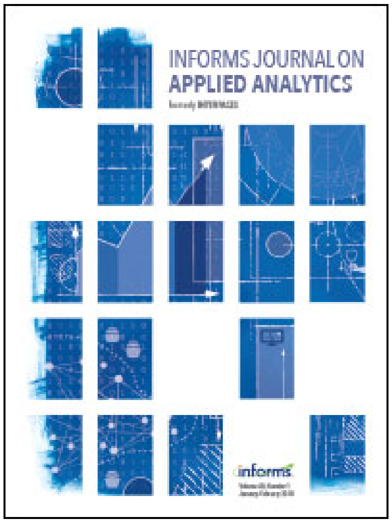

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http://pubsonline.informs.org

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Interfaces
Vol. 43, No. 1, January–February 2013, pp. 5–20
ISSN 0092-2102 (print) | ISSN 1526-551X (online)

http://dx.doi.org/10.1287/inte.1120.0655

THE FRANZ EDELMAN AWARD
Achievement in Operations Research

Supply Chain–Wide Optimization at TNT Express

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The application of operations research (OR) at TNT Express during the past seven years has significantly improved decision-making quality and resulted in cost savings of 207 million euros. The global optimization (GO) program initiative has led to the development of a suite of optimization solutions to assist the operating units of TNT Express to improve their package delivery in road and air networks. To create and deploy these solutions, we established communities of practice (CoPs), at which internal and external subject matter experts meet three times annually at an internal conference. We also created a unique two-year learning environment, the GO academy, where employees of TNT Express are taught the principles, use, and deployment of optimization techniques. As a result of these combined initiatives, OR is now an effective part of the core values at TNT Express.

Key words: express service providers; transportation; supply chain optimization; network design problem; pickup and delivery problem; change management; OR deployment.

TNT Express N.V., one of the world's leading business-to-business express delivery companies, operates the largest express road and air network in Europe, and air and road transportation networks in China, South America, Asia-Pacific, and the Middle East.

In this line of business, express delivery companies move packages (i.e., parcels, documents, or pieces of freight) from a sender to a receiver under various and guaranteed service-level agreements that specify delivery dates and times. Each service offering consists of collecting packages at a customer site, transporting them via a road and (or) air network, and delivering them to a recipient.

Each week, TNT Express delivers 4.7 million packages to recipients in over 200 countries, using a network of more than 2,600 facilities, a fleet of about 30,000 road vehicles and 50 aircraft, and a workforce of 77,000. Because of the highly volatile and competitive nature of the express delivery market, the company must ensure that its network is robust, agile, and able to effectively absorb demand fluctuations. Express delivery companies are focused on achieving both cost efficiency and high levels of customer service, two goals that are often contradictory. The challenge is to design a supply chain that can effectively meet both criteria and manage this critical balance between them. Given that point-to-point

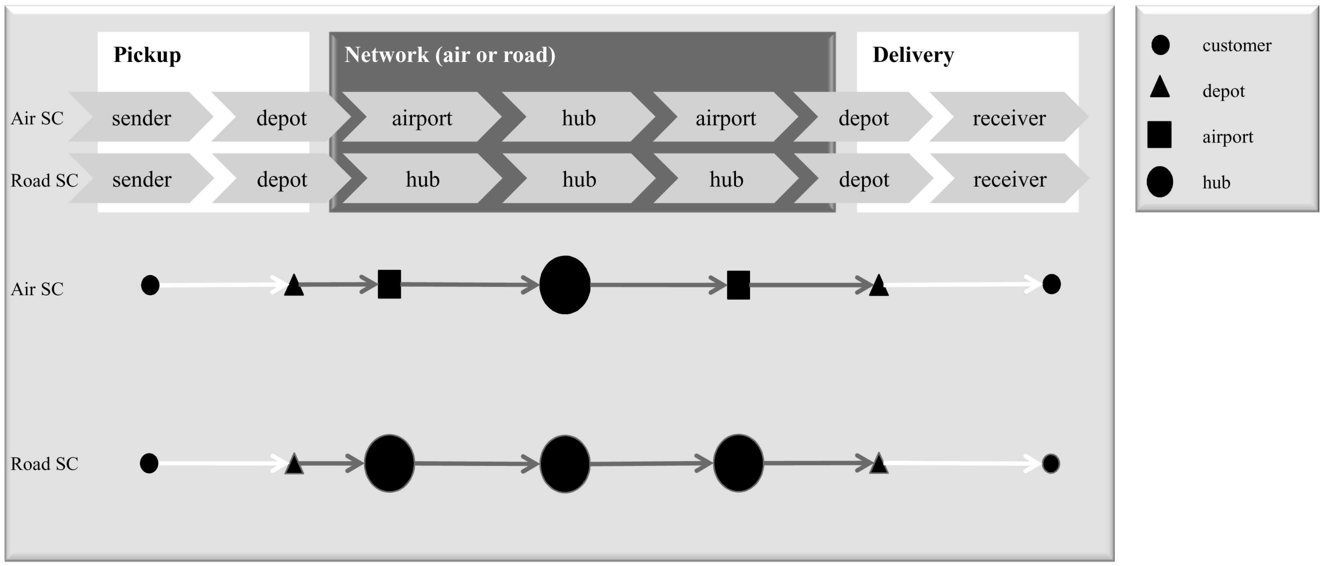

Figure 1: The TNT Express supply chain consists of road and air operations. The pickup and delivery (PUD) process concerns the collection and delivery of packages at the customers; the network process addresses the transportation of packages between depots.

volumes are typically too low to justify a single transport over large distances, we prefer to maximize consolidation to reduce costs. Conversely, our ability to transport packages efficiently is restricted by the types of services we offer, which may vary considerably. For example, we offer time-definite express services with a guaranteed next-day delivery before 9 AM, 10 AM, 12 noon, or the end of the day, but we also offer day-definite services for less-urgent shipments that do not require next-day delivery. As a result, consolidating packages from similar collection origins can be difficult because the delivery time frames may vary considerably. Figure 1 illustrates our air and road supply chains.

After collection, packages are transported to depots, which are local sorting centers that manage the collection and delivery of customer packages. Hubs are large sorting facilities used to consolidate the transport of packages between the depots. TNT Express refers to the collection and delivery of packages at the depots as the pickup and delivery (PUD) process, whereas the transport between the depots is the network process. Cutoff times (i.e., due times) separate the PUD process from the network process: at the pickup cutoff time, the packages must be available at the origin depot for the network process; at the delivery cutoff time, the packages must be available at the destination depot for the delivery process. The PUD process encompasses the processing time at the depots, whereas the network process includes processing times at the hubs. Although we separate the PUD and network processes, implementing each process presents a number of challenges. For example, the PUD process includes assigning customer pickups to a particular depot, deciding on the number of vehicles required, and determining when the vehicles will visit the customer for collection or delivery. In the network process, a number of important decisions are made; these include sorting centers to be visited, sequence and time of departure, and the schedules needed for the vehicles connecting these locations. At the supply chain level, decisions about cutoff times (e.g., allocating more time to one process in favor of another) and the number and location of hubs and depots required must be made.

