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Snider Tire Optimizes Its Customers-Stores-Plants Transportation Network

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Abstract. We successfully redesigned the customer-store-plant production transportation network at Snider Tire, Inc. (STI), one of the largest commercial tire and retreading dealers in the United States, in two stages. We first optimized the plants-to-stores networks, and we then reengineered the customers-to-store truck routes. We used a Lean Six Sigma (LSS) and optimization framework to improve key supply chain processes of plants' capacity planning, and distribution routes optimization by focusing on the root causes of process problems and investigating process alternatives. This approach ensured that managers from this small, privately owned, traditional organization were part of the team that developed the solutions, enthusiastically implemented them, and co-owned them. As a result, STI is saving $2 million (16 percent) in annual transportation costs.

History: This paper was refereed.

Keywords: multilevel transportation-network optimization • Lean Six Sigma

Snider Tire, Inc. (STI) was founded in 1976 in Greensboro, North Carolina. It offers a variety of tire products to commercial and industrial customers that use automobile, trucking, construction, and off-road vehicles. By 2012, STI had evolved into one of the largest commercial tire dealers and retreaders in the United States, operating six manufacturing plants with an additional plant under construction, 45 commercial and (or) mechanical service locations (stores) in 10 states, and employing over 850 associates to serve commercial customers in 30 states. Although it only recently exceeded the benchmark of 500 employees, the definition for a small or medium-sized business, the management style at STI is still typical of the style in small, family-owned traditional firms. Small and medium-sized firms constitute 99.7 percent of U.S. businesses and about 50 percent of U.S. employment (Carusso 2015).

STI is recognized as an industry leader in providing innovative outsourcing alternatives to large, multiple-location trucking fleets. With its recent store acquisitions and the addition of a new plant in the Southeastern region, the management team identified the STI transportation network as a potential source of cost savings. In 2012, STI executives contacted us (the authors) to perform a current-state analysis of their transportation network, including all shipments among the plants, branches, and customers in the Southeastern region. The goal of the analysis included identifying potential changes to the transportation network and creating a standardized solution that could be transferred to other STI regions. We identified two main transportation networks to evaluate: the plant and branch network for retreading tires and the branch and customer network for picking up casings and delivering the completed retreads.

As supply chain improvement consultants, we recognized that although STI had invited us to conduct this cost-cutting project, the company required more than a technical solution. Supply chain consulting and the associated scholarly literature emphasize the technical aspects of improving supply chain processes, such as transportation modeling and network design. In practice, organizations have specialists in logistics, operations research (OR), and management science, who focus their attention on solving these problems as technical problems, and often miss out on the managerial, behavioral, and business-consideration nuances of how supply chain processes contribute to overall business value (Turhan et al. 2011). For a supply chain process-improvement project to succeed, managers need to identify the goals of the project, the stakeholders of the process, and what real improvements will mean to the stakeholders (Lockamy et al. 2000, Linderman et al. 2003, Nair et al. 2011). A disconnect between the competencies of operations research and supply chain optimization analysts and the end users of the solutions (i.e., functional and senior management) leads to a biased and incomplete understanding of supply chain challenges, resulting in unrealistic or ineffective recommendations, which are then either implemented unsuccessfully or do not lead to improved business performance (Sodhi and Tang 2008). More importantly, although small- and medium-sized businesses account for 99.7 percent of U.S. firms and about 50 percent of U.S. employment (Carusso 2015), with the exception of a few publications (e.g., Ahire 2001), we find that the preponderance of publications in applied OR journals focus on sophisticated OR analytics in large firms.

In this paper we show how our use of the Lean Six Sigma (LSS) process-improvement approach helped to ensure that our project efforts were executed efficiently and effectively to achieve practical and significant improvements. We included STI's managers as integral team members to develop and co-own the transportation-network optimization models and improvement solutions. Hence, they wholeheartedly embraced and deployed the improved strategies. Our successful efforts at STI and the approach provide a template of how OR/MS practice could be expanded in scope and scale to benefit small and medium enterprises that constitute such a prominent component of the U.S. economy, which has hitherto not been the primary focus of OR scholarly and applied publications.

Project Background

Over the years, STI's business has expanded through acquisitions. For this growing business, logistics and transportation costs play a critical role in balancing customer service quality and costs of service (and in turn profitability). STI approached us to conduct a strategic evaluation of its current network of retreading and (or) manufacturing plants and commercial stores with respect to the spread of its end customers who typically own automotive and trucking fleets. Effectively managing the STI network was central not only for profitable operations and higher customer service, but also for its direct impact for environmental sustainability through the carbon footprint of the network.

Figure 1 shows the typical flow of a tire through Snider's customer-store-plant network. STI faces the critical challenge of transporting tires and casings from its end customers through a network of stores into its retreading facilities (plants) and back through the stores to customers. We focused our analysis on Snider's Southeastern U.S. network. To serve 4,700 customers through a network of 23 stores and four manufacturing (retreading) locations, STI spends almost $12 million annually on transportation costs.

