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Menlo Worldwide Forwarding Optimizes Its Network Routing

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Since 2000, Menlo Worldwide Forwarding (formerly Emery Worldwide) has faced a particularly challenging business environment that has been exacerbated by a weakened economy, the events of September 11, and a decreasing demand for airfreight. To meet these challenges, the company and Menlo Worldwide Technologies developed a network-routing-optimization model to optimize Menlo Worldwide Forwarding's North American transportation network. The project team and senior managers have repeatedly identified and applied low cost solutions to meet the changing and complex network-routing requirements. By maximizing its use of network capacity, the company has increased profitability and reduced operating costs while maintaining high service levels. In 2002 alone, Menlo Worldwide Forwarding reduced operating costs by 21 percent, increased operating margin by 41 percent, and improved financial results by $80 million in the North American aircraft transportation operation. Moreover, management used the optimization model to facilitate Menlo's transition from a heavily asset-based, integrated airfreight company to an asset-light, freight-forwarding business. This created a flexible operating environment and a competitive advantage for future operations.

Key words: transportation: models, network; industries: transportation, shipping.

Menlo Worldwide is a $2.7 billion company that employs 15,000 people and provides global supply-chain services in more than 200 countries. Four major components operate under Menlo Worldwide's brand name: Menlo Worldwide Forwarding, Menlo Worldwide Logistics, Vector SCM, and Menlo Worldwide Technologies. Menlo Worldwide Forwarding (formerly Emery Worldwide) is a global transportation and logistics provider. Menlo Worldwide Logistics is a leading third-party contract logistics firm. Vector SCM is a joint venture with General Motors (GM) that is GM's lead logistics service provider worldwide. Menlo Worldwide Technologies was formed by combining the information technology departments of the three operating companies named above.

Menlo Worldwide Forwarding has more than 55 years of experience in transportation, logistics, charter, ground, and airfreight operations. Known for its ability to ship heavyweight airfreight (which is defined as freight that typically exceeds 75 pounds per shipment and requires the use of a lift device), Menlo Worldwide Forwarding ships commercial, industrial, and government freight worldwide. The company operates in 229 countries and maintains more than 600 logistics centers around the world. To meet the varied service requirements of its customers, Menlo Worldwide Forwarding has built and operates a complex network of aircraft and trucks within North America (Figure 1). The network connects 150 logistics centers and eight regional hubs and provides next-day, second-day, and economy service within the continental United States and selected Mexican and Canadian locations. The network also connects Menlo's international freight to the North American markets through 12 international gateways.

The core of Menlo's North American network is the nightly transportation and sortation of freight that takes place at the Dayton hub facility. These operations, referred to as "primetime" within Menlo, utilize an integrated network of aircraft and trucks to provide next-day service. This network operates in a hub-and-spoke fashion with the inbound and outbound aircraft and truck routes forming the spokes and Menlo's on-airport sortation facility in Dayton, Ohio, the central hub. The Dayton hub is a one million square foot complex with a sorting capacity of over 1.2 million pounds of freight per hour. It has a 50-slot truck dock and enough ramp space (and ground handling equipment) to accommodate 70 aircraft that

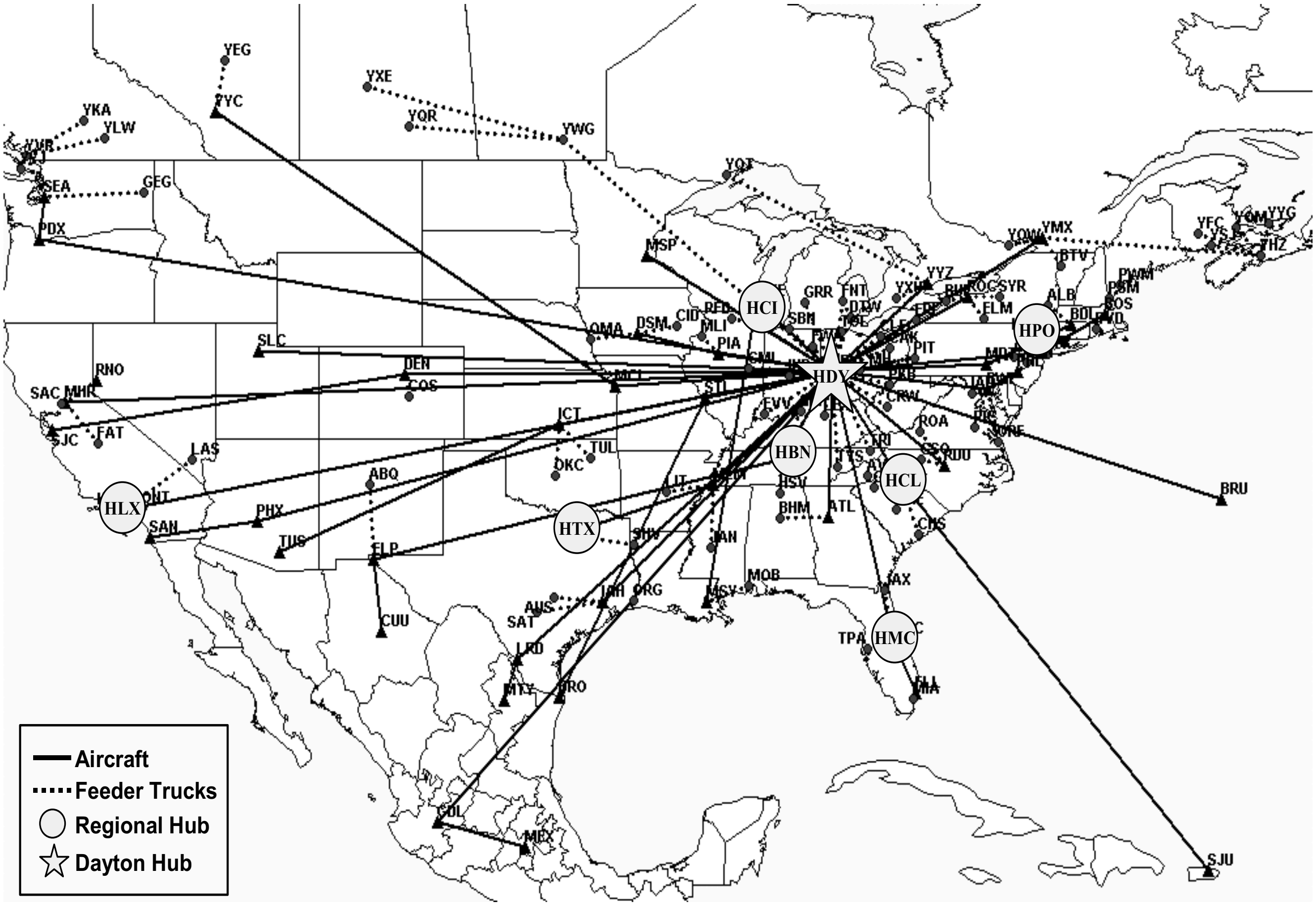

Figure 1: This example of Menlo Worldwide Forwarding's primetime network shows aircraft and truck routes.

can range in size from a Boeing 727-100 to a Boeing 747-200. These features enable the simultaneous loading and unloading of aircraft and trucks, the breakdown and buildup of the aircraft and truck shipping containers and the sorting and processing of the nightly primetime freight, all within a four-hour sort window. Using its North American network, Menlo processes several million pounds of freight daily, generating approximately $1.5 billion in revenue each year.

