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A Strategic Empty Container Logistics Optimization in a Major Shipping Company

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In this paper, we present a system that Compañía Sud Americana de Vapores (CSAV), one of the world's largest shipping companies, developed to support its decisions for repositioning and stocking empty containers. CSAV's main business is shipping cargo in containers to clients worldwide. It uses a fleet of about 700,000 TEU containers of different types, which are carried by both CSAV-owned and third-party ships. Managing the container fleet is complex; CSAV must make thousands of decisions each day. In particular, imbalances exist among the regions. For example, China often has a deficit of empty containers and is a net importer; Saudi Arabia often has a surplus and is a net exporter. CSAV and researchers from the University of Chile developed the Empty Container Logistics Optimization System (ECO) to manage this imbalance. ECO's multicommodity, multiperiod model manages the repositioning problem, whereas an inventory model determines the safety stock required at each location. CSAV uses safety stock to ensure high service levels despite uncertainties, particularly in the demand for containers. A hybrid forecasting system supports both the inventory and the multicommodity network flow model. Major improvements in data gathering, real-time communications, and automation of data handling were needed as input to the models. A collaborative Web-based optimization framework allows agents from different zones to interact in decision making. The use of ECO led to direct savings of $81 million for CSAV, a reduction in inventory stock of 50 percent, and an increase in container turnover of 60 percent. Moreover, the system helped CSAV to become more efficient and to overcome the 2008 economic crisis.

Key words: shipping; container repositioning; logistics; forecasting: applications; inventory; networks: flow; uncertainty; collaborative planning.

Compañía Sud Americana de Vapores (CSAV) is the largest logistics operator in Latin America and one of the world's largest shipping companies in terms of capacity. Founded in 1872, it is the most global Chilean firm. In addition to its headquarters in Chile, CSAV operates seven regional offices: Valparaíso, Chile; Sao Paulo, Brazil; Hong Kong, China; Hamburg, Germany; New Jersey, United States; Barcelona, Spain;

and Mumbai, India. In 2010, CSAV had operations in over 100 countries and more than 2,000 terminals and depots worldwide.

CSAV's main business is shipping cargo using containers, which are transported on ships operated by both CSAV and other companies. The container fleet consists of about 700,000 20-foot equivalent-unit (TEU) containers of over 10 types in terms of size and type of cargo (e.g., 20- and 40-foot dry vans, reefers, and oil tanks). This fleet is valued at approximately $2 billion and serves customer needs of more than 2.9 million TEU (about 50 million tons) per year. CSAV owns only about 5 percent of its container fleet; it charters the rest from leasing companies. In general, CSAV rents containers on long-term contracts that allow it to receive the containers at specific depots in a specific time frame and return them to previously specified locations within a predetermined period.

To cover its worldwide client needs, CSAV coordinates a multimodal network and offers about 40 container transport services. These services have fixed routes and are carried out by more than 180 container ships that have capacities ranging from 2,000 to 6,500 TEU each. Each week, CSAV handles approximately 400 vessel calls, requiring hundreds of thousands of container logistics decisions. Intermodal services, which include thousands of feeder ships, barges, trucks, and trains both from CSAV and third parties, complement CSAV's transport services.

Managing this global operation requires 24/7 attention. CSAV employs more than 6,500 people worldwide, and its decisions impact workers at thousands of suppliers. The CSAV professionals responsible for operations are of different cultures, nationalities, and backgrounds, and live in different time zones, thus making it difficult for them to coordinate and plan interconnected activities.

The company previously managed its container fleet based on decentralized decisions from its regional offices. The high level of interconnection of these decisions, the empty container imbalance among regions, and the uncertainty in main parameters, such as demand for containers, led to significant shortcomings in container management, reflected mainly by CSAV's high level of container safety stock. In 2006, CSAV and researchers from the University of Chile began a project to address this problem. As part of the project, we developed an operations research (OR)-based system, Empty Container Logistics Optimization System (ECO), which optimizes CSAV's empty container logistics by integrating the operational and business decisions of all regional offices. Our objective was to minimize global empty container-related costs while guaranteeing a high service level. ECO is also a collaborative Web-based optimization framework in which multiple agents who have different local objectives and work in dissimilar business conditions make decisions.

In late 2007, we implemented the first version of ECO in Chile and Brazil. When the financial crisis hit the shipping industry particularly hard in 2008, CSAV decided to address the crisis by gaining a competitive advantage through excellence in managing its container fleet; ECO played a key role in achieving this goal. CSAV implemented the system rapidly and implemented globally. In January 2010, ECO became operational worldwide.

In this paper, we use the following structure. *The Empty Container Problem* section presents the problem that we address. In the *Background* section, we discuss how CSAV handled empty container logistics decisions prior to implementing ECO. *The Empty Container Logistics Optimization System* section explains the OR features of ECO and how it improved coordination and decision making by changing CSAV's operational strategy. *Implementing the ECO System* describes the project's history and how CSAV successfully implemented this tool to support its global operations. We discuss quantitative and qualitative results in the *Impact* section and present final comments in the *Conclusions* section.