Operations Research at TNT Express

In 2005, TNT Express embarked on its first operations research (OR) project. The initial strategy was to expand business activities rather than just focus on cost reductions and asset utilization. Senior management understood that focusing on growth would not guarantee a competitive advantage in the long run. Triggered by a story on optimization by Tilburg University professor Hein Fleuren, Marco Hendriks, Director of Strategic Operations and Infrastructure at TNT Express, sensed that quantitative methods should become the key enabler to increase the company's competitiveness. This awareness led to TNT Express' first OR project, which was aimed at optimizing Italy's domestic road network. The results were promising: by rescheduling vehicles and reassigning packages, asset utilization increased and transportation costs decreased by 6.4 percent. This initial success paved the way for the global optimization (GO) program and the close working relationship between TNT Express, Tilburg University, and ORTEC, an OR consulting and optimization software provider that partners with TNT Express on optimization activities.

The idea of incorporating OR into our decision making grew steadily. We were convinced that optimization activities should be at the core of our business and that we should not organize these activities within a separate, large, centralized OR department. To achieve these goals, we established communities of practice (CoPs) and the GO academy. A CoP is a community of TNT Express business experts worldwide, which a central GO team organizes. CoP meetings, at which participants share best practices and optimization knowledge and discuss these ideas with suppliers and academia members, are held three times each year. These meetings typically last two to three days and have 15 to 20 attendees. The GO academy is a two-year program designed to teach management and staff the principles of optimization, which will enable them to recognize optimization opportunities and develop a common global optimization language. As the added value of OR gained visibility, the TNT Express board adopted OR to develop strategies to respond to the consequences of the economic crisis in 2008. Senior management understood that by applying OR across the business, it would be able to manage unit costs more effectively, while continuing to fulfill all service obligations. Unit costs had become important because they were rising steadily as a result of decreasing demand, increasing fuel prices, and more stringent environmental regulations.

The GO Program

The goal of the GO program is to improve decision making throughout the TNT Express organization and in each part of its supply chain. To address the challenges in networks, the PUD process, and the entire supply chain, we set up separate subprograms for each. These subprograms led to the creation of a portfolio of models, methodologies, and tools designed to solve the optimization challenges we encountered. Given that each operating unit is at a different level of operational maturity, the solutions differ in optimization complexity. At the lower end of the maturity scale, dashboards and guards help the operating units to analyze their actual performance and identify new optimization opportunities. For the more mature units, we deploy advanced optimization solutions.

These solutions are important in identifying and realizing each GO subprogram cost saving; these savings were 207 million euros over the period 2008–2011: 132 million euros from the supply chain subprogram, 48 million euros from the networks subprogram, and 27 million euros from the PUD subprogram. The GO program also enabled us to reduce CO_2 emissions by 283 million kilograms—the CO_2 equivalent of 1,000 trucks traveling around the world seven times.

Although we expect more savings in the future, this paper focuses on the solutions that have been in use for some time and therefore contributed the most to the reported savings. These solutions, which we describe in the sections below, are: TRANS in the networks subprogram, SHORTREC in the PUD subprogram, and DELTA supply chain in the supply chain subprogram.

We also describe how our use of OR has evolved to become a key component in decision making via the GO program. We illustrate this by describing the OR methods we applied and the benefits accrued and challenges encountered to date. We then highlight the GO academy—a game changer for successfully applying OR within our company. We conclude by describing our findings on applying OR at TNT Express.

Subprogram 1: TNT Express Routing and Network Scheduling (TRANS)

Network optimization is concerned with optimizing routes for the transportation of packages and vehicle tours. Within TRANS, our optimization software, the network infrastructure (i.e., depots and hubs), the volume of packages to be transported, and the cutoff times are considered to be fixed. A transportation route defines the sequence of hubs, from the depot of origin through to the destination depot, including scheduled times of arrival and departure at the hubs, that a package will visit. A path is the simplification of a route, denoting only the sequence of hubs and excluding time information. Thus, multiple routes can operate along the same path. A tour describes the sequence of locations visited by a vehicle (and driver), including the times at which each location is visited. In general, tours start and end at the same location for the convenience of the driver. A movement connects two successive locations of a tour, with no intermediary stops. Characteristics of a movement are its departure and arrival times and the corresponding vehicle type. An empty movement is a repositioning of a vehicle that is not carrying packages. Figure 2 illustrates these definitions.

Because of the size of the networks that TNT Express operates, using a combined problem to determine the routes and tours would be too complex. Path generation is exponential relative to the number of locations; Italy's domestic network has about 100 depots and 10 hubs, resulting in over 35 billion possible paths for packages. Therefore, we separate the problem into several subproblems, each supported by a specific module in TRANS:

- The service capability analyzer determines the fastest feasible routes based on the prespecified movements in the network. The resulting fastest possible service offerings are visualized on a map. Service implications of modifications to the movement scheme (i.e., the total set of movements operated in the network) are recalculated within a few seconds to support what-if analyses.
- The routing module is an extension of the service capability analyzer. It generates a set of routes (not only the fastest) and assigns the packages to the movements of these routes. If packages cannot be assigned to movements, this is usually because of insufficient capacity, an issue that must be resolved. Conversely, if movements are underutilized, opportunities for improvements may exist. The routing module visualizes the overutilization and (or) underutilization of movements; however, it does not automatically resolve these issues.
- The movement heuristic module constructs a new movement scheme based on the packages and their corresponding paths and assigns them to the