The primetime network operates as follows: Freight is delivered to one of the North American logistics centers by a customer or by a scheduled Menlo pickup. Here the freight is processed for delivery and loaded into a shipping container. From these logistics centers, the freight is transported either to the Dayton hub via an inbound aircraft or truck or to another designated location (such as the nearest air location, one of the company's regional hubs, or an international gateway) by a connecting feeder truck. When the freight reaches its intermediate destination, it is unloaded, sorted, and reloaded onto an outbound truck or aircraft for delivery to the logistics center nearest its final destination.

During the early and mid-1990s, when business within the US was booming, Menlo Worldwide Forwarding's US and international freight volumes grew steadily. To serve its customers' shipping needs and take advantage of business opportunities in such areas as charter sales and US Postal Service Priority Mail, Menlo Worldwide Forwarding expanded its transportation-network and hub-sorting capabilities. It added aircraft to the fleet and expanded and modernized the Dayton hub. It also created a network of seven regional hubs to facilitate its processing of regional, second-day, and economy freight. These changes, however, greatly increased the complexity of the North American transportation network.

Management within Menlo Worldwide Forwarding recognized that it needed sophisticated decision-support tools to help it run the complicated North American network more cost-effectively. Although it had invested millions to develop software that enhanced its shipment tracking, cost accounting, crew scheduling, and aircraft maintenance, these programs were largely stand-alone systems that did not provide users with a means to conduct what-if routing analyses or support network planning.

To address the shortfall, Menlo Worldwide Forwarding began evaluating existing modeling tools and off-the-shelf software packages. The company wanted to reduce network operating costs and replace the manual network-planning process with a computerized process. The firm's original plan was to purchase a commercial software package and contract for any needed changes. Towards that objective, it evaluated several packages. Some could support optimization of Menlo's truck networks but no package was found to optimize the air operations or the integrated aircraft and truck primetime network. Most of the airline software packages were designed to support aircraft maintenance, crew scheduling, airline passenger operations, or aircraft scheduling—not network optimization. Finding no suitable software package, Menlo Worldwide Forwarding selected the software package that was the closest fit and worked with its developer to create a proof-of-concept demonstration that focused on the optimization of the air network. Results of these efforts were uninspiring. Although prototype software was developed to a functional level, this software failed to show any real cost savings potential. The optimized results (albeit preliminary) were no better than those of the existing manual process.

In parallel to the proof-of-concept demonstration, the Menlo Worldwide Forwarding management team opened a dialogue with its sister company, Menlo Worldwide Technologies, to assess the feasibility, pitfalls, and potential benefits of developing the needed optimization capability in house. The results of these efforts were more positive. The company discovered that by leveraging the operational knowledge and experience within Menlo Worldwide Forwarding, and the software development and optimization technology expertise within Menlo Worldwide Technologies, it could form a winning team. The team would comprise a small, select group of individuals from both companies with management oversight from Menlo Worldwide Forwarding. This approach would not only capitalize on the talents resident in both companies, but it would allow for a low cost, incremental and time-phased development of the needed optimization software that would focus on the areas of highest return first. It would also ensure that the software would be tailored to Menlo's operational environment and would allow the company, over time, to capture all the subtleties and business considerations unique to Menlo Worldwide Forwarding.

Menlo Worldwide Technologies

Although Menlo Worldwide Forwarding had a clear understanding of its air and ground transportation networks, its contracted airline operations, and its customers' needs, it lacked sufficient knowledge of the optimization technology to go it alone. Menlo Worldwide Technologies offers comprehensive information technology and engineering resources for the Menlo Worldwide operating companies and their customers. Its service includes execution information technology and network design solutions for transportation, logistics, freight forwarding, and global supply-chain management.

Menlo Worldwide Technologies' optimization technology team focuses on developing business decision solutions for internal and external customers by using operations research and management science techniques, including optimization, simulation, statistics, and data-warehouse analysis. Menlo Worldwide Technologies' optimization technology team develops models and business solutions using the best software for the customer—either optimization software built in house or off-the-shelf software packages.

Moreover, based on its experience in developing optimization models, Menlo Worldwide Technologies emphasizes the model-development processes to ensure that it uses the best technology for the business operating environment. The model-development processes are the following: define the project scope, define the issues, collect and process the data, construct and validate the model, conduct what-if analyses, and develop recommendations.

Following these processes, Menlo Worldwide Technologies systematically proceeds through the network-routing-optimization analysis, sharing its ongoing results with management. Menlo Worldwide Technologies' optimization-technology team works closely with management to ensure that the analysis continually addresses those issues of primary importance to Menlo Worldwide Forwarding. The team can also provide good routing solutions based on Menlo Worldwide Technologies' operational experience, technological expertise, tools, and resources.

By combining Menlo Worldwide Technologies' proven development methodologies, knowledge of optimization technology, and employee skills and capabilities with the operational expertise and leadership within Menlo Worldwide Forwarding, the company formed a winning team.

Problem Overview

Until 2001, Menlo Worldwide's North American transportation network comprised two major components: Menlo Worldwide Forwarding (which was then Emery Worldwide) and Emery Worldwide Airlines.

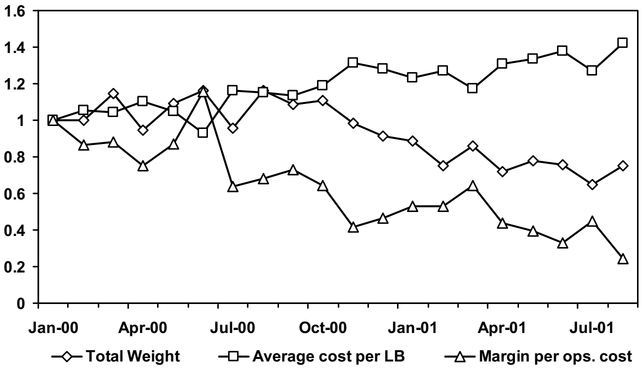

Figure 2: The graph shows the total weight shipped, the average operating cost per pound, and the margin per operating cost between January 2000 and August 2001. We normalized the costs and values to January 2000 data.