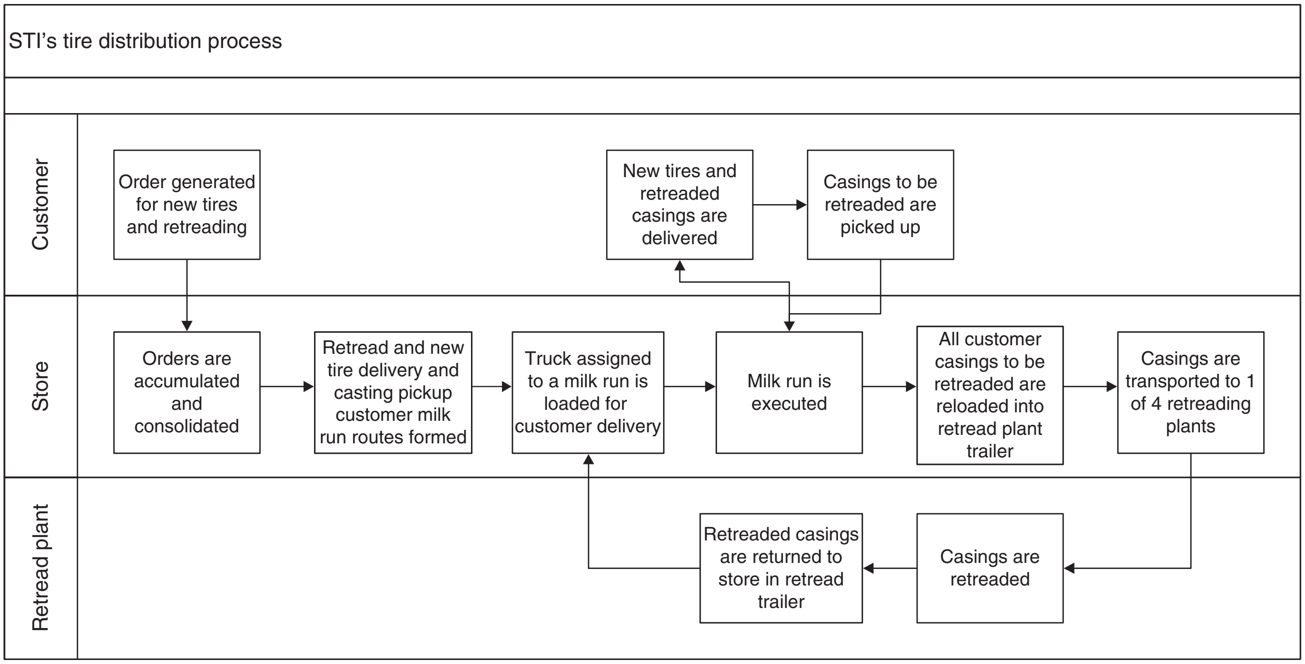
In the current state of the network, STI had serious concerns about suboptimized transportation of tires, such as frequent crisscrossing of trucks during milk runs (i.e., round-trip routes that enable the efficient collection and then return of tires to the firm's customers) and less-than-ideal utilization of its trucks. STI management was convinced that the current transportation processes delivered excellent service to its customers, but did so by dramatically suboptimizing equipment turnaround times, labor utilization, inventory levels, and miles traveled. Thus, the goal of this supply chain reengineering effort was to analyze the current network's utilization of resources and recommend improvements that would generate savings of at least 10 percent in annual logistics costs through more effective logistics management. To realize these benefits, we turned to the process improvements of Lean Six Sigma.

The Lean Six Sigma (LSS) Approach

Logistics and supply chain researchers have recently identified the need for integrating different perspectives and methodologies to successfully address complex supply chain and logistics network problems (Hartley et al. 2002, Golicic and Davis 2012). Recently, Jensen et al. (2013) illustrated a blended application of Lean tools in conjunction with classic OR techniques to improve the productivity of a manufacturing process.

The Lean approach emphasizes the goal of efficiently producing the best value from a process. It starts with recognizing the value dimensions (i.e., the features or steps for which customers will be willing

Figure 1. Snider Tire Incorporated's Tire Retreading Distribution Network Requires Multiple Tire Handoffs Among the Customers, Stores, and Retreading Plants



to pay) of a product or process. It then entails mapping the process and resource details of the value stream and identifying the components of the process that impact this value (Rother and Shook 2003). In contrast, Six Sigma can be described as a business-improvement approach that seeks to find and eliminate causes of defects and errors in manufacturing and service processes by focusing on outputs that are critical to customers and influence the financial return for the organization (Kapuscinski et al. 2004, Schroeder et al. 2007, Evans and Lindsay 2005). The LSS approach combines strengths of the classic Lean concepts of customer-value-focused value streams (e.g., value-added, nonvalue-added analysis, standardization, continuous flow) with those of the classic Six-Sigma approach (e.g., product and process defects reduction and variance reduction) (George et al. 2005, Summers 2011) into a holistic model of operations improvement.

For supply chain-oriented problems, advanced analytics such as mathematical optimization and simulation modeling are often necessary. However, in traditional applications of mathematical tools to supply chain and operations problems, modelers with technical backgrounds often make too many simplifying assumptions and solve models that do not represent the actual problems, or they frequently have a limited or incorrect understanding of the problems due to a focused, technical, and myopic understanding of them (Gorman and Ahire 2006, Nair et al. 2011). Not anticipating the scope and details of activities, failure to execute planned activities, and failure to coordinate outcomes of various dimensions of a project are salient reasons for the failures of complex projects (Matta and Ashkenas 2003). These reasons and the complexity and scope of supply chain projects can be extrapolated logically to impact these projects. Bell (1999) describes a data-model-knowledge framework that emphasizes the need to complement technical and modeling prowess for solving complex OR problems with solving the right problems and using the right data by eliciting knowledge from organizational and (or) process participants (e.g., about problems, constraints, and workable solutions). The LSS approach represents an ideal approach to making operational Bell's data-model-knowledge framework, thus making the case for the LSS approach to have a holistic influence on enhancing the effectiveness and efficiency of logistics and supply chain improvement projects.