The Empty Container Problem

The literature discusses container routing and repositioning problems as they relate to shipping and other means of transportation. Movement of empty containers is usually the result of imbalances in moving cargo. Models often take the form of multicommodity flow problems to reflect the conservation of flow and satisfaction of demand constraints. In Crainic et al. (1993), the authors present one of the first characterizations of these problems, as they develop single and multicommodity network formulations. Erera et al. (2005) present a large-scale multicommodity flow problem on a time-discretized network model developed for the chemical industry; the model integrates container routing and repositioning decisions. Choong et al. (2002) discuss a tactical planning problem for managing empty containers on barges for intermodal transportation. They use an integer program to analyze the effects of the length of the planning horizon. Jansen et al. (2004) report an operational planning system used to reposition empty containers for a German parcel post firm.

In dealing with empty containers, the handling of uncertainty, particularly of demand, can be a major problem. Erera et al. (2006) propose a robust optimization approach based on the ideas of Ben-Tal and Nemirovski (2000). Cheung and Chen (1998) handle the uncertainty issue by using a two-stage stochastic network flow model, and develop procedures to solve this problem.

To define the empty container problem at CSAV, we first describe its dynamics. The typical cycle of a cargo container (see Figure 1) starts when a shipping company takes an empty container from a container depot. The empty container is loaded on a truck and delivered to a shipper, who fills it with the merchandise to be shipped. Once the container has been filled, the company transports it to its final destination, as indicated by the consignee to whom the cargo is to be delivered. Typically the company uses multiple types of transport. The filled container is transported by truck to the main port, where it will be loaded onto a vessel. Some shippers fill the container at the port, saving the travel from the depot to the shipper's location and then to the port. Once all customs requirements for the filled container at the port have been satisfied, the container is then loaded onto a vessel. Once loaded on the vessel, the filled container is transported to the port at which it is to be unloaded. The shipping process might also include transshipments, which involve moving the container from one vessel to another before it reaches its final destination. The destination port is generally close to the consignee's location. The filled container is unloaded from the vessel and is transported by truck, train, or feeder ship to the consignee's location, at which the consignee receives the container, unloads the merchandise, and returns the empty container to the shipping company, which performs maintenance on the container if it is damaged or dirty. Consignees sometimes use filled containers as warehouses, extending the time they keep the containers before returning them to the company, and paying fines for the late return.

We observed four main problems related to managing the fleet of empty containers. The first problem is an imbalance of demand among regions, as

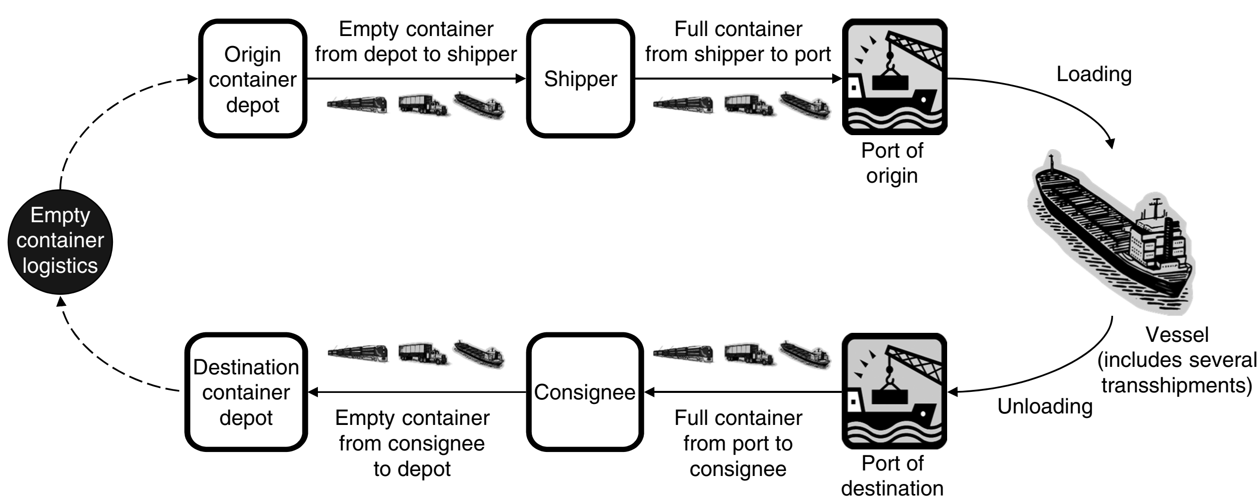


Figure 1: The graphic depicts the typical cycle of a cargo container, which starts empty in the origin depot and finishes empty at the destination depot.

we describe above. Some regions are net exporters of empty containers; other regions are net importers. This regional imbalance of supply and demand for empty containers forces shipping companies to solve this problem by efficiently repositioning the containers.