Emery Worldwide managed the terminal and ground operations and the airlines transported the next-day airfreight within North America. As business grew over the past few decades, the size of the dedicated air fleet and the number of hubs grew and the transportation network expanded. As the capacity and complexity of the transportation network grew, so did operating costs. Beginning in the late 1990s, Menlo Worldwide Forwarding's operating costs steadily increased even as its freight volume and profit margin shrank (Figure 2). Several factors contributed to the sagging profitability, including overcapacity in the routing network, a reliance on high fixed-cost assets, mismatched aircraft capacity and routes, and increasing costs for crews and aircraft maintenance.

Routing Network Overcapacity

In the late 1990s, when the economy looked promising and shipment volume steadily increased, managers could use their years of experience to determine network capacity. However, when the economy slowed and shipment volume dropped, they lacked a sophisticated tool to optimize the network. They faced overcapacity and rising costs for operating the transportation network.

High Asset-Based Operation

In an expanding shipping market during the 1990s, the company increased both the size and number of the aircraft in its fleet as well as the capacity of its Dayton sortation facility. This growth provided customers with excellent service during the boom, but as the economy and airfreight demand weakened this high-fixed-cost network limited the company's flexibility to reduce operating costs when shipment volumes decreased.

Mismatched Aircraft Capacity and Routes

To maximize potential returns and mitigate the high fixed cost of aircraft ownership, the company manually developed aircraft routes to best utilize the fleet. To offset operating expense, it filled unused aircraft space with freight that could have been moved more cost effectively by truck. As a result, the company's truck network became underutilized and did not complement the aircraft network, resulting in decreased margins.

Increasing Crew and Airplane Maintenance Costs

The costs of operating airline crews and maintaining aging aircraft increased over time, which further cut into profitability.

Solution Strategy

In 2001, the team began analyzing the problems and developing an optimization model to reduce the transportation network routing costs. Leveraging the operational knowledge and experience within Menlo Worldwide Forwarding, the team reviewed the challenges, developed modeling processes, applied new optimization technologies and implemented model solutions. The team built the optimization model using a combination of business operations knowledge and the most recent optimization technologies. Menlo management fully understood and supported the optimization modeling technologies and their application. The optimization model was not a mysterious black box; instead, management saw the project as an integral part of the business decision-making process. Moreover, the team tested several modeling options to find the best fit for the company's business environment. The modeling technologies were flexible enough that the team could modify the model to fit the dynamic business operations quickly. The team learned from other software companies to avoid changing the company's business operations to fit the modeling tools.

To develop the modeling tool for the operating environment, the team used a multiphase development process. In the first phase, a model was developed to optimize daily aircraft routes and the associated aircraft fleet to reduce operating costs. Although the model was originally designed for use with the Emery Worldwide Airlines fleet, the model was quickly adapted for use with contractor aircraft after the Federal Aviation Administration (FAA) unexpectedly grounded Emery Worldwide Airlines on August 13, 2001. In the second phase, the model's functionality was expanded to optimize the routing plans for an integrated aircraft-and-truck logistics network to increase utilization of the entire network and reduce overall operating costs.

Solution Development

The objective of the project is to provide optimization decision-support tools to Menlo Worldwide Forwarding with daily, weekly, and monthly adjustments to truck and aircraft operations to minimize their overall cost while maintaining high service levels. The optimization-technology group also makes ad hoc modifications to the model to support other requirements, such as contract negotiations, budget preparation, and commercial carriers. The team worked with management to identify the following priorities.

Optimizing Aircraft Scheduling

Optimizing aircraft scheduling included minimizing operating costs by optimizing aircraft routes, scheduling, carriers, and the type of aircraft on each route. The company also wanted to increase aircraft-schedule flexibility and network-capacity utilization while satisfying market service requirements, provide a computerized modeling system with user interface capability to replace the current manual scheduling processes, and develop a tool for quick what-if scenario analysis.

Optimizing Routing of the Integrated Aircraft-and-Trucking Network

Expanding the aircraft scheduling optimization capability to the integrated aircraft and trucking network was also a priority. The model would be required to determine whether using a plane or a truck would provide the most efficient transportation method depending on the service level required (next-day, second-day, or economy freight) and take both weekday and weekend schedules into consideration. The ideal model would provide more cost-effective routing and improve overall network utilization by incorporating the aircraft-and-truck network.

Yu and Yang (1998) listed the literature on airline planning, modeling, and optimization. In general, airline planning consists of solving five individual problems: schedule development (determining when and where to fly), fleet assignment (assigning the aircraft equipment types), aircraft routing (assigning aircraft to routes), crew scheduling (determining the crew itineraries or pairings), and crew rostering (assigning crews to crew itineraries). Yu et al. (2003) developed a decision-support system for Continental Airlines to generate a global optimal, or near optimal, crew-recovery model. They described the model and the solutions at the 2002 Edelman Award competition.

Airlines currently solve the planning and optimization problems separately (Klabjan et al. 2002), because it is not feasible computationally to solve them as a single problem. Klabjan et al. developed a partial integration model for solving three of the five problems together: schedule development, aircraft routing, and crew scheduling. Cordeau et al. (2001) used Benders decomposition to solve aircraft-routing and crew-scheduling problems simultaneously.

The Menlo Worldwide's aircraft-scheduling model solves four of the five problems together: schedule development, fleet assignment, aircraft routing, and crew scheduling. Because Menlo Worldwide Forwarding currently uses only contract carriers and the contractors manage the crews and the airplane maintenance, the model can assume that the crews and aircraft fleets are always available. This assumption reduces model complexity so that an integrated model can be developed for these four problems to solve them simultaneously.

The model is intended to provide a solution for the complicated problem within a minimal optimality gap (such as 0.1 percent) in a few minutes. The team built several business-knowledge constraints into the model to speed up the search processes for delivering the optimal solution. The model can provide weekly schedules in a reasonable time, and because the solution computation time was improved, management has been able to define more what-if scenarios and evaluate more options before setting up the routes.

Phase 1: Optimizing Aircraft Schedules

Objective and Methodologies

The objective during the first phase was to minimize the cost of weekly aircraft schedules. The single integrated model optimized aircraft operations for the Tuesday-through-Friday schedule and the Saturday schedule together.

In Phase 1, we formulated the aircraft-scheduling problem as an assignment model. Based on projected freight volumes, operations, and service requirements, we generated a robust series of aircraft routes in advance to input into our assignment-optimization model. The feasible aircraft routes were based on origin-destination pairs, freight volumes, aircraft characteristics (types, availability, flying range), market times (departure and arrival time windows), airport limitations (runway length, loading and unloading equipment), and other business constraints that were driven by customer service requirements. We then developed a costing model for calculating the route costs as they are generated.

A route pairing is a combination of an inbound route from any of Menlo's logistics centers to the Dayton hub (HDY), such as Seattle-Portland-Dayton (SEA-PDX-HDY), and an outbound route from the Dayton hub to one of company's logistics centers, such as Dayton-Portland-Seattle (HDY-PDX-SEA). These feasible route pairs have the same beginning and ending locations. The route generator provides inbound and outbound operating hours for each route. The feasible routes include dummy routes, such as Dayton-Dayton-Dayton (HDY-HDY-HDY), which represents spare aircraft for emergency use.