Project Scoping and Execution

At the outset, our scoping discussions at STI revolved around clearly understanding how truck routes impact travel time and distance, and how efficiently the network utilizes the current truck mix. However, after initial brainstorming, we saw clearly that the project goals were really to analyze the total cost performance of the current production-distribution network and to identify opportunities to improve the total cost. Our systematic project-scoping phase led us to the decision to redesign STI's Southern and Eastern customer-store-plant network in two stages. We optimized the plant-stores network through transportation modeling to rebalance the demand allocation from the stores across four of STI's six plants (Stage 1), and then reengineered the truck routes from customers to the stores using routing heuristics (Stage 2).

The organizational-spanning approach we used enabled us to formulate, execute, and clearly communicate the technical details of the optimization analytics to STI's managers. Our project client was a small firm that employed a traditional management style but was resource challenged in the area of advanced analytics. Therefore, the LSS approach provided a logical and effective framework to proactively engage the managers, thus enhancing their trust in the solutions that they ultimately helped to developed and co-owned. Thus, it enabled their enthusiastic implementation of the recommendations and achieved about $2 million in annual cost savings, with simultaneous substantial benefits by reducing employee workloads and increasing employee morale. In the sections below, we provide details of the many critical judgments and decisions we made regarding the level and depth of our analyses and improvement recommendations.

Superteam Organization and Project Scoping

To ensure that we correctly solved the right challenge, we collaborated with and embedded our team (hereafter called consulting team) into STI's internal project team (hereafter called client team or client managers) from the project's beginning using the framework described in Naslund et al. (2010). The commitment of senior management to this project was evident in its sponsorship by STI's senior vice president. The STI project team consisted of the vice president of commercial operations, the director of purchasing, the manager of business development, the logistics and purchasing manager, and the director of manufacturing. In addition, the team also included three senior-level managers from STI's major supplier. Our consulting team included a Lean Six Sigma master black belt, a specialist professor in operations management, and six supply chain analysts. STI's team, including supplier representatives, and the consulting team constituted the project's 16-member superteam.

Through a series of Kano analysis (Matzler and Hinterhuber 1998, Kai 2007) discovery sessions between the superteam members, we identified "improving STI's operational performance by serving their customers better but also more cost effectively" as the overarching project deliverable. We also realized that changes to the current-state network were required to maintain at least the current service levels to customers (in terms of order turnaround time). This overriding consideration was deemed as the minimum success criterion. Our primary goals were to model and optimize the total production-distribution costs for the network, which consisted of the plants and stores, and to reduce total transportation mileage between stores and end customers through reconfiguration of the customer routes. Finally, three stretch goals of the project included (1) developing the final analyses and recommendations using an Excel-based platform, (2) developing training modules to ensure ongoing use of models and analytics, and (3) incorporating scalable analyses that could be executed as business conditions changed across quarters or years. Finally, from the managerial perspective of network management, we defined the project to comprise two stages of transportation-network improvement. Stage 1 consisted of improving the plant and store transportation network. The goal of this stage was to minimize the total fixed and variable costs of transportation for the plants and transportation routes between plants and stores using the process described in Ulstein et al. (2006). Stage 2 consisted of minimizing the total mileage traveled by milk-run trucks between customers and stores, while optimizing route times and maintaining customer service levels, a process discussed in Kant et al. (2008).

Stage 1: Analysis of Plant and Store Transportation-Network Improvement

The current-state network model was developed to capture the relevant elements of tire movement and facility costs. Based on STI's monthly operations planning time frame, we built the first model using June 2011 data and replicated it with data from the remaining months of the peak-period demand (March–July).

We formulated the Stage 1 model as a classic transshipment transportation-network model. The decision variables were defined as the number of tires transported along each route (i.e., between each store and each plant or between two stores) during the month. Demand constraint for each store ensured that the month's demand for tires originating from and returned to each store is supplied. The current-state network included some store-to-store transshipments; therefore, we added appropriate transshipments to the model. The objective function for the model targeted minimizing the total variable transportation and variable plant production costs. Because the project incorporated the parameters of the existing plant locations, plant capacity constraints limited the number of tires loaded into each plant for retreading. Specifically, we held each plant's capacity loading within a range of a maximum permissible utilization and a minimum required utilization to cover fixed plant costs. Appendix A shows the sample model elements (i.e., decision variables definition, objective function, and representative constraints). This model consisted of 610 decision variables and 54 constraints.

The information for the model inputs came from numerous sources, and we sometimes had to run customized reports internally to make information available. For example, we used plant operating reports for fixed costs and variable production costs. STI provided us the driver wages and fuel costs for computing the variable transportation costs per tire. On many inputs, we had to gather the information from published sources. For example, driving distances and driving times for each possible route were compiled from Google Maps.

Looking ahead to the usability of the final models and solutions, we used Excel Premium Solver, a Microsoft Excel add-in, to operationalize the production-transportation optimization model. Even within the model, the data inputs were minimized. For example, once we created the model, we color coded the primary data inputs that could change from month to month. Primary data inputs, namely, driver cost (cost per minute), fuel cost (cost per mile), and desired truck utilization (percentage of maximum capacity) were kept open in Excel to allow user input. Other data, such as plant capacity and variable production costs, and model specifications were locked to prevent user errors.