A company must consider several solutions to mitigate the imbalance. The most efficient and cost-effective solution is to transport empty containers from surplus to shortage locations using container ships and other available transport modes. Empty containers represent a firm's biggest operational cost after ship fuel; therefore, empty container repositioning is a key element in a company's performance. For example, during 2010 in one region in Asia, CSAV had a container imbalance—a deficit of more than 900,000 TEU—that had to be repositioned empty to cover this uneven demand.

The second problem is the multiple sources of uncertainty. The main source of uncertainty is the demand for empty containers, which depends on external factors such as market conditions. Thus, a significant part of the challenge is forecasting the demand for empty containers at each location, for each equipment type, and for a specific date. The time and place at which consignees will return empty containers is uncertain because customers sometimes delay returns. Travel times are also an element of uncertainty. For example, the travel time from Shanghai, China to Port Elizabeth, New Jersey in the United States is 37.9 days on average; the standard deviation is 4.1 days, which represents a coefficient of variation of 11 percent. A final source of uncertainty is the availability of vessel capacity allocated to move empty containers. Filled containers have a higher priority over empty containers because paying customers are awaiting them. Empty containers do not necessarily have a booking waiting for them at their destination; however, they must eventually be repositioned to reduce the container imbalance.

A third major problem relates to handling and sharing operations information. Tracking worldwide container activities, compiling the information, and making it available in real time to all decision makers are technological challenges. In one year, CSAV's tracking systems record over 18 million container activities; these systems process over 400,000 transactions daily to update information related to the container activities. At the beginning of the project, the regional offices used different information, which they obtained from various sources. This often forced planners to make decisions using outdated or inaccurate reports. Moreover, data gathering and processing were done manually, which forced logistics planners to spend much of their time processing worksheets and database extracts rather than making decisions and coordinating empty container activities.

The fourth problem we faced was that the decision makers were distributed throughout the regional offices. Each regional office can handle intraregional decisions, which relate to trips between locations within a geographic area. However, because interregional decisions relate to trips between geographic areas, they require coordination between the regional offices. Coordinating both intraregional and interregional decisions in real time for regions with different cultures and dissimilar operational practices was a problem. Prior to the ECO implementation, each CSAV regional office had a team responsible for coordinating and making empty container logistics decisions, which the headquarters office in Valparaíso coordinated. Regional teams were supplemented by over 30 logistics planners worldwide, who coordinated activities with people both within the company and from third-party companies.

The imbalance, uncertainty, data, and coordination problems inherent to CSAV's business shaped the problem. In addition, if we consider CSAV's global operations at thousands of points worldwide, hundreds of vessels with scheduled itineraries, multiple container types, and hundreds of thousands of empty container-repositioning routes, this problem is hard to manage by even the most skilled team of professionals. Moreover, the seven regional offices coordinating this operation are in different time zones, adding complexity to daily planning and decision making.

Background

CSAV previously managed its container fleet using a decentralized decision-making process through regional offices, which have poor visibility of present and future container flows and no clear definition of stock levels. This process was the result of the firm's rapid growth, which made centralized control difficult given the complexity of global operations. Therefore, CSAV gave significant independence to its regional offices. Decentralization, among other factors related to the size and nature of the problem, led to significant shortcomings in container management, mostly expressed by a high level of empty container safety stock held to satisfy expected demands. This was aggravated by the lack of flexibility in combining containers in different regions, difficulties in handling the natural fluctuations of market conditions, and the lack of tools to support global decision making. Because of this inadequate knowledge about container stocks and future container needs, empty containers were not always repositioned efficiently. Regional offices focused on finding the best local optimum instead of finding a company-wide optimum.

CSAV's philosophy is to achieve a superior level of service (i.e., close to 100 percent customer satisfaction). In the shipping industry, efficiency is important because margins are small and the container fleet represents a firm's major cost. Therefore, an optimized policy for empty container storage and a smart strategy to reallocate the containers are crucial for operations. The uncertainty in the main parameters and the lack of tools to quantify this uncertainty led decision makers to hold high levels of stock of empty containers to maintain their high service standards.

Initially, we did not have a clear picture of the complexity, uncertainty, size, and required coordination of the issues to be addressed. After some work, we realized that our main contribution would be to assist CSAV in centralizing its empty container inventory and repositioning decisions.

The Empty Container Logistics Optimization System

We considered developing a single, integrated, and robust optimization model that would address the entire problem, including uncertainties (Bertsimas and Sim 2004). When we did some tests with small instances of the problem, we found that the time required to find an optimal solution was too long for our needs. Therefore, we opted for a two-stage solution approach, based on a network flow model and an inventory model, as we describe below.

ECO is based on two decision models supported by a forecasting system. First, an inventory model addresses the uncertainty problem and determines the safety stock for each point. Second, a multicommodity, multiperiod network flow model addresses the imbalance problem and supports daily empty container repositioning and inventory levels. The service quality is managed by imposing the safety stock as constraints in the network flow model. Finally, to address the coordination problem, ECO uses a collaborative Web-based optimization framework in which multiple agents make decisions taking local objectives and dissimilar business conditions into consideration.