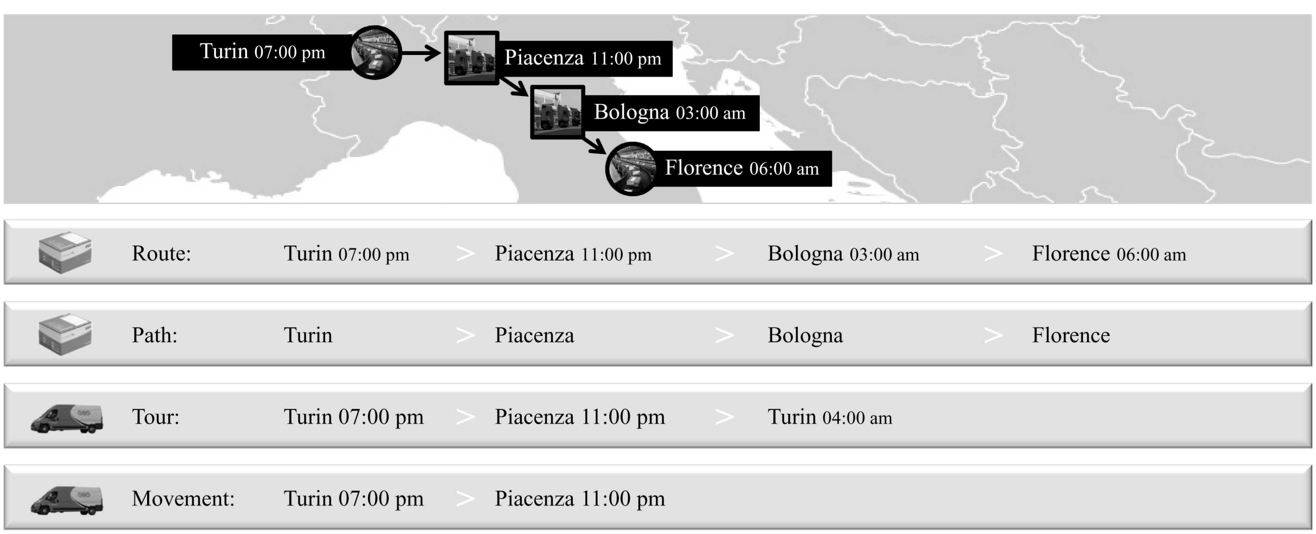

Figure 2: The path and route illustrate the movements of packages from their origin (e.g., Turin) to their final destination (e.g., Florence). The path is the subset of a route that excludes drop-off times. A movement connects two successive locations and is a subset of a tour.

resulting movements. The movement heuristic module can be used in combination with the optimal paths module to generate a new movement scheme, and can also be used to evaluate existing movement schemes.

- The optimal paths module determines the optimal paths for each package, given the current infrastructure of depots and hubs; it also considers service restrictions. In combination with the movement heuristic, this module supports the redesign of a network's arcs in its entirety.
- The tour generation module generates tours based on a movement scheme, including any empty movements. In general, empty movements are minimized to ensure that the tours generated are efficient.

All the above modules were designed and tested in close collaboration with the CoPs, who provided the business knowledge and requirements. Each module can be used as a standalone module or in combination with other TRANS modules; the results can be analyzed via a range of graphical visualizations and key performance indicators (KPIs).

Operations Research Techniques Used in the TRANS Modules

The problem solved by the service capability analyzer and routing modules can be formulated as a multicommodity flow problem (Ahuja and Magnanti 1993) in a time-space network, because of the required connectivity of movements at all locations. Root and Cohn (2008) describe the setup of this time-space network; a node (f_i, t_i) corresponds to a facility (i.e., a depot or hub) f_i at a point in time t_i, and an arc between (f_1, t_1) and (f_2, t_2) represents the flow of packages from facility f_1 to facility f_2, departing at facility f_1, at time t_1, and arriving at facility f_2 at time t_2. Each arc represents a movement. To solve the problem within a reasonable run time, irrespective of network size, we use a heuristic approach. For route generation, we apply a branch-and-bound algorithm to generate a user-defined number of routes that will meet the service requirements (note that the service capability analyzer needs only one route per origin-destination pair). The bounding rules are a combination of the number of hub touches (as low as possible), the arrival time at the destination depot (as early as possible), and the departure time at the origin depot (as late as possible). The branches result from the movement scheme; the occurrence of these branches is restricted to hub locations only, because the transfer of packages from one movement to another is permitted only at hub locations.

In addition to generating the routes, the route module assigns the packages to the routes that are generated. The assignment of packages to routes is based on route preferences and available capacity. In particular, the preferred route is taken for each set of packages (where the preference follows the same rules as the bounding rules), and the packages are allocated to route movements only if available capacity exists; if no capacity remains in any of the route movements, the second most-preferred route is selected; this assignment process is repeated until all packages are assigned to movements or until all routes have been evaluated.

The optimal paths module solves what the literature refers to as the tactical service network design problem. Crainic (2000) provides an overview of solution methods to solve this problem. At TNT Express, we implemented a mixed-integer programming formulation as proposed in Meuffels et al. (2010b), where the number of paths to be generated is restricted. The movement heuristic module generates movements based on the paths of the packages using the heuristic that Meuffels et al. (2010b) suggest. In the heuristic, any of the following three rules are used to schedule a movement: (1) when all packages are available at the departure location, (2) when a full vehicle movement can be created, or (3) because of the time restrictions. To generate tours based on a movement schedule, the tour generation module uses a set-partitioning approach, as described in Van Krieken (2006).

Implementation of TRANS

Prior to implementing the TRANS solution, TNT Express analysts were using spreadsheets to conduct network optimization analyses. However, because of the large size and complexity of the networks, they could analyze only small parts of the networks, which inevitably led to suboptimal solutions. Given that our analysts had been using spreadsheets for many years, we were reluctant to completely change their ways of working. Instead, we decided to develop a solution that was close to their spreadsheet environment, extended with several decision support modules to enable the analysts to work faster and more effectively on improving the performance of the networks.

The requirements and business logic for TRANS were developed and discussed in the CoPs and built by ORTEC and Tilburg University. The first modules developed were the service capability analyzer and the routing module, which our analysts used to identify, visualize, and apply step-by-step improvements to our networks. This step-by-step approach led to strong user acceptance for the tool. The GO academy and the central GO team were important enablers in creating awareness of and implementing this new way of working to improve network performance in our business units worldwide. TRANS has about two dozen users (members of the central network analysis team of a business unit or country) worldwide. As our analysts became more familiar with using quantitative models, we gradually increased the level of optimization complexity deployed. Working with TRANS has become a best practice at TNT Express.

Benefits of TRANS

By using KPIs of the whole network, we gained many insights that we could not gain by using spreadsheets. By carefully considering factors such as empty kilometers and movement utilization, the analysts were able to search for the most cost-effective means of transporting the packages.

The service capability analyzer was frequently used to compare our commercial service offering and the capabilities of a network. Figure 3 shows an example of service improvements for the Barcelona, Spain depot. Our analysts discovered that some service offering deadlines were too tight, resulting in low levels of customer service. By analyzing these types of scenarios in advance, we were able to avoid selling unachievable services to customers.