We produced two sets of feasible aircraft route pairings: Tuesday-through-Friday routes, and Saturday routes. On Saturdays, Menlo has low operation volumes and large market time windows, and it does not serve all logistics centers. Therefore, we have the flexibility to park aircraft to reduce operating costs.

The assignment model consists of all feasible aircraft route pairings, aircraft capacities, performance capabilities, and a variety of other operating constraints and costs for optimizing the aircraft schedules and the utilization of network capacity. The other operating constraints and costs include ACMI (aircraft, crew, maintenance, and insurance), fuel, ground-handling, extra-hour, extra-cycle, and extra-crew costs. Extra-hour cost is incurred when the monthly operational hours for each aircraft type exceed the contracted hours. Similarly, extra-cycle cost is paid when the number of cycles (each flight segment is considered one cycle) for each aircraft type exceeds the allowable number of cycles specified in the contract. Extra-crew costs are incurred if the number of crews, as determined by FAA duty and rest requirements, exceeds the allotted number of crews permitted by the contract.

The objective function minimizes the sum of all of the operating costs above as well as the costs of contracting with third-party carriers. The constraints of the model are aircraft availability, logistics center coverage, extra-cost constraints, container compatibility, connectivity constraints, minimum aircraft use, spare-aircraft requirements, specified-route requirements, and fixed-flight-segment requirements. In addition, the optimization-technology group built a crew-scheduling model, which is embedded in the assignment-optimization model to optimize the number of crews needed on the network (Appendix).

Phase 2: Optimizing Routing of the Integrated Aircraft-and-Truck Network

The second phase of the model provides systemwide, optimal routing solutions for the integrated aircraft-and-truck network (Appendix). To account for service requirements and operating constraints, we formulated the problem as a multiperiod network-routing optimization model for both transportation modes. The model traded off the costs and capacities of various transportation modes (aircraft or truck) at each leg to optimize the overall routing plans. It generated two sets of routing solutions for weekday and weekend operation to meet the different operating constraints for shipping freight between the origin and destination logistics centers.

Phase 2 Optimization Model

We developed a time-space network to represent the routing problem and used column-generation technology to iteratively solve the model. The nodes of the time-space network represented the logistics centers. The arcs represented either aircraft or truck routes used to move shipments between the nodes. The column generator identified feasible routes on the network for moving a shipment from its origin to its destination within the required service time. Based on the shipment opportunity costs from the previous iteration, the column generator derived a new set of routes for the model until the solution met the optimality criteria.

The model's objective function is to minimize the total operating costs of the aircraft and truck networks, including fuel costs, stop charges, daily fixed charges, block-hour costs, aircraft extra-hour costs, aircraft extra-cycle costs, aircraft extra-crew costs, and airport loading and unloading costs. The model incorporated critical operating constraints of the air and trucking network along with the service-time requirement and shipment-balance constraints at each node. The nonlinear transportation costs and the complexity of the business operating constraints of both the air and trucking networks complicated the Phase 2 model. The model optimizes the network routing and the associated transportation modes (that is, either air or truck on each leg). By implementing the solution, Menlo Worldwide Forwarding can increase the cost effectiveness of the integrated network operations, improve the utilization of the truck network, and reduce overall network operating costs.

Realizing the complexity of the integrated optimization model, we developed a heuristics algorithm to speed up the computation. The algorithm determines the shipment volume split between the aircraft network and the truck network and then optimizes the aircraft-network routing and truck-network routing separately. After that, the column generator iteratively generates air and truck routes to improve the solution of the integrated network model until it meets the specified optimality.

Data Collection and Processing

We assembled and examined a variety of data for the model. The new Menlo Worldwide Forwarding enterprise system, E2K, provides most of the shipping and routing data. Menlo Worldwide Forwarding offices and customers around the world use E2K (the company's multimodal communications and operations network that serves as the company's central repository for shipping and financial information). Based on the seasonality of shipment trends, we developed a model for forecasting shipping volume. Using average container weight derived from historical operational data, we converted the total freight volume to the equivalent number of aircraft containers. We also determined the allowable departure-and-arrival time windows for each logistics center. This time window is typically called the market time. It has two important elements: the departure cutoff time and the arrival cutoff time. Inbound to the Dayton hub, the shipment departure cutoff time is the latest time that a shipment can arrive at a station to connect via aircraft or ground transportation to a required downstream sortation center. Outbound from the Dayton hub, the arrival cutoff time is the latest time that a package can arrive to connect with each station's local delivery network. To estimate the aircraft block hours, we also built an enroute-time model. We based this model on historical aircraft performance data, and it determines the aircraft block hours (that is, block-out to block-in), taking into account each station's taxi requirements, aircraft routing and directionality, and seasonality, including winds and temperature variations.

Reporting and User Interface

The optimization-technology group developed a user interface so that users can easily input data, modify model parameters and constraints, develop scenarios, and output routes on a North American map (Figure 3).

Model Integration and System Architecture

The Phase 1 model functionality is embedded in the Phase 2 model. Therefore, we can turn off the truck-routing model to make the model behave like the Phase 1 model to optimize aircraft schedules separately. Alternatively, we can use the Phase 2 model to optimize only the truck network to determine how much freight the truck network can carry. We can use the remaining freight in the aircraft model to generate aircraft schedules. The optimization models were developed using the C++ programming language and CPLEX optimization software. Microsoft Excel and Visual Basic were used extensively to prepare scenarios and reporting solutions.

