as reverse logistics (Parkhi, 2015). Since the pursuits relating to the Supply Chain of any merchandise cannot be drawn out in a stand-alone manner, the plethora of operational activities that go into the entire process should be working together just like the tires of a car and at the same time also follow a system-wide plan of action which is determined through a global optimization approach (Priya, 1964).

In the past, varying frameworks have been formulated for the optimization of SC practices. The inception of lean SC can be seen as the first and foremost breakthrough where the contraction of cost, flexibility as well as the augmentation of the process was targeted through the minimization of different sorts of waste (Kwon, 2016). The tools of OR have been used time and again, the most used ones have been the optimization and simulation techniques. They have been used in multiple fields time and again in order to improve SC performance and efficiency. The inclusion of optimization has given the managers a one-of-a-kind platform during the process of decision making (Kwon, 2016).

Supply chain management (SCM) has been a popular field of research in operations research since a long time now. Over the years, many researchers have tried to work on and improve the design of the supply chain structure over time and optimize the model in order to minimize the cost. Supply chain optimization aims to make use of the available resources and technology in the best way possible. The supply chain consists of the purchasing of raw materials to the assembling & manufacturing of the parts to the final distribution of the products. SC just doesn't focus on the delivery part but also has a grave role to play when it comes to the flow of materials and knowledge within the organisation (Parkhi, 2015). An organisation with a superior SCM will time and again has a competitive advantage over those who don't.

Moreover, the simplified representation of the SC generated by simulation can capture details and the dynamic behaviors of the system. Simulation modelling can also assist users to perform a what-if analysis in the most effective way (Michalewicz, Michalewicz, & Spitty, 2007). However, both techniques have their own pros and cons. The design of the supply chain network (SCN) is a strategic decision, which has long-term effects and can be affected by a variety of decisions at the planning (like inventory and transportation policies) and operational (like pricing and service quality) levels. Due to the interdependency among different elements of a SCN, the overall optimality of the network might be unwarranted by individual optimization of the variables in each element.

During the last few years, most production-based businesses in general, and wineries in particular, have been under tremendous pressure to enhance their top-line growth and bottom-line savings. As a result, many businesses are turning to systems and technology that can help them improve short and long-term demand forecasts and optimize supply chain activities. In this paper we are going to discuss about different OR tools used in the different stages in a winery's supply chain, discuss about their limitations, and find out ways to make those tools more efficient.

2. LITERATURE REVIEW

There are many studies testing conventional mathematical models to optimize individual elements in the supply chain (Kwon, 2016). New, updated methods and models have been proposed in order to better suit organizations. The conglomerate of Operations Research and SC has seen a high usage in the wine industry all across the globe and a lot of companies have started paying heed to the new-age technology for optimality and better profits (Michalewicz, Michalewicz, & Spitty, 2007).

The wine industry is subject to an extensive procedure full of grunt work and labor-intensive activities. The inclusion of OR in the SC of the grapevine industry has smoothened the process to a large extent and we will be throwing light on how that has been done and executed through various process that are involved in the entire ecosystem of the wine industry.

The first step of the process is Viticulture which is the cultivation of grapes. Hernandez et al. (2009) provides a routing model to assist new viticulture methods with the main aim to minimize pesticide application (Moccia, 2013). Spraying units are typically used to treat the entire vineyard at once. Expert systems can recommend pesticide application time with a high spatial resolution, i.e., at the parcel level. As a result, minimizing pesticide spraying leads to a difficult routing problem for spraying units. A Multi-Trip Vehicle Routing Problem with Time Periods (MTVRPTW) was proposed, in which the customers are vineyard parcels to be serviced by spraying units in certain time windows with capacity limitations and a maximum number of simultaneous routes (Moccia, 2013). The objective function is to have the minimum routing costs of spraying units.

The next step is grape harvesting. Ferrer et al. (2008) show how to schedule wine grape harvest operations using a mixed-integer linear algorithm (Moccia, 2013). In the planning horizon, the decision maker should determine the quantity of the grapes to be harvested in vineyard blocks. A block has an expected optimal date for harvesting before or after which the quality is compromised. The main decision variables are to select the harvest mode, trace the quantity of grapes being harvested in blocks on each day of the planning horizon, and assign blocks to wineries. Constraints set limits on how much labor, harvesting equipment, and winemaking resources may be allocated. Traveling Salesman Problem (TSP) is used to model the costs of routing caused by moving equipment (Moccia, 2013). In order to route harvest machinery, a TSP is defined for each day and for each destination winery. The objective function combines two goals: lowering harvesting costs and increasing quality.