The main decision variables considered in the network flow model are (1) how and when CSAV should reposition empty containers to fulfill its needs at specific locations using the various transport modes, (2) what the level of empty containers should be at each point and period, including safety stock to handle the uncertainties, and (3) when and where CSAV should lease and return containers.

Appendix A shows the multicommodity network flow model. Its main constraints are container flow-balance equations, demand satisfaction, capacity constraints (defined by both weight and number of slots available), safety stock limits, and initial conditions. Because one goal of the model is to achieve a predefined service level, the inventory variables have the safety stock as lower bounds. If the safety stock cannot be fulfilled with currently available empty containers, the variables representing shortages account for the additional requirements for empty containers. Finally, we consider other constraints such as unfeasible or undesirable repositioning options. The model's objective is to minimize costs associated with empty container loading, transport, unloading, leasing, and inventory.

We determined that ECO should be run three times per day to support regional offices located in different time zones. To achieve three runs per day, we limited its run time to no more than two hours, using warm starts and other speed improvements. For example, the model incorporates only the main location equipment-type combinations. The 2,000 terminals and depots are grouped into 600 locations. From the 600 locations and 10 equipment types, 2,500 location equipment-type pairs account for more than

99 percent of the company's operations. We considered only these combinations. However, this is one of the many parameters that ECO system administrators can fine-tune.

After logical preprocessing, which eliminates unneeded constraints and variables, a typical instance of the network flow model has approximately 3.7 million parameters, 1.2 million variables, and 600,000 equations. To reduce the solution time, we first run a relaxed continuous version of the problem and then round off the container flows. Given that these are integer-friendly MIP problems, the error gaps are small.

To address the problem of uncertainties, we developed an inventory model. We imposed the service quality by including adequate safety stock in the network flow model at each location based on container type and period. Both the network flow model and the inventory model required that we generate empty container demand and return forecasts.

After a lengthy analysis, we found that the best forecasts required that we integrate time-series models with specific knowledge from the sales force and local logistics planners. We based the safety stock on the accuracy of the forecasts (Thomopoulos 2006). The ECO system has a module that keeps track of historical demand and return-forecast accuracy, which allows us to have updated estimators for the standard deviation and the mean forecast error for each location, equipment type, and period.

An important part of the project was understanding the relationship between forecast error and safety stock. In Figure 2, we present an example of a location and a specific equipment type in which we computed safety stock based on different service levels and standard deviations of the demand-forecast error. For example, for a service level of 99 percent, a forecast with a standard deviation of 12 units requires a safety stock of 28; this rises to 77 when the standard deviation is 33.

The results in Figure 2 showed CSAV management the importance of having the best possible demand forecasts. After a long testing period, management agreed that the best possible forecasts could be determined by a combination of approaches, as we describe below.

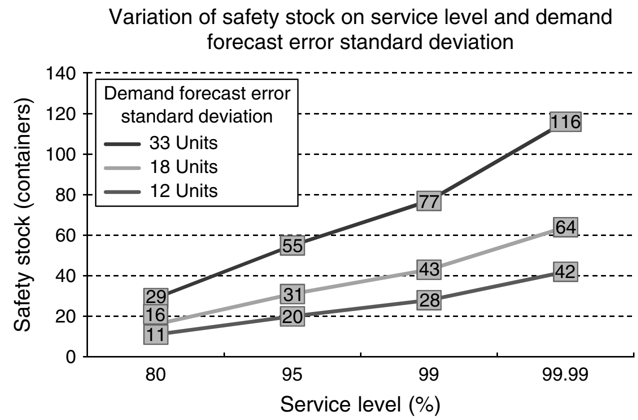


Figure 2: The safety stock depends on the demand forecast accuracy given by the standard deviation of its error and the service level given by the company. This example shows the values for one location and one equipment type, assuming that the only source of uncertainty is given by demand of empty containers.

1. Time-series forecasts: We tested several time-series forecasting techniques, including ARIMA models (Box and Jenkins 1976). However, we obtained the most accurate forecasts using seasonal and trended moving averages. Therefore, ECO uses two types of time-series forecasts: (1) a moving average forecast, which uses the average of the past n days; (2) a trended seasonal forecast, which uses past demand from the same season and adds a yearly trend that is computed from the previous year's figures.

2. Sales force forecast: CSAV developed a qualitative sales forecast, the consensus forecast model (CFM), in which the sales agents worldwide register their demand expectations; we elaborate on this forecast, filter it to ensure its accuracy, and use it to complement the time-series forecasts.

3. Logistics planners' forecast: We realized that logistics planners sometimes have information that must be considered in the forecasts; therefore, we included the option of introducing manual demand forecast values.

To forecast returned containers, we consider the first two methods. Note that in each instance, over 1,500,000 forecasts are calculated based on updated information and new user settings. This calculation considers both demand and return forecasts, the length of the horizon (i.e., 128 days), and the main location-equipment type combinations.

Logistics planners determine which forecast will be used at each location based on the forecast accuracy and their own experiences. In addition, they enter their demand expectations for specific locations, equipment types, and dates, which can replace the information in the ECO system forecasts. Then, the forecast type that the planner in each region configured is used in the network flow model.