We computed the current-state total cost relevant to the network model based on the current-state flows of tires along their managerially selected routes. We then ran the optimization model to allow for minimizing the tire-flow cost along all routes. The results showed that STI's current managerial practice was within 99.5 percent of optimality. Only a 0.5 percent reduction in total costs (or $60,000 per year) would result from optimizing these decisions, thus indicating that STI was effectively allocating the stores' demands to plants. Although Stage 1 did not yield significant savings, it was a necessary first step of analyses before moving to improving the store-customer network. It also helped in creating high levels of trust with the client managers as we validated their decisions about the overall transportation-network configuration in a transparent and comprehensive manner.

Stage 2: Optimization of the Store and Customer Transportation Network

Similar to Stage 1, we launched our investigation of Stage 2 through a team-based discovery of STI's priorities. The continuous involvement of STI's team also enabled us to correctly and completely specify the analytic models in Stage 2, avoiding the errors of omitting relevant considerations and including trivial or irrelevant components that complicate analyses without adding insights. We identified the primary goal of this stage of the project to be minimization of the total distance (conversely, covering all customers with minimum number of drivers and routes) traveled by drivers between the stores and customers while optimizing the drive routes to a route length of either one operating day or two operating days, and meeting the customer service levels customers (in terms of order turnaround time) for customers based on their volume of demand. Based on the geographical density of customers served by STI, the superteam's first round of analyses focused on three prominent STI stores in

Table 1. Reallocating Customers Across Stores and Optimizing Travel Routes Provide Substantial Savings in the Total Distances Traveled

	No. of customers allocated to each store			Total Euclidean distance for the network (miles)			Total rectilinear distance for the network (miles)		
	Current state	Future state	Change (%)	Current state	Future state	Change (%)	Current state	Future state	Change (%)
Store 1	122	64	−48	21,698	5,756	−73	28,135	7,495	−73
Store 2	19	61	221	1,088	5,315	389	1,377	6,871	399
Store 3	56	72	29	9,013	7,627	−15	12,118	8,636	−29
Total	197	197	—	31,799	18,698	−41	41,630	23,002	−45

North Carolina and STI's customers served by these stores. These stores represented a substantial segment of STI's customer base. Next, based on a visual mapping of these stores and customers, we used a heuristic of allocating customers approximately equally to the three stores to create physically separate, nonoverlapping partitions. Table 1 shows the changes in number of stores allocated, and corresponding reductions in distances between the stores and their allocated customers. Note that the judgmental partitioning in consultation with the client team yielded a more balanced allocation of the customers across the three stores and resulted in a net 41 percent reduction in total Euclidian (straight-line) distance between the customers and their allocated store travelled across the network, and a 45 percent reduction in rectilinear distance.

Once the partitions were derived, we conducted weekly milk run routing optimization analyses to iteratively derive routes consisting of customers visited by a truck on either a one-day drive time route or a two-day drive time route for meeting a week's demand for the customers served by the store. In our case, we use the term "milk run" to indicate a preplanned, round-trip routing in which several customers are visited to both pick up tire casings and deliver retreaded tires. The superteam defined a route as a specific path traversed by a milk-run truck, starting from the store and traversing selected customers in a specific sequence before returning to the store. Milk-run deliveries are a standard feature of just-in-time suppliers. In our case, the mathematical optimization problem aimed at (1) identifying the span of feasible routes (that is, number of customers covered by a route) corresponding to each store and (2) optimizing the sequencing along the identified set of customers on these routes quickly became computationally intractable because of the large number of customers. We then decided to use contemporary mapping software (Google Maps) in conjunction with the formulation of routing heuristics that incorporated STI's business considerations in addition to logical distance minimization and maximal material flow criteria to develop the optimal number of routes for each store. Appendix B shows the mechanics of the milk-run routing optimization.

The goal of optimizing the milk runs for each store was to identify a minimum number of weekly driven routes that would cover all the customers' demands with as few trucks as possible. The revised routes were compared with current-state routes for each store in terms of number of routes (trucks) used to meet the demands and service levels for all customers of the store. For example, a current-state route with a total of 106 tires covers nine customers at a total of 264 miles. An improved route covers 12 customers with a total of 162 tires on the truck traveling a total of 216 miles. The new route clearly represents a great improvement over the current-state route. Note that we developed the new route using the nearest-neighbor heuristic; see Appendix B.

We addressed the dual questions of how many routes and what are their optimal configurations by simultaneously considering the service-level needs of individual customers. For example, some customers have large demands and (or) mandate two deliveries per week. The truck can hold a maximum of 210 tires. Then the total time for the route (total drive time + total load and (or) unload times at all customers along the route) should be either as close to one-day work (i.e., a 14-hour day including breaks) or a two-day work. Note that all of these constraints on developing routes were

Table 2. After Route Optimization is Accomplished Across All Three Stores, the Total Number of Miles Traveled Decreases by 41 Percent, Resulting in a Decrease of 24 Percent in Total Travel Time

	No. of routes			Total no. of miles traveled			Total route time (including travel and load-unload time) (hours)		
	Current state	Future state	Change (%)	Current state	Future state	Change (%)	Current state	Future state	Change (%)
Store 1	15	8	−47	10,216	2,364	−73	273	103	−62
Store 2	10	9	−10	1,088	2,787	389	81	113	40
Store 3	5	6	20	878	2,068	−15	38	83	118
Total	30	23	−23	12,182	7,219	−41	392	299	−24

identified by the superteam working jointly to incorporate the relevant business policies and customer service requirements. As a result of their involvement in development of the new recommendations, whether during their work with the mapping-based cluster analysis or with the nearest-neighbor heuristic, the STI team members developed a high degree of confidence in the results and merits of new route formations.