Grape harvesting is followed by the crushing of the grapes. The objective of using crushers is to process wine grapes and they are also often connected to different types of pressing machines. Computational intelligence techniques re-optimize and produces alternative schedules to fill available capacity as changes occur. The capacity of the pressing machines and fermentation containers is the most significant limiting element. It is important to develop optimum schedules for all crushers throughout time. The generated weekly schedule may be subject to frequent modifications due to contractual considerations, weather conditions, seasonal influences, and daily production variances (Michalewicz, Michalewicz, & Spitty, 2007). There are also a number of constraints in this part of the wine supply chain, including time constraints and fermentation container throughput; continuous truck throughput via the crusher, scheduled equipment repairs and maintenance, scheduled changeover and clean up, and special demand-fulfilling variety shortages to address meeting demand (Michalewicz, Michalewicz, & Spitty, 2007).

Next is the processing stage. Cakici et al. (2006) present, demonstrate and solve the Cellar Tank Piping Network Problem (Bohle & Maturana, 2007). There are huge wineries that contain large underground cellars that are used to age wines in wood barrels, as well as other steel tanks located below and above the ground. When the wine in a given barrel or tank is considered prepared for further blending or processing, it is transferred to another storage location or a bottling line via a piping network. A requested job or flow is determined by this. The Cellar Tank Piping Network Problem determines the path in the piping network from the origin to the destination of every flow, and the scheduling of the flows. Multiple flows are requested through a single day, since it is a higher priority bottling schedule it is a reactive decision and so the CTPNP should be solved quickly (Bohle & Maturana, 2007). For a single flow problem, the main objective is the minimization of the required connections like clips and hoses and the secondary objective is the minimization of the number of pipes required for pumping. For multiple flows, a sequence should be decided and this adds another term of the objective function which minimizes reconnections (Bohle & Maturana, 2007).

In the tank farms, wineries make daily decisions about the processing and storage of wines and juices, with big wineries having hundreds of tanks with varying capacities and characteristics. The Tank Farm Optimizer from SolveIT Software was created to replace the whiteboard method of planning and scheduling tank farm activities (Moccia, 2013). Given the tank farm's physical restrictions, the algorithm creates optimal tank farm designs for the whole vintage.

When creating a production schedule, the Tank Farm Optimizer uses advanced non-linear optimization algorithms (such as genetic algorithms) that take into account the following key objectives: minimization of pack-up and pack-down transfers; minimization of changeovers from red to white in transfer paths and tanks; minimization of transfer distance; minimization of the number of liters transferred; and minimization of the number of liters transferred (Bohle & Maturana, 2007). In the past obtaining practical solutions was a worrisome task but since the inclusion of OR in SCM activities and use of dynamic programming as well as complex system simulation technology has eased out the process to a certain extent.

The Advantages of using OR in SCM include:
The reduced costs and optimal use of resources. The transferal and transportation trellis in SC includes bridging the gap between the suppliers of resources, warehouse facilities, production plants and the most crucial part which is the end consumer (Priya, 1964). There have been numerous reports which show that the use of transportation problems to reduce the transportation cost by optimal rationalisation due to various parameters. Since a reduction in the transportation cost is seen evidently the reduction in greenhouse gases are also seen which makes this not just economical but also environment-friendly.

The curtailment of inventory through streamlining safety stocks. In areas with wide network, the placement of inventory in the immediate neighbourhood of the final demand isn’t an optimal solution economically, for taking call to actions with respect to fluctuations in the final demand and reducing the lead time in supplying to customers (Priya, 1964). Moreover, with globalization being the recent trend of all major companies in particular in manufacturing industries. The benefit from optimising the inventory location and quantity of service products based on the link between service level and inventory costs is substantial (Parkhi, 2015).

Weaknesses of using OR in SCM include:
The have been large-scale management issues. The chance to grow one’s business goes hand-in-hand with the issue of heavily increased supply chain complexity when it comes to management. It is essential for companies to scale up all aspects of their business as it grows. Inventor and distribution issues are two of the major problems encountered by going global (Priya, 1964). Furthermore, while globalisation is an advantage it can also pose as a disadvantage since you are not the only entity with access to supplies, products, and labour around the world – competition is not just concentrated to one location but scattered globally (Parkhi, 2015).