To calculate the safety stock, we included the variance of the forecasts errors and the uncertainties because of repositioning travel times and capacity availability for shipping empty containers (see Appendix B).

The data problems mentioned above required significant changes in information quality and availability. CSAV undertook several projects to improve container-activity gathering and data transmission in its regional offices. Moreover, it designed several initiatives to improve information quality (e.g., regarding container activities, demand forecasts, and vessel schedules). As a result, the information quality has improved in both the ECO system and in many other systems and business units in the company.

As a result of implementing ECO, the average computer time required to track container activities fell from over 48 hours to fewer than 24 hours. In some areas, this resulted in dramatic reductions in the time between an activity's occurrence and its entry into CSAV databases. These reductions were the result of projects that CSAV undertook to improve the process that dictates how to gather and transmit information from the agencies and depots worldwide.

Container activities also include the equipment ID, the activity's date and type (e.g., loading, discharge, demand, drayage), and complementary information such as booking numbers, ports, and schedules. The quality of this information has also improved significantly, allowing the system to provide better information to the logistics planners about the status of the containers and the time each is expected to be available for use.

Data are sent to ECO directly from many of the company's core databases, which transfer updated information every minute. However, we were aware that information is not perfect; therefore, we integrated a data-cleansing module into ECO. Information quality has improved significantly because of CSAV's data-quality initiatives, some of which were born out of problems that were detected during the development and testing of this project.

To tackle the coordination problem, we designed and implemented a framework that optimizes CSAV's global operations based on a collaborative and participative optimization model on the Internet. The team at each regional office sets the parameters for each geographical area; the optimization model then considers all the settings simultaneously to deliver a global result. For example, users can configure the type of forecast to be used in the network flow model, set the desired service level at each location for each equipment type, and refine costs and some constraints. The network flow model solutions are integrated with updated business information, and several reports and dynamic indicators are made available to all planners and logistics people worldwide. Users from all regional offices review and share optimized plans and use them as a common basis for planning, coordination, and decision making. Bulk upload functionalities and integration with common office software allow parameter tuning and solution analysis in a user-friendly and timely way, given the amount of information available and considered in each instance.

Implementing the ECO System

Implementing the ECO system was a long process. In 2006, we evaluated the potential savings to ensure that this approach would address CSAV's main problems, while improving efficiency and performance. Our first approach was to gradually implement the system in all the regional offices, starting with the headquarters office in Valparaíso. We used a prototype-based development process, which required a large amount of field work; however, it ultimately helped us to understand the major decisions and problems that logistics planners faced. It also allowed us to gradually improve the network flow model, the inventory model, and the forecasting module.

At that time, CSAV empty container logistics operations did not include analysis of global processes or global systems; therefore, each region used a different operational method to solve its logistics problems. This became one of the most difficult parts of the implementation; we had to coordinate different cultures, processes, concepts, and languages to implement a global unique process and tool.

Another challenge was implementing this new way of handling empty container logistics simultaneous with the existing process. The people who were testing, tuning, and starting to use ECO had to continue doing their jobs as usual. We did not force its usage. We trained the users in the methodology and basic OR concepts, believing that using ECO would make their jobs easier.

In early 2007, we tested the first prototype using historical data; our tests showed significant opportunities for reductions in storing and shipping empty containers. This allowed us to move to the next step—using dynamic information in the system and supporting real decisions. In late 2007, we implemented a successful prototype in Valparaíso, Chile and Sao Paulo, Brazil. This prototype allowed us to work with two regional offices to understand how they used the system and determine any problems. For example, we realized that coordinating the regional offices would require a collaborative Web-based interface. Based on the results of the prototypes developed in Chile and Brazil, CSAV management committed to sequentially installing the system in all regions.

In 2008, the financial crisis hit the shipping industry particularly hard; international trading fell significantly, and freight and charter rates plunged. The shipping industry has a relatively large time lag between economic cycles and shipping orders. Therefore, the crisis resulted in a large surplus of ships; many shipping companies went bankrupt or became insolvent; they were no longer able to make their assets profitable, and therefore required complex debt restructurings. Between July 2008 and March 2009, CSAV's freight cargo fell 18 percent, its sales dropped 38 percent, and its market value fell 66 percent.

To address the crisis, CSAV determined that it would gain a competitive advantage through excellence in managing its container fleet. Radically changing its management strategy was imperative, and ECO played a key role in achieving this goal. Management decided to improve CSAV's operations and instill a standard of excellence in staff at all regional offices; it would be based on integrating and optimizing the decisions regarding managing its container fleet.

CSAV implemented ECO in 2009 and launched it globally in January 2010. The plan required all regional offices to implement ECO simultaneously. Therefore, to test and use the system, the offices had to be connected in real time. Once the main features were ready, a team from CSAV went to each regional office to introduce the system and train logistics planners in the methodology and in using the collaborative Web interface. In January 2010, testing and revisions in all regions were completed and the system became operational worldwide. The ECO system replaced the existing decision-making process, thus globally optimizing CSAV's large and complex container shipping system.