With the routing module, analysts can quickly evaluate changes to the movement schedule and easily apply any adjustments (e.g., alter a movement's time frame, adjust the vehicle type of a movement, change a movement's start or end location, or remove a movement from the schedule). Because it can generate more efficient tours, the tour generation module substantially reduced subcontracting costs and CO_2 emissions. We recently introduced the optimal paths and movement heuristic modules, which we are currently piloting in Italy; the preliminary results are encouraging.

Thus far, we have used TRANS to analyze approximately 15 road networks. From 2008–2011, we accrued cost savings of 48 million euros, reduced

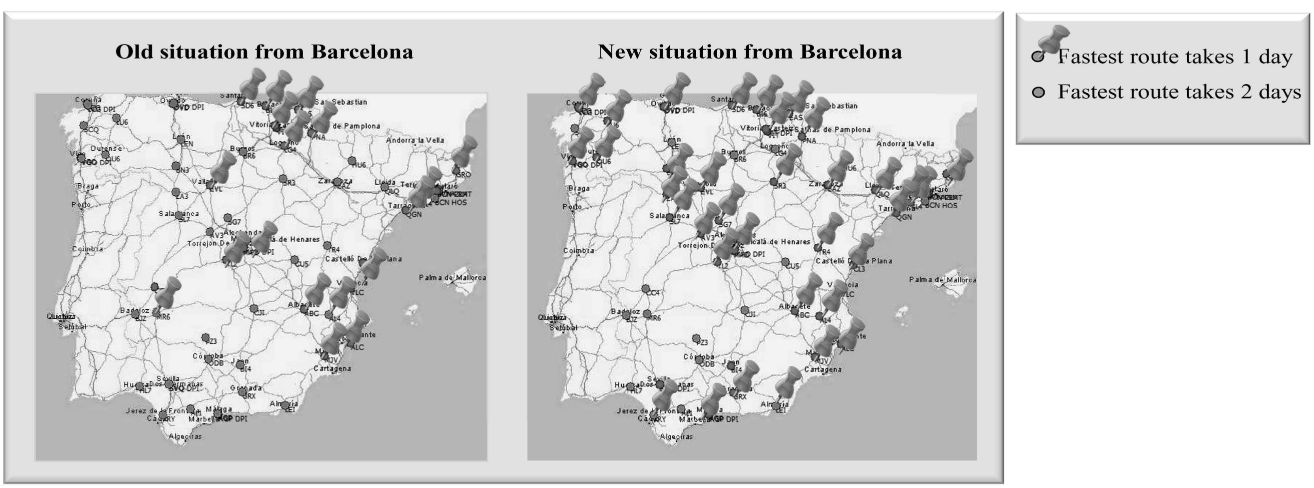

Figure 3: The service capability analyzer can be used to improve service capabilities, as this figure illustrates for the depot in Barcelona, Spain. On the left, the figure shows the old situation (i.e., prior to using this analyzer) with the locations for which a one-day service from Barcelona is available; on the right, the figure shows the new situation (i.e., after using the analyzer) in which more locations and regions have a one-day delivery service available from Barcelona.

kilometers driven by 69 million, reduced CO_2 emissions by 44 million kilograms. Some countries contributing to these savings used only the service capability analyzer and routing modules—not the full suite of modules described above. Based on the achievements to date, we anticipate additional savings in the near future, particularly as the use of the more advanced optimization modules becomes more widespread.

In addition to these quantitative benefits, we achieved a number of qualitative improvements, particularly in the area of service provision. This type of solution reduces the analysts' workload and provides them with opportunities to improve their analysis quality and their way of working. An example is the creation of annual schedules. Prior to using TRANS, analysts created a single annual schedule that included exceptions during peak periods. With TRANS, analysts can now create multiple schedules, including ones that can cope with the volume differences between workdays and weekends. Finally, TRANS changed the mind-set of both analysts and managers: each group now focuses on searching for additional opportunities to optimize the network.

Subprogram 2: Tactical Planning in Pickup and Delivery (SHORTREC)

At TNT Express, PUD, which is planned at the depot level, impacts the first and last mile in the supply chain. Given that PUD accounts for more than 30 percent of operational costs, it is an important focus area of the GO program. At TNT Express, a round corresponds to a single vehicle starting at the depot, visiting customers in a certain sequence for collection or delivery of packages, and returning to the depot. Customer PUD rounds are determined during tactical round planning. Effectively organizing the PUD process is challenging because millions of packages must be picked up and delivered each week.

The optimization problem in the PUD process is to minimize the total pickup and delivery costs while meeting all service-level requirements. This implies minimizing the number of rounds (fixed cost) and the kilometers and hours driven for each round (variable cost). In PUD optimization, the depot locations and their cutoff times are fixed. Constraints that must be considered are vehicle capacity, service levels, driver regulations, and some softer constraints to ensure repetitiveness in the rounds and workload balancing. From an operational point of view, it is important to ensure that the daily pickup and delivery rounds remain consistent to prevent (1) disruptions to the sorting and loading processes at the depots, (2) increased workload, and (3) potential errors. The creation of consistent rounds increases customer satisfaction because the same driver visits the customer each time and can establish a positive working relationship with that customer. However, generating and executing similar rounds for each day of the week is difficult because of volume fluctuations. To deal with these challenges and support our analysts in PUD optimization, we implemented a modified version of ORTEC's advanced vehicle-routing and optimization software, SHORTREC.

Operations Research Techniques in SHORTREC

In logistics, the problem of generating rounds at minimum cost is known as the vehicle-routing problem (VRP), which Dantzig and Ramser (1959) studied first. Golden et al. (2008) provide a more recent overview. Given that the VRP problem is NP-hard, only small instances can be solved to optimality. Because of our problem sizes (e.g., the Rome depot handles 90,000 stops per week), combined with the additional nonstandard constraints to enhance productivity at the sorting facilities, we selected a heuristic optimization approach in SHORTREC.