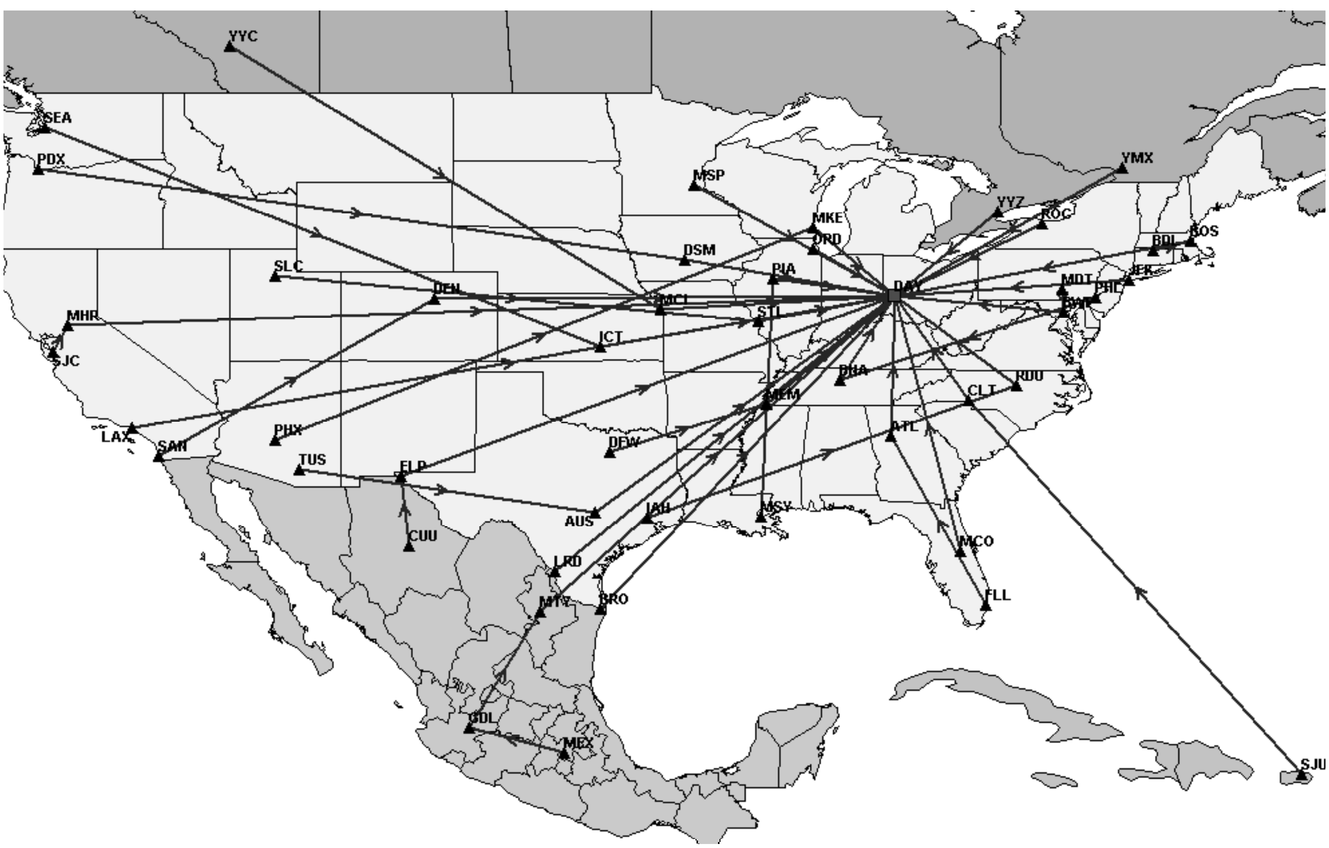

Figure 3: The system seamlessly displays the routes for each scenario on a North America map. The figure shows the inbound aircraft routes into the company's primary hub in Dayton, Ohio for one scenario. Outbound routes, which are not shown, might differ from inbound routes.

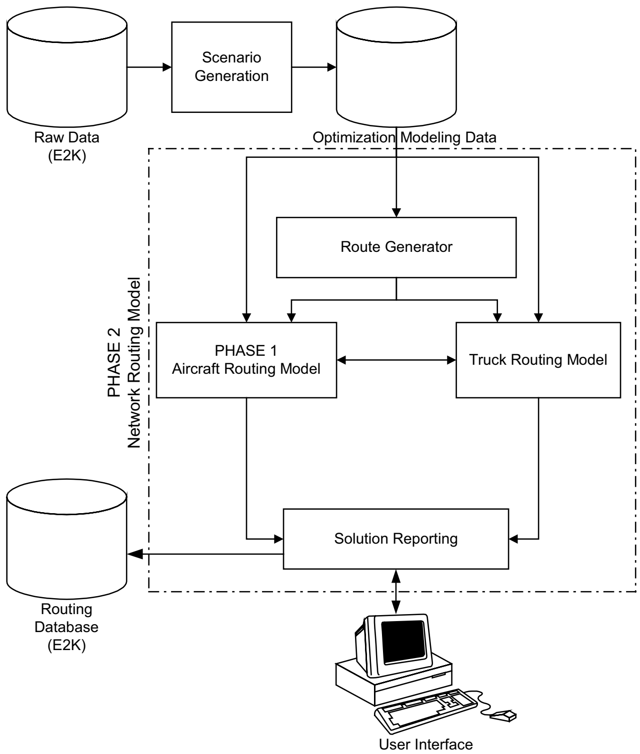

Figure 4: The figure shows the high-level data flow between the optimization models and the online shipment database. The functionality of the Phase 2 model includes the functionality of the Phase 1 model.

Information from various databases feed the optimization database. The optimization database processes the data and generates the final data that the optimization model will use (Figure 4). Then, the user specifies the scenario constraints and runs the model through the graphic user interface.

Implementation

The model has become an invaluable tool for developing network plans and for analyzing Menlo Worldwide Forwarding's air-and-truck-transportation network. Menlo uses the model to build schedules that meet its customers' needs. The company also uses the model to minimize aircraft operating costs and to use the assets available within the Menlo Worldwide Forwarding network more efficiently. Although we are constantly finding new applications for the model, Menlo Worldwide Forwarding is currently using it for the following tasks: weekly planning, planning monthly and quarterly schedules, preparing the budget, and analyzing contracts.

Weekly Planning

To take full advantage of the model's cost-saving opportunities, the transportation-and-logistics organization within Menlo Worldwide Forwarding periodically performs network optimization. This organization is responsible for creating weekly aircraft and truck schedules. In its weekly planning, it does not seek wholesale changes but rather tweaks the scheduled routes and aircraft to improve operations and accommodate any unexpected changes in aircraft availability, market volumes, and other operational dynamics. It uses the model proactively (for example, to respond to new markets and logistics center expansions) and reactively (for example, to cope with an overload). On Monday, the freight volumes from the previous week's operations are fed into the model along with any aircraft or market-volume changes. By controlling the model constraints, the schedule planner can eliminate or consider changes in aircraft departure or arrival times, routing options, and aircraft assignments. The optimized results identify possible changes in routes and cost savings and help schedule planners to evaluate their impacts. The planners discuss the results at schedule-planning meetings on Wednesdays and identify schedule changes for management approval. Menlo Worldwide Forwarding can thus minimize changes and rapidly adjust its operations in response to variations in its customer base or market volumes.

Planning Monthly and Quarterly Schedules

Menlo Worldwide Forwarding also uses the model for planning monthly and quarterly schedules. The process differs from weekly planning. First, the planning is intended to create a robust network solution that Menlo can fly with little change for a long time. To ensure that the company is implementing a low-cost solution, the planners minimize the number of constraints. They consider such factors as aircraft-base changes, aircraft-fleet size and mix, market closures or additions, and various market times. Because some possible changes may affect other business functions, the planners must include all possible significant changes, run model iterations, and obtain the approval of marketing managers, field operations, and corporate management before implementation. Accordingly, for both monthly and quarterly planning, planners go through iterative processes that rely heavily on parametric analysis to resolve conflicting business interests. They use the model's results to identify the lowest-cost solution within specified network parameters and operational constraints and to quantify the cost impacts of departing from a baseline solution. Because Menlo Worldwide Forwarding relies on contracted aircraft and on other air-cargo space available through commercial sources, the model results help ensure that Menlo contracts for adequate aircraft capacity but not excess capacity. The results also ensure that the types, number, and mix of aircraft match the lane volumes and operational and market requirements. The model also enables the planners to adjust the network for expected changes in Menlo's customer base, for expansion or contraction in the number or location of Menlo's logistics service centers, and for seasonal variations in freight volumes.