To generate and implement a global process to support the tool that we were implementing worldwide, we coordinated weekly logistics meetings with staff in each region; in these meetings, we defined the empty container flows for the following weeks and targeted optimal levels of safety stock at each location. The process also incorporated the best practices in using the system. We consolidated all this information in an operations manual that all CSAV offices use today.

ECO runs with the participation of all regional offices. The results of the runs are incorporated with business information and presented on a Web platform to which all logistics planners have access. They consider the system's suggestions and complement them with their information on the status of ports, ships, possible new demands, and other critical variables, and generate the final repositioning plan. The planners create the inventory and shipping plans for empty containers based on the system's suggestions, share them with the rest of the organization, and execute them on time.

ECO was implemented using four servers, each with a specific function:

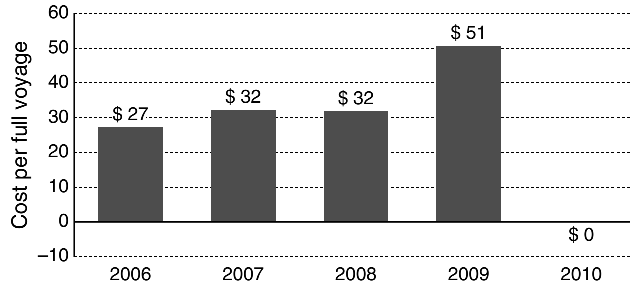
1. A database server stores and computes updated parameters for the network flow and inventory models. More than 60 million container activities are stored and used for computing necessary information (e.g., historical demand, empty container returns, and travel times). This server uses a marginal approach to generate all the parameters based only on the changes from the previous run.

2. A second database server stores the network flow model solutions combined with business information.

3. A Web server generates dynamic Web pages to meet user information needs.

4. An application server runs the network flow model through GAMS/CPLEX software and includes the ECO system application, which controls the flow of information entered into the network flow model and the database storing the solutions.

Today, ECO serves CSAV's regional offices and is used as a framework to support empty container inventory and repositioning decisions. The head office in Valparaíso uses ECO output as a common platform for planning and coordinating interregional decisions among the regional offices.



Average per voyage excess cost 2006–2009:	$35
Voyages 2010:	2.894 million
Total savings:	$35 · 2.9 = $101 million
Estimated ECO effect:	80%
Total ECO savings:	$81 million

Figure 3: The graph shows the cost per full voyage from 2006 to 2009, compared to 2010. The cost during 2010 was considered as level zero, and marginal costs are shown.

Impact

The project had both a wider and deeper impact than originally intended. It led to significant improvements in data gathering, real-time communications, automation of data handling, and quality of the decision processes; it allowed managers to make decisions with better, standardized information. ECO allowed for global decisions that were clearly superior to the ones obtained locally by each region.

In quantitative terms, ECO resulted in savings of $81 million in 2010, compared with the 2006–2009 average costs. In 2010, the cost reductions were mainly the result of reducing empty container inventory stocks by 50 percent and increasing container turnover by 60 percent.

Figure 3 shows the cost per full voyage, considering year 2010 as baseline with cost zero. The average cost in 2006–2009 was $35 per full voyage more than in 2010; we used this value to estimate the ECO-related savings. Considering the 2.9 million voyages in 2010, the total savings were $101 million. We estimate the ECO-related impact to be 80 percent of these savings, considering that the demand forecasts, stocks visibility, return forecasts, and logistics solutions proposed are vital to the decision making. However, other minor projects were ongoing; we assign them the remaining 20 percent. This results in the $81 million savings mentioned above.

CSAV's flexibility to modify the size of its container fleet shows that the savings come from improved efficiency because of better management of the fleet. The company has the flexibility to return or hire leased containers and determine the size of the fleet based on market conditions. Thus, the improved efficiency in container management generates the savings.

The ECO implementation had an impact both by reducing empty container logistics costs and by making CSAV more profitable than it had been in the previous decade. Average net income for the years 2000–2008 was $60 million; however, CSAV lost $669 million in 2009 because of the financial crisis. The savings from this project are an important part of the company's 2010 net income of $170 million. If we consider that CSAV had a demand for 2.9 million TEU in 2010, the net income per TEU was $59, an increase of 91 percent over what it would have been without the ECO-related savings. In addition, the savings generated by the ECO implementation surpassed by far the average net income of CSAV in the previous four years, even if we disregard the 2009 net income (see Figure 4).