A representative analysis of current-state and future-state routes for Store 1 shows that in the current state, 15 routes serve the customers allocated to Store 1. Of these, two are three-day routes, six are two-day routes, and seven are one-day routes, covering 10,216 miles in 273 hours (travel + load and unload times). The improved routings result in only eight routes; of these, only two are two-day routes and the remaining seven are one-day routes, covering 2,364 miles in 103 hours.

Table 2 summarizes the net improvement in mileage, total route travel time, and number of routes for all three stores using the route-improvement heuristics. The net improvement for the three stores represents a saving of 93 hours of route total time and about 4,965 miles of travel per week, which computes to annual savings of about $245,000 in driver wages and fuel costs. We extended this analysis to all 23 STI stores within the project scope, thereby resulting in estimated annual cost savings of $1,932,000, which represent a cost improvement of approximately 16 percent.

Enhancing Client Confidence in Implementation and Sustenance Plans

Across the two stages of STI's network optimization, we recommended significant changes to the operating policies of tire movement across the network. In particular, in Stage 2, we proposed radical changes in two areas: (1) allocation of customers to stores, and (2) redesign of routes (both number of routes and travel configuration of each route) in terms of the precise sequence of customers visited along the route. We undertook proactive and comprehensive measures to ensure that the STI leadership and functional managers understood the logic of these dramatic changes, and we developed several supporting documents for the implementation of changes, use of the new policies, and continuation of improvements. We developed detailed instruction manuals for archiving the logic of the analytic models and providing the standard operating procedure to be used for understanding and refining the networks at recommended times during the year or business cycle.

Monitoring the revised route lengths and durations represented one of the most critical aspects of ensuring that STI sustained the gains of the new network configuration and represented an efficient future state on an ongoing basis. Note that we proposed the new routes based on current demand patterns from the current set of customers, baseline productivity data for driving times, and tire load and (or) unload times per tire. We selected an individual moving range (ImR) chart to monitor each route over time. Because the weekly performance of each route in terms of drive time has only one measurement (I), the subgroup size equals one. The moving range (MR) chart provides a measure of variability over time by plotting the difference between two consecutive route times. We developed guidelines and detailed instructions for using individual observation trends and moving range (X and ImR) charts to track actual route times to ensure that they did not exceed the expected and (or) allowable upper and lower control limits set on the route time for each route. Figure 2 depicts special-cause detection for out-of-control exceptions and trends that need to be investigated for underlying root causes and for proactively updating the network configurations.

We packaged the project findings and recommendations into a comprehensive 200-slide PowerPoint presentation, Excel-based models, instructions on using GeoBatch software from BatchGeo LLC (https://batchgeo.com/) to map and calculate distance, user guides for the two stages of analyses, and control plans for the new process. It was compiled as an organic set of documents throughout the project, and it involved the STI team members who had direct knowledge of how our team developed the new strategies. We presented the final findings and associated tools to STI's senior management in a five-hour marathon session. The members of the management team made immediate decisions on incrementally making changes to the network, leading up to a substantial reorganization of the network. Moreover, the entire project's effective use of the organizationally inclusive approach enhanced STI management's understanding of the value of a holistic analysis and improvement of the entire network. This, in turn, helped the managers co-own the recommendations, thus leading to their wholehearted acceptance and implementation actions. STI has now embedded the methods of analyzing, monitoring, and refining the policies for transportation and routing into its overall network management strategy.

The Lean Six Sigma (LSS) Approach: How It Helped

Throughout our project, we employed the LSS approach to ensure a systematic organizational-spanning perspective at each stage of project execution. Embedding the LSS approach within this project enabled our consulting team and the company's supply chain leaders to (1) recognize the most important dimensions of the process, (2) systematically identify the solutions to their transportation-network operational problems using the correct methods and (or) tools, and (3) successfully complete the project with maximum confidence for its implementation and the continuation of gains.

The scoping phase of the project was aided by project organization within a superteam and Kano analysis, both of which focused us on important issues, while weeding out unnecessary details. Organizing the project in a superteam structure enabled us to engage STI's management at the ground level of the project's execution and proved critical in developing practical solutions that STI co-owned. STI's management insights helped establish accurate project boundaries so we could better concentrate on the transportation-related optimization.