Our objective is to maximize the efficiency of the supply chain in the winery field. We aim to do this by minimizing pesticide application and determining the best method which should be used for spraying. Then, finding how to schedule the work in wine grape harvesting and how can the processing and storage of wine can be maximized in the minimal time possible. Moreover, minimizing the connections and pipes needed while processing.

3. METHODOLOGY

This research paper is written on the basis of secondary data derived from different sources such as,

- Online articles
- Informational websites on the wine process
- Research papers on the topic of supply chain management and wine processing

The methodology entails extensive research on how to optimize the steps of the winery process. It included understanding the factors involved in each step, for example in the grape harvesting phase, the different criteria to consider were matching the harvest date predicted by the oenologists to the market orders, the division of machinery and labor, and using manual labor or machinery in the picking, to name a few. Only after we thoroughly understood the process, we could find the limitations in the method and ways of improvement. This paper has been made with a view to justify the importance of operations research for today’s businesses due to the scale at which they operate and the necessity for them to reduce costs to survive in the highly competitive market.

4. FINDINGS AND ANALYSIS

The goal of operations research is to address decision-making issues and optimization is an integral part of that. Supply chain is inclusive of all the pursuits undertaken in order to ensure a hassle-free and timely delivery of all products as well as ministrations to the clientele. SC just doesn’t focus on the delivery part but also has a noteworthy role to play when it comes to the flow of materials and knowledge within the organisations.

In viticulture, there is a major inconvenience when we talk about spraying with capacity limitations since the amounts of pesticides sprayed varies depending on a variety of parameters such as grape variety, type of pest present in a particular geographical location, seasonal changes, and so on. Setting a precedent that the same quantity is necessary for each unit is inaccurate and is thus not the best assumption. On the other hand, instead of spraying the whole lot together in Multi-Trip Vehicle Routing Problem with Time Periods (MTVRPTW), the pesticide spraying can be done in units during certain time windows with capacity limitations. However, the amount of time taken for spraying will considerably increase (opportunity cost of lowering routing costs of spraying units) (Parkhi, 2015). Since there are many simultaneous routes generated, the route with the optimum mix should be selected.

Wine grape harvesting is a crucial part of the process and the fineness of the wine depends on this step. The grapes need to be harvested on the optimal date and all grapes take a different amount of time to ripen. The grapes do not perform equally, even under the same conditions, some turn out to be really good while some taste bad. It is important to understand the reasons for the difference in performances so that it can be dealt with in time and re-harvesting can be done as soon as possible to meet the yield requirements. The harvesting period mostly starts 30 to 70 days after the grapes are set (The Editors). You have to wait for the berries to change color from green to yellow for the white varieties or red-purple to get the red varieties (The Editors). An oenologist estimates this and determines the optimal time to harvest the grapes. It is important to schedule the harvest date estimated by the oenologists, with the weather forecasts, the division of the machinery and labor, and matching it with the orders. The key goal is to minimize the cost of harvesting and maximize the quality of the grapes and wine by optimally assigning the tasks to the different workers. This problem can be solved using the assignment problems method. The goal is to find the best way to distribute the tasks among the workers in order to maximize the efficiency. The first task is the weather prediction and for this part of the process one person, who is usually the oenologist, is sufficient. Then the seeds are sown and different plots can be managed by different individuals so that they can study and understand the plot well. People can be assigned based on the number of plots they can handle, this depends on experience, skill, and a lot of other factors. The plot then needs to be checked continuously and fertilizers and other pesticides need to be taken care of in order to maximize the quality. This can be done by the same person allotted to sow the grapes as they know that particular plot and the desirable ripeness well. The last step is to hand pick the grapes or mechanically harvest the grapes. It needs to be decided if it is better to do this manually or technologically and what is more efficient.

The third step is the crushing of grapes and it differs for different winemakers. The process might sound simple but is quite complicated in its true essence. In earlier times grapes were crushed by feet but in the modern times to ensure proper health hygiene almost everyone has switched to crusher-destemmed machines in order to crush and remove the stems from grapes. Modern day technology has made this part comparatively smoother as compared to earlier times and so there isn't any considerable issues faced during this part of the process (The Editors). However, the crushing technology has completely eliminated the need of human labor in this part of the process.