This efficiency improvements gave CSAV these savings and a competitive advantage, which were key elements in helping CSAV to overcome the crisis and position itself as one of the major carriers in the world. According to CSAV CEO Arturo Ricke,

> The ECO system allowed us to manage the highly complex problem of our empty container fleet logistics very efficiently, which is fundamental in the global management of the firm. This improvement was a

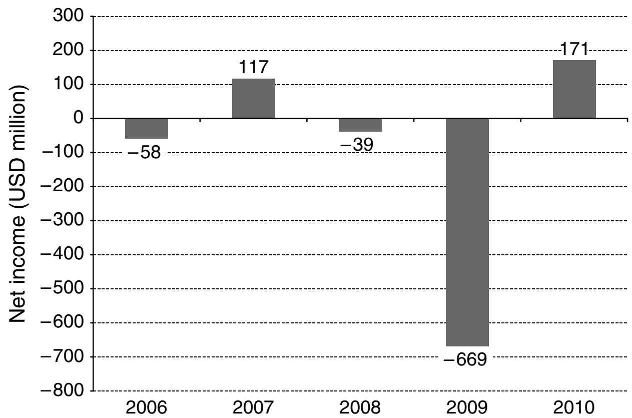


Figure 4: The chart shows CSAV's net income from 2006 to 2010.

> major contribution in turning our company around and is now one of the key elements in CSAV's operational strategy.

We estimate that the ECO system will generate an additional $200 million in savings during 2011–2012.

On the qualitative side, OR made CSAV's tracking and information systems useful; the optimization system tells operators what to look for and focus on in a global, complex, and changing network. ECO provided decision makers with a robust and trustworthy methodology that gives them target inventory levels. In addition, the optimization model provides them with a reliable source of alternative repositioning options, which can sometimes suggest new solutions that they have not considered.

ECO made contributions in at least four areas:

• Data quality, management, and availability: ECO development required a dramatic improvement of information quality, management, and availability. These improvements positively affected other areas of the firm.

• Personnel efficiency: Before its ECO implementation, CSAV used approximately 30 logistics planners to manage the container fleet. In August 2008, these planners managed 550,000 TEU in the container fleet. During 2010, the 30 logistics planners used ECO to manage and coordinate empty container logistics of a 700,000 TEU fleet. These planners were able to absorb this higher workload because the system significantly reduced the time required to gather and process the information they used.

• Unification of processes: Prior to creating and implementing ECO, each regional office used different information and procedures to plan and coordinate empty containers logistics, thus making the coordination and tracking of logistics decisions difficult. Today, ECO serves as a common platform for analysis and coordination, providing a standardized empty container planning process.

• Better reporting and control: Prior to the ECO implementation, empty container logistics planning required a mostly manual gathering of information from different sources. ECO allowed operators more time to focus on core tactical and strategic decisions. Logistics planners now spend most of their time making decisions and coordinating activities rather than processing data and reports.

In addition, in the past five years, CSAV's container business has increased significantly. Its use of ECO has allowed CSAV to maintain the same quality of service while incrementing the number of empty containers provided to customers well below the increase in the number demanded. The overall environmental and economic effects have been positive.

Conclusions

This project and the resulting OR-based solution provided a decision support framework that changed how logistics planners make their decisions and coordinate empty container logistics. This change produced important qualitative and quantitative results and also plays a key role in CSAV's operational strategy today. OR allowed CSAV to coordinate empty container logistics and support decision making under uncertainty, changing conditions, and imperfect information.

The ECO implementation demonstrated important features of OR usage—how it must integrate with information technology, data handling, and communications. Most importantly, it fostered a genuine partnership between the researchers at the university and the users at CSAV throughout the entire development process. As CSAV managers became convinced of the significant benefits of an OR approach, we were able to align the organization behind a change in its operational strategy, which led to the significant positive benefits described.

The use of prototypes was also an important part of the project; at an early stage of the project, it allowed us to understand the real needs and challenges faced by logistics planners.

ECO enabled CSAV to make the organizational changes needed to centralize the coordination of empty container decisions. The collaborative Web interface assisted the distributed planning process over distinct time zones. The optimization of the network flow and the inventory levels subject to safety stock constraints proved to be the right approach to support the decision-making process. The improvement in data gathering and management needed to run ECO provided high value for users in other functional areas at CSAV.

We believe that the main lesson of this project was how OR at CSAV facilitated a structural change that had very significant positive results.

Appendix A. The Multicommodity Network Flow Model

We present a simplified version of the network flow model considered in ECO. Neely (2008) provides a detailed description.

Decision Variables

$w_t^{ik} \in \mathbb{Z}_+$: Number of containers of type k in inventory at location i on day t.

$x_{tsv}^{ijk} \in \mathbb{Z}_+$: Number of containers of type k that are moved by vessel v when it departs from location i on day t and arrives at location j on day s.

$\underline{y}_{tsv}^{ik} \in \mathbb{Z}_+$: Number of containers of type k that are unloaded from vessel v at location i when it arrives on day t and departs on day s.

$\bar{y}_{tsv}^{ik} \in \mathbb{Z}_+$: Number of containers of type k that are loaded into vessel v at location i when it arrives on day t and departs on day s.

$\underline{z}_t^{ik} \in \mathbb{Z}_+$: Number of additional containers of type k that are required at location i on day t.

$\bar{z}_t^{ik} \in \mathbb{Z}_+$: Number of containers of type k that are no longer required at location i on day t.