The Budget

To create a realistic operating budget, Menlo must forecast shipment volumes for the coming year and design air and ground networks to accommodate these volumes. Because planners must consider many assumptions and possible network trade-offs, they use an iterative process. The model allows them to rapidly perform accurate trades and identify and evaluate their impacts. For example, in 2002 the model was used for the first time to develop Menlo Worldwide Forwarding's 2003 air-haul budget. Although this process generated many more network variations than in previous years, both the number of man-hours required and the duration of time to complete the budget were reduced. Throughout the process, the model proved to be a valuable tool for generating and costing the initial baseline routings and in iterating subsequent network changes.

Vendors and Contracts

Menlo Worldwide Forwarding contracts with third-party air and truck carriers for most of its operations. Because most of the company's network costs and its next-day-delivery performance depend on aircraft operations, it must choose aircraft sizes, types, and vendors carefully. Moreover, provisions in the contracts determine the actual cost of operations. For example, monthly minimums and the costs for extra hours, extra cycles, and extra crews are based on the rates and parameters specified in the contracts. By running the models for a fixed shipment volume, we can perform parametric analyses. These analyses not only allow us to determine the best complement of aircraft (that is, the number, type of aircraft, and operator) to meet specific network requirements at the lowest operating costs, but it also allows us to identify the aircraft and routing changes and quantify the operating cost differential if something other than the optimal mix is selected. By examining the results, we can also determine how specific contract provisions are influencing cost and aircraft selection. We can then use this information to negotiate more favorable contracts with our aircraft operators.

Benefits

In September 2001, we began giving management what-if routing scenarios to review. Each iteration of our modeling exercise resulted in a good solution that helped management reduce operating

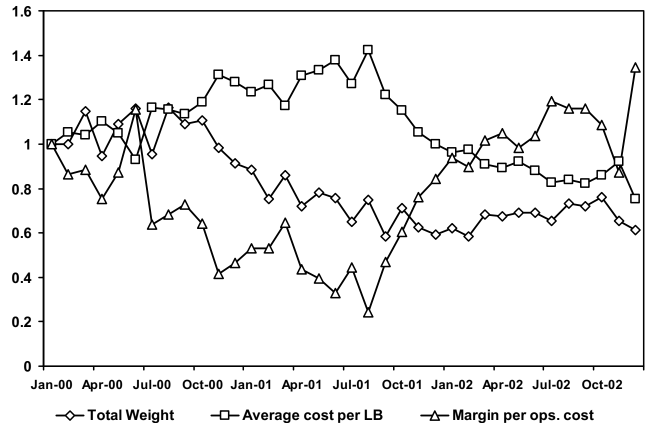

Figure 5: The graph shows the total weight shipped, the average operating cost per pound, and the margin per operating cost between January 2000 and December 2002. We normalized the costs and values to January 2000 data.

cost and increase operating margin. Based on our analysis of the model results, Menlo Worldwide Forwarding implemented the solutions and dramatically improved utilization of its network capacity. It reduced its cost for air-haul operations and increased its profitability despite the weak economy (Figure 5).

By using the model, Menlo improved its utilization of the capacity of the North American routing by 30 percent, reduced operating costs by 21 percent, and improved operating margins by 41 percent. These reductions in costs accounted for 62 percent of the company's profitability increase in 2002. Menlo also increased its management efficiency, transformed its business model, and integrated its truck-and-air-routing networks. Finally, Menlo is planning to transport the model to its European routing network.

Network Capacity Utilization

Menlo used the optimization model to evaluate all possible combinations of routes and aircraft to determine the best routes and aircraft to fly those routes. The model helped Menlo Worldwide Forwarding's management to reduce the size of the fleet by using the right size aircraft for each route and increasing the use of available capacity. It reduced the number of aircraft by 48 percent and network capacity by 59 percent. We also increased the utilization of network capacity by 30 percent and reduced average aircraft size by 20 percent (Table 1).

Operating Costs and Margin

We used the model results to minimize the network operating costs by optimizing the routes, carriers, aircraft, fuel consumption, and flight-crew assignments. Because Menlo implemented results in September 2001, it has reduced average air-haul operating cost

Operational Metric	Jan 2000 (%)	Jan 2001 (%)	Jan 2002 (%)	Jan 2003 (%)
Aircraft network shipment volume	100	87	59	54
Number of primetime aircraft	100	88	58	52
Aircraft network capacity	100	87	47	41
Average aircraft size	100	98	81	80
Aircraft network capacity utilization	100	101	126	130

Table 1: The North American network metrics for January 2000, 2001, 2002, and 2003 (values normalized to year 2000 data) show improvement between January 2000 and 2003. January was selected for the comparison because it is one of the lowest margin months.

per pound by 21 percent, increased its operating margin by 41 percent, and saved $80 million in operating costs in 2002. Part of the $80 million was a $12 million reduction in average fuel costs (Table 2).

Contribution to Profitability

After a staggering loss in 2001, Menlo exceeded its financial targets in 2002 in large part through routing optimization. Between 2001 and 2002, Menlo Worldwide Forwarding improved its results by $130 million. The North American network-routing optimization contributed $80 million, or 62 percent, of the increase in profitability. The optimization project has also improved the company's financial prospects. Prior to implementing the optimization project, Menlo Worldwide Forwarding's profit margin was continually shrinking. After it implemented the model's solutions, its operating costs dropped and its margin dramatically increased (Figure 5).

Increased Management Efficiency

The optimization model has proven to be a great decision-support tool that continues to improve the cost-effectiveness of Menlo Worldwide Forwarding's business operations by expanding management's route-planning capabilities. Menlo Worldwide Forwarding uses the modeling tool and the shipment forecasts to develop an optimal routing solution each week. The model's speed enables Menlo management to evaluate many scenarios before creating schedules. By analyzing multiple what-if scenarios, management can identify the root causes of service problems and develop better routing solutions. It also uses the model to create new routes ad hoc during the week if necessary.

The optimization model also proved valuable for creating a new flexible network quickly. When the FAA unexpectedly grounded Emery Worldwide Airlines on August 13, 2001, we used a prototype of the model to develop new routes using third-party contractors to replace the company-owned planes. Over the weekend, Menlo Worldwide Forwarding switched to the new contracted airlift with no disruption in service—a remarkable feat by the business team that rapidly implemented the model's outputs.