To ensure that the rounds are sufficiently robust to handle volume fluctuations and to ensure a balanced workload across rounds, we introduced the concept of μ-zones. A μ-zone is a geographical area comprising a set of customer visits and a total average working time (i.e., drive time plus stoppage time) within a specific time bucket (e.g., an hour). Our preference is to establish visually attractive (i.e., nonoverlapping and convex) μ-zones. In the PUD process, a round traverses a series of neighboring μ-zones; each customer location in the μ-zone is visited, while driver regulations are satisfied. Volume fluctuations lead to changes in working time within a μ-zone (and, as a result, the working time of the round) and the utilization of the vehicles. By reassignment of μ-zones to rounds, the change in working time of the round

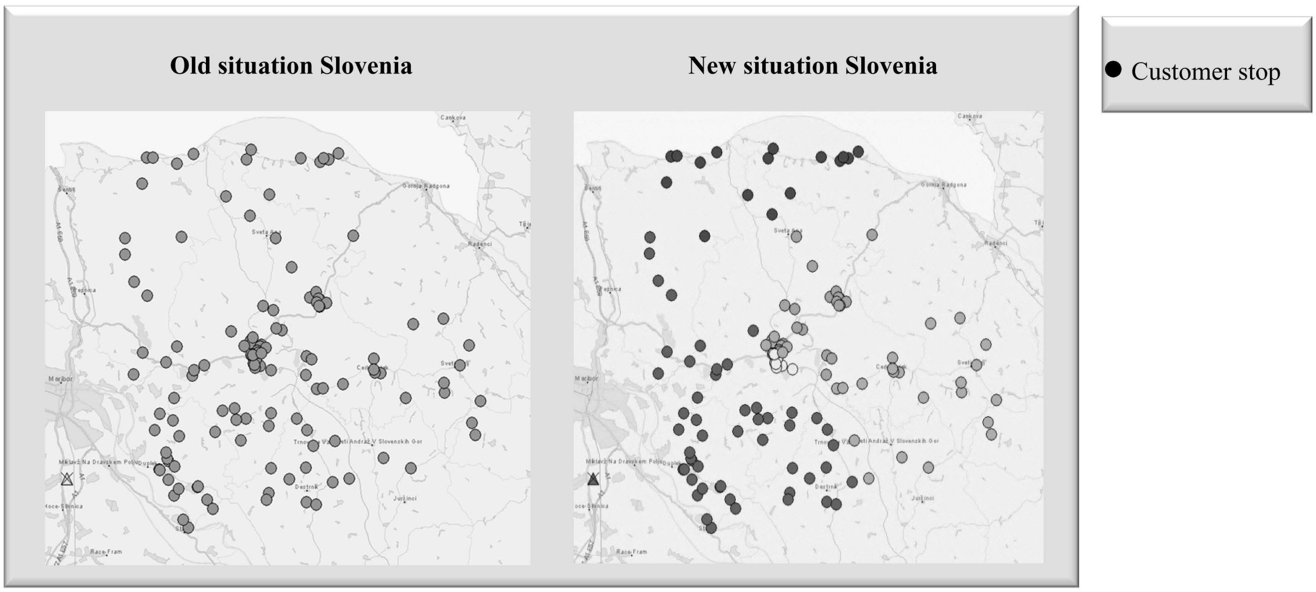

Figure 4: The figure shows μ-zone construction in SHORTREC for a part of Slovenia. On the left side, the old situation (i.e., prior to using SHORTREC) shows the stops to be clustered; on the right side, the new situation (i.e., after using SHORTREC) shows the resulting clusters—each with a different shading.

can be absorbed with minimal change to the overall round structure, preventing large changes in the depot sorting process. In cases of large fluctuations in volume, new rounds are added or removed. The μ-zones are created using the k-means clustering algorithm (Kärkkäinen 2006) and can be clustered into separate, geographic territories, each one served by a single PUD round (see Figure 4).

To ensure that a PUD round is both feasible and cost effective, the round is evaluated in detail and optimized using the local search improvement algorithms in SHORTREC. The round might be improved by changing the sequence of customer visits within or between the μ-zones. If required, μ-zones can be exchanged between rounds. For an extensive description of the improvement algorithms used in SHORTREC, refer to Kant et al. (2008).

Because of the size of the problem instances, calculating distances and driving times was another challenge. The normal procedure is to calculate the distance and driving times, store the results in memory, and construct the rounds. However, this process requires a huge amount of memory (recall that the Rome depot has 90,000 stops per week). By using the concept of highway-node routing (Schultes 2008), a method that exploits the layered structure of digital road networks, we were able to reduce computation times and memory consumption, allowing for on-demand calculation of distance and driving times. As a result, depot managers and analysts can optimize large instances on a normal desktop computer using SHORTREC.

Implementation of SHORTREC

Given that TNT Express has more than 2,000 depots, it was infeasible to implement SHORTREC in all locations at short notice. Therefore, we set a goal of optimizing all the rounds in the depots of our main business at least once a year. Local staff and the central GO team implemented the optimization projects. To build trust and overcome resistance, the first step in the standard SHORTEC implementation procedure was to model the existing round structure of a depot. Supported by the graphical capabilities of SHORTREC, a member of the central GO team demonstrated to the depot manager that the SHORTREC results using the current rounds were comparable to the actual costs, kilometers driven, and round structure. Schedule improvements were then generated using a standard set of optimization scenarios. This standardized approach was developed in conjunction with the CoP members, carefully documented, and tested in various countries. The set of scenarios describes different ways of working in PUD and contains various scenarios, including evaluating combined PUD rounds, combining the pickups and deliveries of different types of packages (with regard to service and volume), or analyzing the cutoff times at the depot. Each depot must apply this standard set of scenarios, allowing each to reach a high level of optimization. This standardized implementation approach enabled us to rapidly deploy SHORTREC and disseminate PUD optimization knowledge within the organization.

Benefits of SHORTREC

SHORTREC has been deployed successfully in many European countries, including the UK, Germany, The Netherlands, Belgium, Italy, France, Spain, Austria, Denmark, Norway, Sweden, Portugal, and Greece, and has been used in various optimization projects worldwide. This deployment is ongoing because our ultimate goal is to optimize each depot at least once a year.

During 2008–2011, six percent of the depots in Europe (260,000 rounds) have been optimized, resulting in 25 million euros in cost savings and an estimated accumulated CO_2 reduction of 11 million kilograms. With SHORTREC, we are now able to weigh the additional cost of creating visually attractive PUD rounds against the advantages that can be achieved in the sorting process at the depots. Moreover, because of the improved quality of the rounds, customer service has improved. Furthermore, daily improvements in terms of our ability to cope with volume fluctuations have been achieved as a result of the generated μ-zones. By using OR techniques, we are able to easily adapt decisions on the structure of rounds to absorb volume fluctuations by simply exchanging μ-zones between rounds.

Subprogram 3: Supply Chain Optimization (DELTA Supply Chain)

Because of the worldwide financial crisis at the end of 2008, TNT Express faced a strong decline in volume that continued until mid-2009. This drop in volume and associated revenue brought about an abrupt decline in air network performance, a problem that required an immediate solution. Because the air network forms a crucial part of our global service offering, we were impelled to start an end-to-end supply chain optimization project that would reduce aircraft use, preserve future growth capabilities, but not worsen service. Based on the achievements of the GO program up to that time, we realized that we needed a tool that could support us in making strategic decisions and bring fact-based decision making to the board room. We decided to build the DELTA supply chain model, which would include every relevant detail of our supply chain and focus on reducing aircraft use as its first priority. Using the results of this model gave us the insight that we could decommission 12 of 59 airports and open one new airport, thus significantly reducing air transportation costs with minimal impact on customer service. More importantly, the results enabled us to survive the financial crisis. Stimulated by this success, the DELTA supply chain model became an important instrument in the development of our board's Vision 2015 strategy.