Parameters

$d_t^{ik} \in \mathbb{Z}_+$: Expected demand for containers of type k at location i on day t.

$r_t^{ik} \in \mathbb{Z}_+$: Expected return of containers of type k at location i on day t.

$g_t^{ik} \in \mathbb{Z}_+$: Number of containers of type k already scheduled to arrive at location i on day t and in transit.

$\Delta_t^{ik} \in \mathbb{Z}_+$: Safety stock for containers of type k at location i on day t.

$l^D \in \mathbb{Z}_+$: Lead time for unloading containers, number of days required to make containers available.

$l^U \in \mathbb{Z}_+$: Lead time for loading containers, number of days required to prepare containers for loading.

Main Constraints

The difference in the number of containers that are loaded and unloaded from a vessel in a given call is equal to the difference of containers that arrive and leave the location on this vessel.

$$\forall\, i, k, t, s, v \quad \underline{y}_{tsv}^{ik} - \bar{y}_{tsv}^{ik} = \sum_{j,r} x_{rtv}^{jik} - \sum_{j,r} x_{srv}^{ijk}.$$

Inventory dynamics account for flow conservation, including lead times when loading and unloading containers.

$$\begin{aligned}\forall\, i, k, t \quad w_{t+1}^{ik} &= w_t^{ik} + g_t^{ik} + r_t^{ik} - d_t^{ik} - \sum_{v,s} \bar{y}_{(t+l^U)sv}^{ik} \\ &\quad + \sum_{v,s} \underline{y}_{s(t-l^D)v}^{ik} + \bar{z}_t^{ik} - \underline{z}_t^{ik}.\end{aligned}$$

The inventory must at least include the safety stock.

$$\Delta_t^{ik} \le w_t^{ik}.$$

The model also considers capacity constraints for the various means of transport and the initial inventory available at each location, among other operational constraints. In particular, given the detailed formulation of the model, containers might be unloaded at a given port and then loaded again at this port in some instances. To avoid this nonlogical step, we introduced binary variables. The objective function is to minimize operational costs.

Appendix B. The Inventory Model

We consider safety stock requirements—at period t, with orders at each period, and with a single source of uncertainty—in demand for empty containers. The safety stock depends on the demand forecast error and is given by

$$S_t = \max(\lceil \hat{\mu}_t^{e,D} + z_\alpha \hat{\sigma}_t^{e,D} \rceil, 0),$$

with the following notation:

$\hat{\mu}_t^{e,D}$: Estimator of the mean demand forecast error t days ahead.

$\hat{\sigma}_t^{e,D}$: Estimator of the standard deviation of the demand forecast error t days ahead.

z_α: Safety factor to achieve a service level of α percent in demand forecast coverage.

The previous model was enhanced by assuming that orders are placed at periods in which main vessels call and that demand is not the only source of uncertainty. Then, the safety stock in period t is given by

$$S_t = \max\left(\left\lceil \sum_{l=t}^{q(t)} (\hat{\mu}_l^{e,D} - \hat{\mu}_l^{e,R}) + z_\alpha \sqrt{\sum_{l=t}^{q(t)} (\hat{\sigma}_l^{e,D^2} + \hat{\sigma}_l^{e,R^2})} \right\rceil, 0\right),$$

with the following notation:

$q(t) = p(t) + d + \lceil \hat{\mu}_{N(t)} + z_\beta \hat{\sigma}_{N(t)} \rceil$.

$\hat{\mu}_l^{e,D}$: Estimator of the mean demand forecast error for day l.

$\hat{\mu}_l^{e,R}$: Estimator of the mean return forecast error for day l.

$\hat{\mu}_l^{e,D}$: Estimator of the standard deviation of the demand forecast error for day l.

$\hat{\mu}_l^{e,R}$: Estimator of the standard deviation of the return forecast error for day l.

z_α: Safety factor to achieve a service level of α percent in demand and return forecast coverage.

z_β: Safety factor to achieve a service level of β percent in the coverage from estimated times of arrivals.

d: Number of days required to unload containers.

$p(t)$: Day of arrival of next vessel, after day t.

$N(t)$: Next vessel, after day t.

$\hat{\mu}_{N(t)}$: Estimator of the mean error of the time of arrival of vessel $N(t)$.

$\hat{\sigma}_{N(t)}$: Estimator of the standard deviation of the time of arrival of vessel $N(t)$.

In the previous expression, $q(t)$ represents the day of the next call plus the time needed to cover for uncertainty in this next call. In addition, note that we assumed that the demand and return forecast errors have normal distributions and are independent variables. We also assumed that delay times have normal distributions. To achieve a specified service level, we needed to calculate both α and β.

To include the uncertainty in empty container capacity on vessels, we added a procedure in the inventory model. Safety stocks are adjusted using a factor calculated using the standard deviation of the empty container capacity of each vessel that has calls at each location considered.

This inventory model was used to provide daily safety stocks, which were included as the minimum empty container requirements at each location in the network flow model. The basics of inventory management are in Silver and Peterson (1985). Neely (2008) gives a detailed description of the model used.

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