Cost Metric	2000 (%)	2001 (%)	2002 (%)
Air haul operating cost per pound	100	111	79
Margin per operating cost	100	67	141

Table 2: This table of operating costs and margin between 2000 and 2002 (all values normalized to year 2000 data) demonstrates the model's benefits after its implementation in September 2001. The costs related to operating both Emery Worldwide Airlines and the contracted carriers were embedded in our 2001 cost data; therefore, we used 2000 as our baseline to estimate the total cost saving.

The New Business Model

In December 2001, Menlo Worldwide Forwarding, a heavily asset-based business that owned or held long-term leases on aircraft, became a flexible network made up of third-party aircraft contractors on short-term leases. Our technical capabilities made it easy to modify the model to incorporate the principal cost elements for the new fleet of contracted airlift. We used the model to optimize total aircraft network costs by integrating contractual requirements and terms, such as the number of crews, the aircraft cycle ratio, and operating hours, into the model to minimize the overall operating costs. The aircraft-cycle ratio, crew costs, and extra hourly charges for operating aircraft were crucial new cost elements. We also embedded the crew-assignment model in our model to optimize overall operating costs and simultaneously provide the optimized number of crews and crew assignments on each route.

Thanks to the success of our model, Menlo Worldwide Forwarding moved rapidly from a fixed-cost fleet system to a highly dynamic flexible system. Management can take the outputs of the optimization model and quickly translate them into changes in the company's contracted airlift capacity.

Conclusion

In 2002, one year after adopting the network-routing-optimization model, Menlo Worldwide Forwarding had increased its utilization of network capacity by 30 percent and reduced operating cost by $80 million. Menlo Worldwide Forwarding and Menlo Worldwide Technologies worked together to develop the network-routing-optimization model that optimized Menlo's North American transportation network, and it has become essential for daily routing decisions.

We are pleased to have had the opportunity to apply optimization technology and develop what is now Menlo Worldwide Forwarding's most important routing tool. The optimization model solved the company's aircraft-scheduling, fleet-assignment, aircraft-routing, and crew-scheduling problems simultaneously. We expect to use our knowledge and apply our optimization technology further for other Menlo components and our external customers.

Appendix: Model Formulation

Sets and Parameters

N: the set of logistics center locations and hubs.

AR: the set of aircraft routes, including spare and dummy routes at the Dayton hub or logistics centers.

TR: the set of truck routes.

AC: the set of aircrafts.

TK: the set of trucks.

D: the set of operation days that includes Tuesday-through-Friday and Saturday operations.

T: the number of time buckets for crew service time.

M: the set of service types (next day, second day, and economy).

S: the set of shipments from origin logistics center i to destination logistics center j at day d service level m where $i, j \in N$, $d \in D$, and $m \in M$.

E: the set of container types.

T: number of time intervals to group routes based on the block hours.

Coefficients and Parameters

The subscripts r, a, i, and d represent routes, equipment, logistics center, and operation day, respectively.

c_{dar}: operating cost of route r for day d where $r \in AR \cup TR$, $d \in D$, and $a \in AC \cup TK$.

b_{dar}: block hours for route r where $r \in AR$, $d \in D$, and $a \in AC$.

g_{dar}: number of flight legs of route r where $r \in AR$, $d \in D$, and $a \in AC$.

M_a: available aircraft a where $a \in AC$.

N_{da}: minimum number of aircraft a for day d where $a \in AC$ and $d \in D$.

H_a: fixed monthly operation hours for aircraft a where $a \in AC$.

h_a: cost of an extra hour for aircraft a where $a \in AC$.

R_a^c: cycle (flight leg) ratio for aircraft a where $a \in AC$.

r_a^c: cost of an extra cycle for aircraft a where $a \in AC$.

R_a^w: crew ratio for aircraft a where $a \in AC$.

r_a^w: cost of an extra crew for aircraft a where $a \in AC$.

DN_d: number of operating days per month for day d where $d \in D$.

O_{da}: number of spares of aircraft a requirement for day d where $a \in AC$ and $d \in D$.

Cap_a: the capacity of the equipment a where $a \in AC \cup TK$.

$WT(s)$: shipment size where $s \in S$.

Variable Definition

x_{dar}: equal to 1 if route r is selected at day d; 0 otherwise; where $r \in AR \cup TR$, $d \in D$, and $a \in AC \cup TK$.

y_a: total number of aircraft a in the network where $a \in AC$.

z_a^h: extra hours for aircraft a where $a \in AC$.

z_a^c: extra cycles (legs) for aircraft a where $a \in AC$.

z_a^w: extra crew of aircraft a where $a \in AC$.

z_{dat}^w: extra crews of aircraft a at the block hour time bucket $t \in T$.

Phase 1 Model: The Aircraft Scheduling Model

Phase 1 Model Formulation

$$\text{Minimize} \quad \sum_{d\in D,\, a\in AC,\, r\in AR} C_{dar}x_{dar} + \sum_{a\in AC} h_a z_a^h + \sum_{a\in AC} r_a^c z_a^c + \sum_{a\in AC} r_a^w z_a^w.$$

Phase 1 Model Constraints

(1) Aircraft availability: Total number of aircraft in the system (flying, spare, and parked) should be less than or equal to available aircraft.

$$\sum_{r\in AR} x_{dar} \le y_a \quad \forall d \in D,\ a \in AC,$$

$$y_a \le M_a \quad \forall a \in AC.$$

(2) Minimum aircraft use:

$$\sum_{r\in AR} x_{dar} \ge N_a \quad \forall d \in D,\ a \in AC.$$

(3) Spare aircraft constraints: Specify the minimum number of spare aircraft required for regular maintenance.

$$\sum_{r\in AR} s(r)x_{dar} \ge O_{da} \quad \forall a \in AC,\ d \in D,$$

where $s(r)$ is an indicator function; $s(r)$ takes on the value 1 if r is a spare route and 0 otherwise.

(4) Logistics center coverage: Each logistics center should be covered only once for inbound and outbound flight.

$$\sum_{a\in AC,\, r\in AR} IB(r)L(r,i)x_{dar} = 1 \quad \forall d \in D,\ i \in N\backslash\{HDY\},$$

$$\sum_{a\in AC,\, r\in AR} OB(r)L(r,i)x_{dar} = 1 \quad \forall d \in D,\ i \in N\backslash\{HDY\},$$

where $IB(r)$ is an indicator function; $IB(r)$ takes on the value 1 if r is an inbound route from a logistics center to the Dayton hub and 0 otherwise. $OB(r)$ is an indicator function; $OB(r)$ takes on the value 1 if r is an outbound route from the Dayton hub to a logistics center and 0 otherwise. $L(r,i)$ is an indicator function; $L(r,i)$ takes on the value 1 if the route r stops at logistics center i and 0 otherwise.