This step is followed by the processing of the wine. In their tank farms, wineries make daily decisions about the processing and storage of wines and juices, with big wineries having hundreds of tanks with varying capacities and characteristics (Apallas, 2016). These tanks may be insulated or refrigerated. After the grapes have been crushed, fermented, and pressed, some of these tanks may be used to store juice, while others may be used to store wine. On the tank farm, the process of planning and scheduling wine and juice transfers is far from simple, as wine juices that will be mixed later should be kept together in nearby tanks (Apallas, 2016). This results in lower operational costs and a more efficient blending process. Second, the tanks should be nearly filled to their maximum capacity. This would reduce the number of 'half-empty' tanks and increase the number of empty tanks accessible for incoming juice. Third, tank allocation should be flexible enough to permit last-minute adjustments owing to unforeseen circumstances (such as changes in volume, demand, quality).

Due to a lack of software tools to monitor and optimize tank farm activities until recently, most wineries have relied on a whiteboard approach, which gives no forward-looking vision and does not allow for cost-or quality-optimized decision-making (Bohle & Maturana, 2007). Planning and schedule optimization can result in significant reductions in spillage, labor and power usage, throughput, and tank utilization. Solve IT Software's Tank Farm Optimizer (Bohle & Maturana, 2007) which was intended to replace the whiteboard technique for planning and scheduling tank farm activities, is one option used commonly. Given the physical limitations of the tank farm (tank characteristics, transfer pathways), incoming juice, bottling plan, and any user-defined business rules, the system creates optimal tank farm plans for the entire vintage. The Tank Farm Optimizer analyses predicted grape intake and bottling needs to produce a production plan that minimizes the number and distance of transfers between tanks, as well as the quantity of liters transported, to reduce the overall cost of wine production on the tank farm (Bohle & Maturana, 2007).

The is followed by the step to determine the path for the piping network. Major vineries use the cellar tank piping problem to determine the path in the piping network from the origin to the destination of every flow and the scheduling of each flow. Although the cellar tank piping problem aims on minimizing the number of pipes and reconnections it works as trial-and-error method, which redundantly increases opportunity cost. Moreover, the maintenance, breakage or replacement of said pipes including the barrels and tanks which is required for further processing and blending adds on to the cost.

The use of operations research might look very lucrative but as any other function it has its own limitations. OR focuses on either the maximization and minimization of a certain aspect and at the end of the day, we often end up ignoring some other aspects. It is important to consider all the possible underlying implications to the suggested method and solution before finalizing it.

5. CONCLUSIONS AND LIMITATIONS

In these modern times the need for the inclusivity of supply chain management has become more important than ever. It is now in the center of every aspect of the day to day working of the company. In these cut throat times wineries are looking for OR tools to effectively optimize their supply chain. A recommendation that we covered in the paper was Solve IT Software which empowers wineries with end-to-end optimization to handle numerous wine production issues existing in areas of the wine supply chain. There are limitations to it too, complexity and unavoidable unpredicted factors can lead to drawbacks in the system.

OR can optimize one aspect of a process but it is difficult to optimize the process when all possible factors affecting it are considered. In the viticulture part when we considered minimizing the pesticide application, the time taken increased. Therefore, it is challenging to find a solution that will consider all the related variables. Furthermore, for the wine grape harvesting, it was difficult to determine if it better to manually or technologically harvest the grapes as there was not enough data on the mechanical harvesting time and other factors relating to technological grape harvesting. Applications such as SolveIT software which commonly for planning and scheduling numerous tank farm activities is not as easily available to everyone. While OR is a vast field, it was challenging to find OR solutions to some parts of the supply chain such as connections of pipes from the processing to the tank farm. The supply chain management process is complex and the solutions found are simplified and there may be other unpredicted factors or variables that may arise when testing these models and solutions in real life.

The future research applications and scope includes use of computational intelligence. This is a type of artificial intelligence that uses heuristic algorithms as opposed to traditional AI (such as in neural networks and evolutionary computation). To develop programs that are intelligent in some way, computational intelligence incorporates aspects of learning, adaptation, evolution, and fuzzy logic. An often-asked inquiry seeks assistance on the sorts of issues for which Computational Intelligence approaches are better suited than, for instance, traditional operations research methods. One recommendation we found that can be of great help to the problems faced by this industry be it time optimization, cost optimization or the uncertainties faced, is the increased usage of the Solve IT Software. It has created a suite of software programs that can optimize the end-to-end wine supply chain to handle numerous wine production issues prevalent in various areas of the wine supply chain. These software applications are built on Computational Intelligence concepts. Predictive modelling for grape maturity (using weather forecasts and measurements on Baumé, pH, and TA), vintage planning, crush scheduling, tank farm optimization, and bottling-line sequencing are just a few of the software tools available. These applications, when used together, can optimize all planning and scheduling operations throughout a winery's supply chain.

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