The DELTA model enables us to optimize our complete supply chain for a fixed depot and hub infrastructure under varying volumes and ways of working (e.g., cutoff times, road and air transport). To the best of our knowledge, this is the only model in the express delivery industry that covers a complete air and road supply chain. We decided not to build one integrated model, but to design specific submodules to separately optimize the key components of the supply chain. By choosing to model the supply chain in this way, we could more easily understand and rely on the model's capabilities, which led to increased support for the decision-making process.

Operations Research Techniques in the DELTA Supply Chain Model

A typical DELTA model run begins with a volume-demand scenario. Cutoff times are imposed to secure the times required for both the PUD and network processes. The model aims to use road transport rather than air transport because the former generally results in lower costs and CO_2 emissions. The road network model determines the shortest paths for the packages by using the locations that may be visited as input. To incorporate network timing effects, we use hub time windows for the sorting activities, setting the latest arrival and earliest departure times to and from the hubs. Based on these time windows, we are able to determine if the service requirements for the specified packages can be met via road transportation. For packages that can be shipped by road, the number of required movements is calculated based on the routings of the packages. Any empty movements are determined using a classical transportation model that calculates the number of empty repositioning movements to estimate the cost of repositioning.

For the packages that are unable to meet the service requirements via the road network, we construct an air network using a separate model to create a minimum-cost air schedule between the airports in the network. The model starts by assigning depots to the airports in the air network based on one of two criteria: (1) best service (i.e., latest departure from, and earliest arrival at, the depots, based on the predefined earliest departures or latest arrivals at the airports), or (2) lowest cost (i.e., shortest distance between the airport and depot). Based on these assignments, the model determines the packages to be transported from the airport to the air hub and vice versa. Next, a mixed-integer programming problem is solved to determine the minimum-cost air schedule. The model ensures that sufficient aircraft capacity is available to carry all the packages, and it balances the number of incoming and outgoing aircraft per aircraft type at each location. The aircraft that can be used are restricted by a minimum and maximum number per aircraft type and the aircraft operating characteristics, such as maximum flying range, effective speed, cargo capacity, and landing restrictions. For airports, the model includes the following: the earliest permitted arrival or departure times, airport closing times, and the consideration that some airports do not permit multiple stops by TNT Express airplanes. Finally, for the air hub, the sorting time window is included, setting the latest arrival and earliest departure time for the aircraft, and the runway capacity at the air hub.

This model is based on the work of Armacost et al. (2002), with some additions to capture the specifics of the TNT Express operation. One main difference is the restriction of the number of stops at an airport. At some airports, we strongly prefer that all packages arrive and depart via one aircraft because this simplifies the handling process. A second difference is the inclusion of more detailed modeling of the runway capacity at the air hub. Instead of restricting the total number of arrivals and departures at the air hub, we would like to position them across time. Our approach is similar to the work of Barnhart and Schneur (1996). We also include the functionality to use a minimum or maximum number of aircraft per type, which may be used in the European Air Network, to cope with restrictions on fleet availability. For some situations, we even would have functionality to fix specific aircraft operations between two airports in the network. This request originated because the European Air Network is sometimes used in a combined setting for domestic network operations (in which TNT Express-owned aircraft are used).

With the road and air network complete, a binary integer programming model estimates the impact of the network movement arrival and departure times on the PUD cost. This model determines the optimal wave structure of every depot. We define a wave as a set of rounds that start and end at the same time at the depot. In the case of multiple arrivals at a depot, starting part of the rounds before all packages have arrived might be beneficial because this ensures that the rounds have a longer working day. This is particularly useful when packages destined for nearby customers might arrive at the depot at different times. If so, multiple rounds will have to be assigned to the same location area, resulting in larger average distances between stops. Similar advantages and disadvantages apply to collections whereby multiple departures occur in the network. The binary integer model determines the optimal number of waves required to balance both the length of rounds in a wave and the extra kilometers to be driven. In a final step, the model calculates the total cost and service KPIs of the complete supply chain to support management decision making.

DELTA Supply Chain Model Implementation Challenges

Because of the board's tight schedule to rationalize air operations in 2008, substantial work was required within a very short time frame. Some team members were requested to completely clear their agendas of other activities for a number of weeks. A cross-functional strategic operations team, including modeling and optimization specialists from both ORTEC and Tilburg University, was set up. The team monitored the progress of the project and became the platform for discussion and agreement on the many issues encountered during the project. The development of the DELTA supply chain model was a difficult task because the model covers all of Europe and consists of about 650 depots, 90 hubs, and 150,000 origin-destination combinations. The challenge was to provide the right level of detail to support the board in its decision making, but not so much detail as to render the results useless and distract the board from crucial insights and decision factors. Fortunately, work done in the previous years in each GO subprogram provided us with the experience we needed to agree on the relevant details of the model. However, because many team members were not yet familiar with strategic modeling, some members wanted to incorporate much more detail than was needed. As a result, a great deal of discussion and salesmanship ensued so that the team members would agree on the appropriate (strategic) level of detail that would be acceptable to each stakeholder.

Data gathering was another major challenge. Our experience led us to believe that the data gathering and verification exercise for this type of analysis could take months, even for one country. We were tasked with acquiring data for all of Europe within only eight weeks.

Convincing people to execute the model was not an issue, because its major users were people in the strategy department of GO and consultants of ORTEC; however, building the decision makers' trust in using the model results was a challenge. They often did not immediately accept the initial results, mainly because certain details had been omitted from the calculations; however, more importantly, the new insights gained from the DELTA supply chain model violated their prior beliefs about operating the TNT Express supply chain. To show that the model's results were relevant and consistent, we formulated a number of scenarios, evaluated them, and explained them in detail. For example, to determine which airports to close, we generated and optimized more than 20 scenarios. Although the model showed consistent results for these scenarios, the air network analysts recalculated the results with very similar outcomes. As trust in the DELTA supply chain model grew, the TNT Express board became more confident in the results and decided to move forward based on the insights gained. It implemented the model results and used them to build its Vision 2015 strategy.