(5) Extra hour constraints: Specify the monthly fixed hours requirement and the extra hours that are incurred from our routing plans.

$$\sum_{d\in D,\, a\in AC,\, r\in AR} DN_d b_{dar} x_{dar} \le H_a y_a + z_a^h \quad \forall a \in AC.$$

(6) Extra cycle constraints: A cycle is a flight leg from an aircraft's takeoff to landing. This constraint specifies the number of extra cycles that the network used for aircraft a.

$$\frac{\left(\sum_{d\in D,\, r\in AR} b_{dar} x_{dar}\right)}{R_a^c} \le \sum_{d\in D,\, r\in AR} g_{dar} x_{dar} + z_a^c \quad \forall a \in AC.$$

(7) Extra crew constraints: An extra crew member would be added into the network to avoid the total flight hours of a crew member exceeding FAA daily flight hour limitation. By matching a long inbound route with a short outbound route or a short inbound route with a long outbound route, the network can keep the crews' flight hours below the FAA's limit and avoid extra crews. The model partitions the FAA daily flight-hour limitation into T time buckets, and each time bucket has the same time span (say 15 minutes).

$$z_{dat}^w + \sum_{k=1}^{t} \sum_{r\in AR} IB(r) TM(r,k) x_{dar} \ge \sum_{k=t+1}^{T} \sum_{r\in AR} OB(r) TM(r,k) x_{dar} \quad \forall a \in AC,\, t = 0,1,2,3,\ldots,T-1,$$

$$\sum_{k=1}^{T} z_{dak}^w \le (R_a^w - 1)\left(\sum_{r\in AR} x_{dar}\right) + z_a^w \quad \forall a \in AC,\ d \in D,$$

where $TM(r,t)$ is an indicator function for the block hour bucket; $TM(r,t)$ takes on the value 1 when the total block hours of route r belong to the time bucket t and 0 otherwise.

(8) Container compatibility constraints: Most of the logistics centers used the containers unloaded from outbound routes to load shipments. Because the inbound aircraft may be different from the outbound aircraft, this constraint ensures that the container type is compatible with the inbound aircraft and the outbound aircraft. Container compatibility constraints do not apply to all logistics centers because some logistics centers can handle multiple types of containers. For example, the constraint does not apply to the Dayton hub.

$$M^* \sum_{r\in AR} CP(e,i,a) OB(r) L(r,i) X_{dar} \ge \sum_{r\in AR} CP(e,i,ac) IB(r) L(r,i) X_{dar} \quad \forall i \in N,\ d \in D,\ e \in E, \text{ and } M \text{ is a big number},$$

where $CP(e,i,a)$ is an indicator function; $CP(e,i,a)$ takes on the value 1 if container type e is compatible for aircraft a at logistics center i and 0 otherwise.

(9) Inbound and outbound aircraft-equipment balance constraints: The aircraft equipment at the origins of the inbound routes and the destinations of the outbound routes should be balanced every day. At the Dayton hub, denoted by HDY, the outbound aircraft equipment is balanced with the previous day's inbound aircraft equipment. A dummy route that has the same origin, intermediate, and destination locations represents the aircraft parked at the logistics center.

$$\sum_{r\in AR} D(d,r,i) OB(r) X_{dar} = \sum_{r\in AR} O(d,r,i) IB(r) X_{dar} \quad \forall i \in N \backslash \{HDY\},\ d \in D,\ a \in AC,$$

$$\sum_{r\in AR} D(d-1,r,i) IB(r,i) X_{d-1ar} = \sum_{r\in AR} O(d,r,i) OB(r,i) X_{dar} \quad \forall i \in \{HDY\},\ d \in D,\ a \in AC,$$

where $D(d,r,i)$ is an indicator function that takes on the value 1 if i is the destination of route r starting at day d and 0 otherwise. $O(d,r,i)$ is an indicator function that takes on the value 1 if i is the origin of route r starting at day d and 0 otherwise.

Phase 2 Model: Master Model for Aircraft-and-Trucking-Network Routing Model

The functionality of the Phase 2 model includes all the functionality of the Phase 1 model. The formulation of these two models is similar in the aircraft network. Both aircraft model costs include all principal aircraft operating costs, such as the standard aircaft, crew, maintenance, and insurance costs (ACMI), block hour, fuel, airport landing-and-departure, loading-and-unloading, extra-cycle, extra-hour, and the extra-crew costs. The trucking routing model and costs are added into the Phase 2 model. A shipment can be shipped by either truck or air on multimode-transportation multileg routes. A shipment can be dropped at an intermediate logistics center for transfer to other routes. The model must ensure that every shipment is picked up at its origin and delivered to its destination. This increases the model size and the complexity of the solution methodologies. The integrated aircraft-and-truck network became complicated, and we used column-generation technology to solve the Phase 2 model.

Phase 2 Model Formulation

$$\text{Minimize} \quad \sum_{d\in D,\, a\in AC\cup TK,\, r\in AR\cup TR} C_{dar}x_{dar} + \sum_{a\in AC} h_a z_a^h + \sum_{a\in AC} r_a^c z_a^c + \sum_{a\in AC} r_a^w z_a^w.$$

Model Constraints

The master problem of the Phase 2 model includes all the constraint sets except set 4 of the Phase 1 aircraft-network model. The Phase 2 model includes the following extra constraints: Constraints 1 through 3 for ensuring that the shipment travels from its origin to its destination by either aircraft or trucks. Constraint 4 is the weight limitation for each route. The shipment-service-requirement constraint is included in the column generator to make sure the route meets the service time requirement.

(1) Shipment pickup constraint: This constraint ensures that a shipment is picked up from its origin i.

$$\sum_{a\in AC\cup TK,\, r\in AR\cup TR} V(r,s,i)X_{adr} = -1 \quad \forall s\in S,\ d\in D,\ i\in N,$$

where $V(r,s,i)$ is an indicator function that takes on the value -1 if the route r picks up shipment s at shipment origin i and 0 otherwise.

(2) Shipment drop-off constraint: This constraint ensures that a shipment is delivered to its destination i.

$$\sum_{a\in AC\cup TK,\, r\in AC\cup TR} W(r,s,i)X_{adr} = 1 \quad \forall s\in S,\ d\in D,\ i\in N,$$

where $W(r,s,i)$ is an indicator function that takes on the value 1 if the route r drops off the shipment s at shipment destination i and 0 otherwise.

(3) Shipment balance constraint at any intermediate locations or hubs: This constraint ensures that no shipment stays at any intermediate hub location. A shipment has to be picked up on the next day when it is dropped at an intermediate hub location.

$$\sum_{a\in AC\cup TK,\, r\in AR\cup TR} V(r,s,i)X_{a,\,d+1,\,r} + \sum_{a\in AC\cup TK,\, r\in AR\cup TR} W(r,s,i)X_{adr} = 0 \qquad \forall s\in S,\, d\in D,\, i\in N,$$

where i is an intermediate hub that is neither the origin nor the destination of shipment s.

(4) Route capacity constraint: This constraint ensures that the total shipping on a route does not exceed its capacity.

$$Cap_a x_{adr} \geq \sum_{s\in S,\, i\in N} V(r,s,i)WT(s) \quad \forall r\in AR\cup TR.$$

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