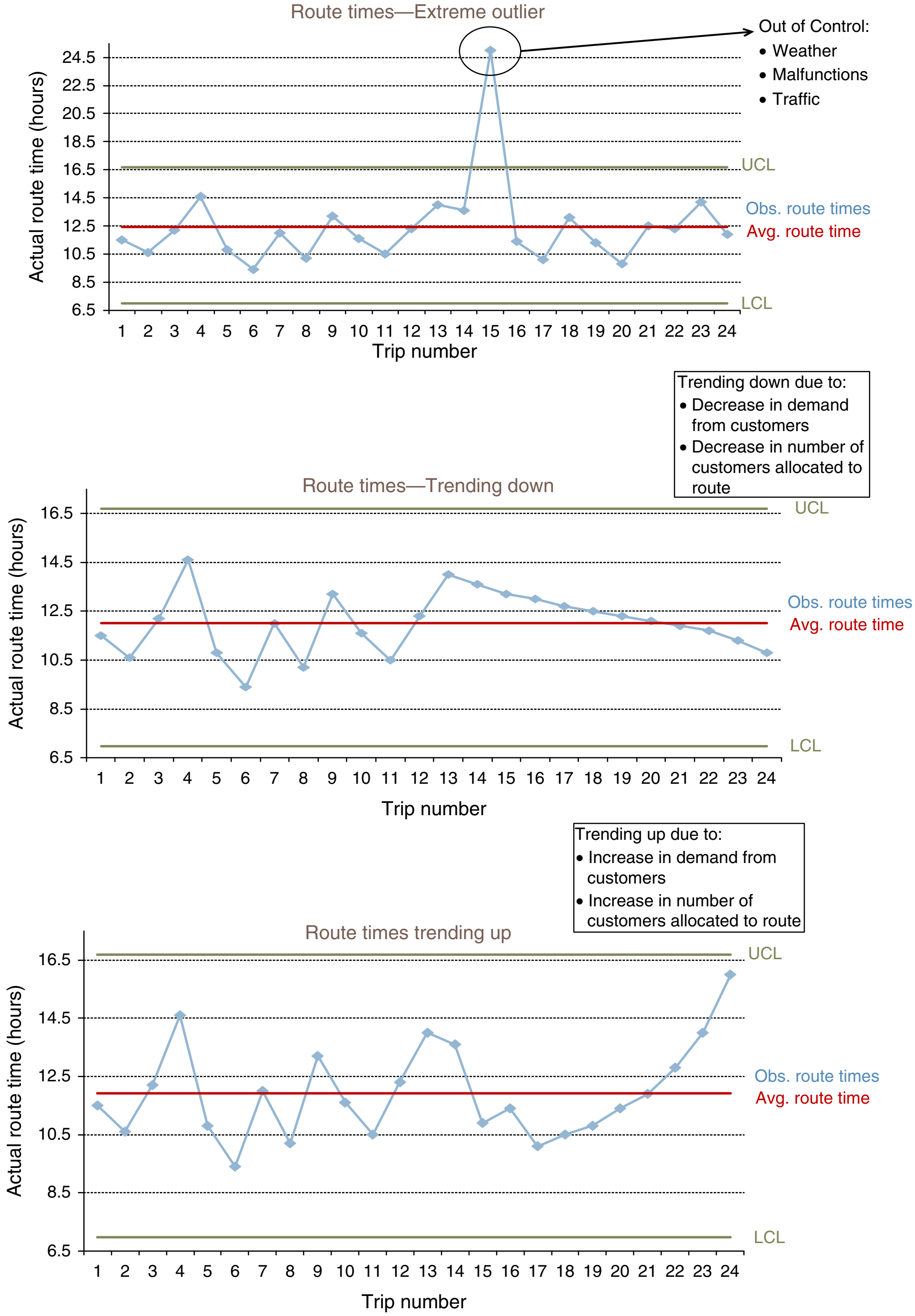
In the measurement and analysis phases, detailed swim-lane mapping was valuable in helping us to understand the time and cost drivers within the network. It also enabled a shared visual understanding of the network and time-cost components. Our consulting superteam worked proactively to enhance the nontechnical functional managers' understanding of the model logic, and in turn provide comprehensive amounts of information for model inputs. We spent a substantial amount of time in meetings and conference calls discussing precise operational definitions to ensure that we were incorporating the right data into the model (i.e., measurement system analysis).

During the testing of the analytic model results, the STI team members made every effort to understand the technical workings of the model and assisted in making the models user friendly. They appreciated the potential value of our project recommendations in substantially transforming the transportation policies, although STI would have to drastically change policies in many cases. By giving careful attention to the development of training documents, control charts, and standard operating procedures, we were able to ensure full commitment to the implementation of the network revisions. Over the past two years, we have witnessed the fruits of our comprehensive joint effort and are confident that they will continue to accrue in the future.

Conclusion

Although small and medium-sized organizations account for 99.7 percent of U.S. firms, publications in applied OR journals have historically focused on the application of OR analytics in large firms. In this paper we highlighted how we helped STI to attain annual savings of $2 million (16 percent reduction) in its annual transportation costs (and additional important human resource-related benefits) and develop a holistic supply chain mindset through a well-focused and executed transportation-network optimization project. We also

Figure 2. (Color online) We Use X and ImR Charts to Monitor and Control the Actual Route Time; X and ImR Charts are Capable of Providing Warning Signals That Can Indicate When Routes Need to be Reevaluated



explained how employing the organizational-spanning LSS approach made our project efforts efficient and effective in realizing practical and significant improvements. This framework enabled us to solve the actual problem while simultaneously ensuring that the client managers fully understood how their practical challenges were being translated into the OR models that we built. We hope that supply chain applied research will integrate this thinking into planning and implementing substantial and sustained improvements that are co-owned by client organization's managers.