Benefits of the Strategic Analyses

The DELTA supply chain model has become a vital instrument for generating and analyzing air network optimization scenarios for various airport compositions. In 2008 and 2009, we opened one new airport and closed 12 of our 59 European airports (see Figure 5); the impact on service levels was minor—less than 0.5 percent of the volume arrived more than one hour later. Furthermore, we also eliminated six aircraft, three of which were expensive A300 aircraft. Naturally, this incurred some additional costs because of the longer distances driven between airports and depots. However, total net accumulated savings were 132 million euros and the CO_2 emissions reduction was 228 million kilograms. Achieving these reductions within such a short period improved our agility and ability to create value, even with volatile demand.

To develop the TNT Express Vision 2015 strategy, a number of operating modes and European network designs were evaluated using the DELTA supply chain model. Various scenarios were analyzed (e.g., separating parcel and freight volumes in Europe, reducing stop-time in PUD, altering the available time between PUD and network operations by varying the cutoff times, and investigating the robustness of our road and air networks). The insights gained from the DELTA supply chain analysis strongly contributed to the development of our strategic vision. Combining volumes (i.e., parcel and freight) resulted in a cost avoidance of four percent on supply chain costs. Although this insight was initially counterintuitive, analyzing the cost details resulting from the model convinced us of the correctness of the outcomes.

The DELTA supply chain model allows us to test our supply chain operation improvement ideas without having to experiment in practice. For example, when we used this model to calculate the impact of

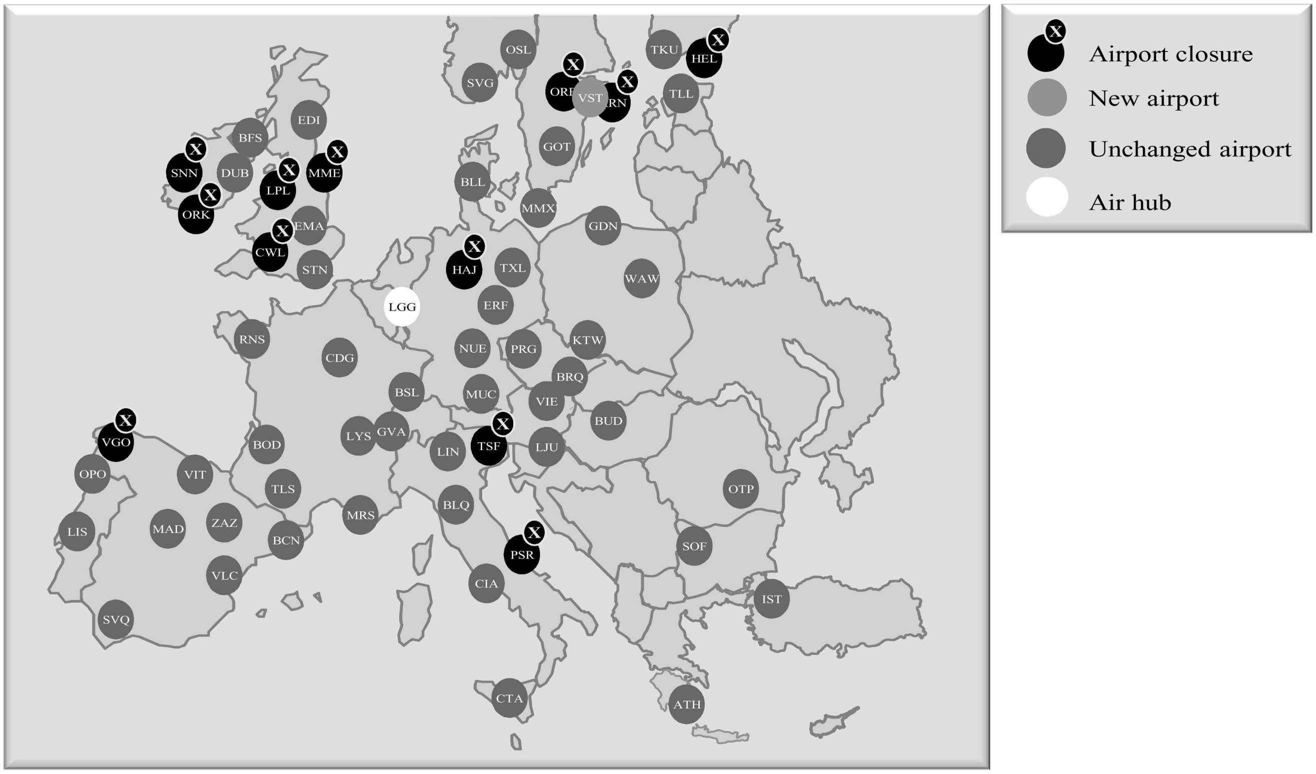

Figure 5: The figure shows the final result after management decisions; management decided to close 12 airports and begin TNT Express operations at one new airport.

changing the cutoff times, it provided insights on the trade-offs between network costs and PUD costs that we would have to make. As a result, we initiated follow-up projects to analyze and change the cutoff times for potential new locations in our network. The model also indicated that substantial benefits could be achieved by increasing the capacity of certain depots and hubs. The reported benefits did not include the benefits of the Vision 2015 projects.

Finally, after observing the potential improvements that could be achieved by optimizing the balance between the PUD and network processes, we started to develop models to optimize the depot and hub infrastructure. Initial results show that the savings potential is enormous; in the coming years, these savings will be achieved gradually because changing the infrastructure quickly is impossible. We will continue to use the DELTA supply chain solution regularly to search for large improvements.

General Deployment Challenges

Implementing tools such as TRANS and SHORTREC takes time and effort. First, it takes time to convince analysts, network managers, and depot managers, most of whom are unfamiliar with optimization, to adopt new tools that they might initially see as reducing their control of the analysis. Second, the available data, although numerous, were spread across many local information technology (IT) systems, thus reducing the quality and quick availability of the data required. Some data (e.g., the delivery or pickup address) must be detailed, and the data received are often either incomplete or incorrect. This problem was partially solved by introducing GO data management, a data cleansing and conversion tool that makes the data retrieval from our IT systems repeatable. In particular, this tool describes a set of business rules to map the source data onto the GO data structures; this is an evolving process because business rules or data structures sometimes change. Furthermore, we realized that significant effort is required to create a user-friendly and fast model that supports the analysts in evaluating various planning scenarios and understanding the differences between them.

When developing decision support solutions, we knew that we would be setting the standard for all countries in which TNT Express operates. This proved challenging because these countries have many ways of working, variances in volume profiles, and local regulations, any of which could impact our creation of a standard model. For example, TNT Express uses loose-loaded trucks in Italy, pallets in France, and cages in the European road network. TRANS had to support all these requirements; in addition, we had to find the right balance between generic and country-specific requirements in each instance.

Another challenge we faced was objectively tracking results. Managers who successfully meet their optimization targets often receive a budget decrease in the subsequent year. This could affect the quality of the submitted results, especially because the managerial bonus system is based on the budget targets. Even a slight deviation from the optimal solution in practice may increase cost, making it difficult to attain the bonus targets. Therefore, to measure the results objectively, we introduced a benefits tracking system that uses three levels of savings to monitor the benefits: identified expected savings, agreed savings, and implemented (realized) savings. The savings presented in this article are the implemented (realized) savings; cost avoidance is not included.

GO Academy

Most new users were resistant to change, even when we could demonstrate successes in nearby operating units, because they felt that their business was not comparable. Furthermore, the task of explaining the general optimization principles of the tools was time consuming. These two challenges led us to implement the GO academy, a unique learning concept in optimization.

The main objective of the GO academy is to teach optimization principles to TNT Express employees and to acquaint them (at a high level) with the available optimization tools, without turning them into mathematicians. We discovered that one of the most important lessons we can teach is that investing a little in one part of the supply chain can result in large benefits in other parts. Another principle we taught is that to strategically optimize a supply chain, considering all details is unnecessary. Third, we teach that the combinatorial explosion forms the basis of many frequently encountered planning problems. We use various methods to teach these principles; these range from conceptual explanations and practical assignments to simple but powerful computer games. An example of the latter is the GO game, in which a tactical and strategic solution for an express network must be constructed; Meuffels et al. (2010a) contain a description of this game. To date, over 500 managers and staff, including the TNT Express board of directors, have successfully completed this game.

Module	Name	Topics
1	Introduction module	Customers and their supply chains
2	Strategic optimization	Infrastructure design (DELTA)
3	Networks and PUD	Planning in networks and PUD (TRANS and SHORTREC)
4	Hubs and depots	Bottleneck theory, mechanization principles
5	Implementation	Change management techniques
6	Graduation	Presenting for impact, elevator pitches

Table 1: The six GO academy modules train participants in optimization principles and practices used by TNT Express. The table lists the modules and the topics included in each module.

The GO academy training program consists of six three-day modules conducted over a period of two years, interspersed with small group assignments (see Table 1). After a group completes each module, the group composition is changed to promote networking—a key benefit of the academy. After completing the fifth module, students are given two days per week for six months to complete their final assignment, a master case study. The case study, sponsored by one or more senior managers and guided by an academic supervisor, is based on an actual challenge at TNT Express. Students present the master case results on graduation day. Within the operations arena of TNT Express, this day has become a big networking event that most of our senior managers and our CEO, at times, attend.

In addition to optimization skills, the GO academy training program focuses on the development of personal and interpersonal skills: presentation skills, debating ability, working on camera, and elevator pitches.

Graduating employees are designated as supply chain masters, an internal title that remains in effect as long as the employee completes at least one optimization project per year. Project results, suggestions, and ideas are published on an internal website, Collaborate. These projects are judged as part of an annual supply chain master competition; on graduation day, an award is given for each category (i.e., networks, PUD, and supply chain).

Since its inception, the GO academy has successfully met its main objective—to teach the principles of optimization. We frequently find that it is unnecessary to convince people of the benefits of optimization because they are coming to us for support and advice. This is a definite turn of events and one that proves the effectiveness of the training academy concept.

Furthermore, the supply chain master case studies have delivered a number of significant benefits in several areas. In addition to cost savings of approximately 5.7 million euros, networking within TNT Express has improved dramatically. After collaborating on assignments during their two years in the GO academy program, employees build strong relationships with each other; they also feel more empowered to ask for support from colleagues in other operating units or even in other parts of the world. Employees now use the same business language and have the same understanding of definitions and terminology (e.g., cutoff time, μ-zone). At TNT Express, it has become apparent that platforms such as the GO academy are ideal arenas for discussing and explaining the operational implication of strategy changes. The GO academy has exceeded our expectations.

Transportability

The above lessons are applicable and transportable to any organization that wants to apply and embed OR on a large scale. To illustrate the transportability of our approach, we outline our contribution to the World Food Program (WFP), the world's largest humanitarian aid organization, which feeds more than 90 million of the poorest people on earth. In conjunction with the WFP, we developed a simple hub-and-spoke network for food distribution for Ethiopia. The feeding of children in more than 2,000 schools in Liberia has been optimized with SHORTREC and has yielded 10 percent savings on transport costs. We are proud that the WFP is actively involved in our CoPs and GO academy. We currently are sharing our core ideas of supply chain optimization with the WFP strategic logistic team in Rome.

Challenges

The introduction of optimization to TNT Express has been and will continue to be an intensive process with many challenges. Of course, data availability and quality are always an issue in an OR project. In addition, more decision makers need to become familiar with optimization principles, especially in cross-functional areas such as marketing, sales, and finance. Applying OR principles at the board level brings another set of challenges. Given the involvement of people from varying backgrounds, we required a great deal of discussion to determine the right level of detail for strategic modeling. Gaining acceptance of our approach required a high level of didactical skills and salesmanship. The most significant challenge related to the time pressure because of strict time lines (e.g., shareholder meetings, executive board meetings) and short decision time frames.

Concluding Remarks

The best way to apply OR in a business that is unfamiliar with the concept of optimization is to start simple and follow the maturity level of the business in applying more advanced methods. Forcing the use of OR—if it is not well understood—will only increase resistance and decrease user acceptance. The ability to visualize the business challenge contributes significantly to lowering resistance because users are able to more easily recognize the challenges. Using basic OR techniques from the start makes possible the building of trust and understanding, and improves data quality. Most of the savings and CO_2 reductions discussed in this paper can be attributed to these basic OR solutions.

As soon as people become more familiar with OR modeling, advanced techniques (e.g., scenario analysis, simulation, and mixed-integer programming) can be introduced. The development of OR models and tools in close collaboration with the business leads to increased trust and acceptance by end users. We facilitated model and tool development by introducing CoPs, in which our subject matter experts and external OR experts derived and honed the requirements of the solutions to be developed.

Parallel to developing tools, we realized the importance of teaching employees the fundamentals of optimization to encourage the dissemination of knowledge and allow for fast implementations. As a result of the GO academy, a huge network of people who recognize optimization possibilities and whose knowledge the company can easily tap into exists within TNT Express. We initially set up our central GO team with five people and currently have about 30 people whose full-time jobs involve applying OR at TNT Express; senior management and over 200 supply chain masters support them. Optimization has become part of the core values at TNT Express.

Acknowledgments
We thank all the people who contributed to the success of the GO program and the GO academy. Moreover, we are very grateful to the people who gathered the data presented in this paper. We give special thanks to Yoshiro Ikura and Andres Weintraub for their active guidance as our coaches in the Franz Edelman Award Competition.

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