STI took the final leap toward validating our project's recommendations by first piloting the improved network configuration for three stores and later doing a full-scale implementation across all of its 23 stores, six manufacturing plants, and associated customers. As a result of this implementation, STI has achieved annual savings of $2 million in its transportation costs. Moreover, the improved transportation schedules have allowed STI to remain compliant with the increased enforcement of driver hours-of-operation rules from the Federal Motor Carrier Safety Administration (FMCSA) at higher volumes than anticipated in 2012. In addition, driver morale has improved noticeably. On a strategic front, the project has altered STI's mindset about how transportation function is managed, and the company has used the analyses to further relocate some of its facilities to help drive additional cost reductions in its network. Our successful LSS approach at STI provides an effective template for expanding the scope and scale of advanced OR analytics to help small and medium-sized firms. Any organization that has multiple production facilities serving multiple markets and (or) distribution centers (DCs) that are geographically dispersed with one or more geographical clustering of these DCs has the potential to use the models and the approach we have presented in this paper.

Acknowledgments

The authors thank STI's project managers, especially Sean Baird, for their energy and enthusiasm for developing a practical and implementable solution. The authors also acknowledge analysts Thomas Gonzalez, Julie Lanier, Molina Torres, Caleb McRady, Victoria Seay, and Jerry Thompson III for their diligent work on this project. This project was supported by the Center for Global Supply Chain and Process Management at the Moore School of Business, University of South Carolina.

Appendix A. Truncated Example of the Linear Programming Transshipment Model

Decision Variables

In Figure A.1, X_{ij} = the number of tires transported between locations i and j.

Objective Function

$$\text{Minimize } Z = C_{cA}X_{cA} + C_{cB}X_{cB} + C_{dA}X_{dA} + C_{dB}X_{dB} + C_{cd}X_{cd} + C_{dc}X_{dc},$$

where:

C_{cA} = (the one-way variable cost associated with transporting a tire from store c to plant A) + (the variable cost of retreading one tire at plant A);

C_{cd} = the one-way variable cost associated with transporting a tire from store c to store d.

Constraints

Demand constraints

$$X_{cA} + X_{cB} + X_{cd} - X_{dc} = \text{Demand for retreads at store } c;$$
$$X_{dA} + X_{dB} + X_{dc} - X_{cd} = \text{Demand for retreads at store } d.$$

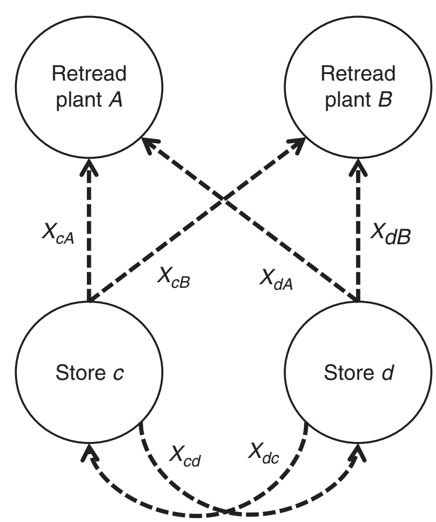
Minimum capacity constraints

$$X_{cA} + X_{dA} \geq \text{Minimum production at plant } A;$$
$$X_{cB} + X_{dB} \geq \text{Minimum production at plant } B.$$

Maximum capacity constraints

$$X_{cA} + X_{dA} \leq \text{Maximum production at plant } A;$$
$$X_{cB} + X_{dB} \leq \text{Maximum production at plant } B.$$

Figure A.1. The Decision Variables in the Transshipment Model Represent the Quantity of Tires Shipped in a Single Step Between All Possible Pairs of Facilities. Tires May be Moved From Store d to Plant A Either Directly (X_{dA}) or by Being Transshipped Through Store c (X_{dc} and X_{cA})



Appendix B. The Nearest-Neighbor Heuristic

Problem

Given a collection of cities and the cost, distance, and time of travel between each pair of cities, the traveling salesman problem is to find the cheapest, shortest, or fastest way to visit all the cities in the collection and then return the starting point.

The Nearest-Neighbor Procedure

1. Choose one city as a starting (or depot) location.
2. Locate the city from all other cities which is cheapest, shortest, or quickest to link to the depot node.
3. From the cities not selected in steps 1 and 2, locate the city that is the cheapest, shortest, and (or) quickest to link to the city selected in step 2.
4. Repeat step 3 until all cities have been selected and linked.
5. Link the last city selected to the depot node to complete a tour.
6. Repeat steps 1–5 with each city in the collection serving as the depot node.

Advantages of the Nearest-Neighbor Procedure

The procedure is as follows:

1. Is easy to understand;
2. Is visual and thereby easy to implement using mapping software;
3. Finds good, but not necessarily optimal, solutions; and
4. Can solve large problems.

Disadvantages of the Nearest-Neighbor Procedure

The procedure is as follows:

1. Cannot easily deal with nonsymmetric distances;
2. Requires a unique formulation for each problem; and
3. Requires many trials per problem.

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Verification Letter

Sean Baird, VP, Commercial Operations, Snider Fleet Solutions, 1545 St. James Church Rd., Newton, North Carolina 28658, writes:

"I am writing to provide my reaction to the consulting project executed by Professor Sanjay Ahire and Professor John (Jack) Jensen to improve our Southeastern United States tire logistics network during spring 2012.

"Snider Fleet Solutions, founded in 1976 in Greensboro, North Carolina, sells a wide mix of tire products and services to commercial and industrial customers that use automobile, trucking, construction and off-road vehicles. We are also one of the largest commercial tire dealers and retreaders in the United States, with 6 manufacturing facilities, 45 commercial/mechanical service locations in 10 states and about 4,700 commercial customers in 30 states. We are known as an industry leader in providing innovative outsourcing alternatives to large, multi-location trucking fleets.

"With our fast growth against a background of private ownership, we have been challenged with systematic improvements in our logistic network to keep up efficiency and effectiveness with our increasing footprint of manufacturing facilities, retail stores (branches), and customers. In spring 2012, Drs. Ahire and Jensen approached us through Michelin North America (our strategic supplier) to help us with improving our supply chain performance on behalf of University of South Carolina's Global Supply Chain and Process Management (USC-GSCPM) Center.

"Over the course of four months (January–April 2012), they scoped and implemented a series of technical solutions to identify inefficiencies in our network and provide recommendations to substantially improve our costs while maintaining the customer service levels. It was not just the quality of analytics that they brought to bear on the project—which by themselves provided a clear path forward for us—but the approach that they followed that has transformed the way we approach our strategic operational and supply chain challenges now.

"Drs. Ahire and Jensen introduced our top management team to the Lean Six-Sigma approach as a way to execute a complex supply chain logistics problem. Right from the definition of the project's goals and scope, to directing the analyst team to map out the entire logistics network and transportation process to collecting the right data, to developing complex analytic models to recommending operational changes to the network, they ensured that our project team was in sync with the workings of the models and analyses. Unlike typical consultants, they developed the various measurements and analyses in collaboration with our team and made us understand why and how they would use the various pieces of information being gathered. When developing the analytic models of plant-branch transportation using Excel Solver, they actually made the models quite user-friendly and helped us understand the importance of the data and parameters being input into the models. On the branch-customer network, again they explained the logic of the milk-run techniques and developed the recommendations that incorporated our practical constraints through constant participation from our team. Most importantly, they developed a robust plan for implementation and control of the improved processes through a set of training manuals and standard operating procedures as well as control charts to sustain the improvements. With such a focus on producing the right solutions to the relevant problems and ensuring long-term acceptance of the consulting recommendations, Drs. Ahire and Jensen demonstrated the value of incorporating the Lean Six-Sigma DMAIC approach (and associated tools) into logistics improvement initiative in an unequivocal manner.

"Based on a focus on our Southeastern U.S. operations, they estimated about $1.9 million in annual operating cost savings using the recommended optimal transportation models for our plants-branches (stores) network, and branch (stores)-customers network. We implemented all of the recommendations on the portion that was from the retread plants to the commercial stores. As far as the portion from the commercial stores to the customers, we have implemented 90% of the stores-customers network in the Southeastern U.S. network. We have already realized about $2 million per year in transportation cost savings on the implementation.

"In addition to these dollar savings, we have accrued an equally important benefit from the project. Back in 2012 when we did the project, the Hours of Service restrictions from the U.S. Federal Government were not under as much scrutiny as they are now. Route optimizations from the project have helped us remain compliant with these stricter regulations even as we have grown our business over the last couple of years. And finally, we have used the integrated analysis approach to relocate some of our facilities and further drive cost reductions in our network.

"Based on our experience and success with this project, we have developed a mindset of viewing each major operations and supply chain improvement project through the orientation that was applied here. I would deem this contribution to change in our perspective as valuable as the actual cost savings generated by the project. We appreciate the competencies and attitude the professors brought to Snider, and endorse the overall contributions made by them to our operations for the specific significant consulting project and beyond."

Sanjay L. Ahire is a professor of global supply chain and operations management at the Darla Moore School of Business, University of South Carolina (USC). He also serves as the associate director of the USC-Global Supply Chain and Process Management Center, and leads the Sonoco-USC Lean Six Sigma Green Belt Initiative. He holds a PhD in management science from the University of Alabama, and a master's degree in management studies and bachelor's degree in chemical engineering from the University of Bombay (India). Dr. Ahire has published extensively in operations strategy and process improvement in leading journals. In 2012, Dr. Ahire became the first tenured university professor to receive the Six Sigma Master Black Belt certification from the American Society for Quality. Dr. Ahire has served as a supply chain and operations improvement consultant to numerous major organizations. He received the prestigious Wickham Skinner Teaching Innovation Achievements Award from the Production and Operations Management Society in 2002, the University of Dayton Alumni Teaching Award in 2005, the Southwest Ohio Council on Higher Education Excellence Award in 2005, the Alfred Smith Teaching Excellence Award from Darla Moore School of Business (University of South Carolina) in 2015, and the University of South Carolina Michael Mungo Undergraduate Teaching Excellence Award in 2015. He was the University of South Carolina nominee to the national U.S. Professor of the Year Award from Carnegie Foundation in 2015.

John B. Jensen is a clinical professor of global supply chain and operations management at the Darla Moore School of Business, University of South Carolina (USC) where he also serves as the managing director of the USC-Global Supply Chain and Process Management Center. He received his PhD in operations management from the University of South Carolina. Dr. Jensen's research has been widely published. In addition to teaching courses in operations management and process excellence, he consults through the Center's outreach initiatives with several firms. Jensen won the Alfred G. Smith Award for Teaching Excellence in 2013 and the International MBA Program Outstanding Elective Professor in 2012 and 2013. In 2008, he was awarded the University of Southern Maine Faculty Senate Award for Excellence in Teaching, and in 2007 the Outstanding Teacher Award within the College of Business.