A Spreadsheet Decision Support Optimization Model for Railcar Storage at Canadian Pacific Railway

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# Abstract

Canadian railway companies operate in a capital intensive segment of the transportation industry. In most railway companies, the covered hopper railcar fleet is one of the larger fleets due to its use in moving grain and potash, commodities that move large volumes of product. This railcar fleet is also difficult to manage due to demand seasonality and joint commodity use.

This paper demonstrates how an aggregate planning model can be used to support decision-making related to optimization of covered hopper railcar storage. Exploratory research prior to model development involved interviews with company personnel. The model was developed through quantitative research and implemented using spreadsheet optimization. The results indicate that using this model can reduce the total cost of storage through effective planning. The model also provided insight to improve railcar storage such as the elimination of excess storage locations and the need to do further investigation. The company is in the process of implementing suggestions from this paper.

**Keywords**: Aggregate planning, storage, spreadsheet optimization, mathematical programming, railways, transport

**Introduction**

This paper focuses on the handling of railcars used to move grain and potash in Canada. The seasonal nature of the grain and potash industries impacts the number of railcars required to meet demand and necessitates implementation of appropriate policies regarding railcar fleet sizing, particularly in regard to railcar storage so that fluctuating demand can be met. Railcars are generally put into storage on unused railway track at various locations around the country. A spreadsheet mathematical programming model of the aggregate planning process was implemented to serve as the starting point for a decision support system. The results indicate that considerable insight can be obtained by modelling the process and the company is in the process of implementing suggestions from this paper.

The Canadian Pacific Railway (CPR), is a transcontinental railway covering over 22,080 km (13,800 miles) of rail network in Canada and the United States. CPR holds a strong market position within bulk commodities, with a large portion of overall revenues being derived from coal, sulphur, grain and potash shipments. CPR moves grain and potash in covered hopper style railcars, designed to protect the product from weather during transportation As of 2007, the company owned or long-term leased a fleet of 25,400 covered hopper railcars, including 9,000 government owned railcars (Canadian Pacific Railway, 2008).

The perception within railroad companies is that these optimization methods are not being fully exploited to answer questions regarding asset utilization. For example, the covered hopper railcar fleet at CPR is sized through these methods; however, the resulting plan is not integrated with the company’s railcar storage policies. Consequently, there have been operational inefficiencies and confusion during the execution of the storage plan, which this paper aims to address.

## Railcar Storage

Despite the costs associated with railcar storage, the costs associated with keeping unused and empty railcars in service are often much higher such as the lack of revenue (opportunity cost) associated with the moves, crew costs, locomotive costs, train lost capacity costs, and yard lost capacity costs due to congestion.

If a railway company accepts the necessity of storing railcars, the next question becomes which railcars to place in storage. Different types of railcars in the fleet have different storage costs.

Leased covered hoppers cannot always be returned to the lessor at an appropriate fleet reduction time, due to the long-term nature of many leasing contracts. Another incentive for keeping leased railcars active is to improve the railway’s ability to respond (flexibility) to sudden increases in demand. Railcars returned to the lessor might not be easily recalled to meet increased demand, resulting in operational inflexibility; thus orders and revenue may be lost.

Railway-owned covered hoppers were purchased in part to increase the available railcar capacity as well as to ensure the fleet could meet customer demand when necessary. These railcars are newer than the governmental fleet and require less maintenance to remain active. The railway’s investment in these railcars, and the lower costs required to operate them creates an incentive to store the governmental railcars instead of railway-owned railcars. Government-owned covered hoppers cannot be returned to the government in a manner similar to a leased railcar and due to the agreement with the government, can only be used to move grain in Western Canada. The cars cannot be used in any other service such as moving potash or grain in the United States without incurring a higher cost. This limitation encourages railways to place these railcars into storage when there is a need to reduce the active covered hopper fleet size.

The leased and CPR-owned covered hopper railcars incur similar costs while under CPR direction. Thus, these two groups can be treated as one group for analytical purposes. Thus this leaves two distinct groups of covered hopper railcars for use in the development of a storage model: government railcars (Type 1) and CPR railcars (Type 2).

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# Literature Review

Operational research models have long been used in managing different aspects of railways. An extensive survey of literature relating to the movement and flows of empty vehicles can be found in Dejax and Crainic (1987). Mathematical programming models include Brosch et al. (1980), Sherali and Tuncbilek (1997), Cordeau et al. (1998), Sherali and Maguire (2000), and Andersen and Christiansen (2009) all related to fleet sizing. Lui et al. (2008) all use mathematical programming to address the question of yard location and capacity expansion, while Alfieri et al. (2007) address personnel scheduling issues.

Mostard et al. (2005) analyze the newsboy problem with resalable returns. The resalable newsboy problem is similar to the reusable nature of railcars in that the returned items can be used to meet future demand; thus, one item meets multiple demands. This cyclical return is handled through the use of a railcar demand model to adjust the overall demand into railcar demand. DuPont Canada Inc. (Lesyna, 1999) has successfully built a discrete-event simulation model to look at their private railcar fleet and answer the question of optimal sizing of the fleet under certain conditions. Wardrop (2008) discusses the use of analytical tools in railway operations in Australia. Laporte (2008) traces the development of Canadian operational research applications including those for the railway industry. Krajewska et al. (2008) and Korvik et al. (2010) address the issue of railway revenue management. Fagerholt et al. (2010) and Bauer et al. (2010) discuss reducing railway greenhouse gas emissions. Seguin et al. (1997) discuss the use of methods to facilitate real-time decision making in general which is also applicable to railway decision making. Similarly Avramovich et al. (1982) discuss decision support in trucking which can be applied to railways. As is evidenced in the literature, research focusing on the optimization of fleet size and fleet assignment has been well documented. Many models have been suggested and implemented in these areas; however, the resulting impact on the storage of railcars has not been discussed.

**An Aggregate Planning Model for Railcar Storage**

This study is intended to answer several research questions related to the interaction between customer demand and storage policies and their effects on railcar fleet size, operational costs and customer satisfaction. A discussion of the method used to develop the aggregate planning model provides a background for the results and conclusions drawn from the aggregate planning model.

The planning horizon for railcar fleet sizing is generally one year in the future with monthly updates to confirm that the fleet size will meet any changes in demand. Customer demand is aggregated for a single railcar type. For example, grain and potash demands are aggregated together, as both commodities use the same type of covered hopper railcar. Supply and demand may both change throughout the year. Supply may change due to leases that expire, higher than anticipated mechanical failures, or increased cycle times. Demand may change due to changing market conditions, competition, or customer expectations. Management objectives are to reduce railcar fleet costs and improve overall railway efficiency.

Current Planning Process

Demand is based on anticipated customer orders as determined on a yearly basis by the marketing department. In the case of grain, the demand forecast is based on the Canadian Wheat Board’s anticipated crop for the year and subsequent division amongst the railways according to anticipated market share. This demand forecast is then converted to railcar demand based on the capacity of each car and the reusability. The reusability takes into account the fact that the rail car can be used multiple times during the year.

Railcar requirements are then compared against the available supply of railcars to determine when a surplus or shortage of railcars occurs. The surplus is used as the base plan to reduce fleet size by storage planning, while a shortage indicates a potential need to increase the railcar fleet size. Only if a railcar shortage exists for a significant period (such as eight to twelve months) will the railcar fleet size be increased. This caution is due to the long term nature of the railcar leasing contracts. Thus, if a railcar shortage exists for only a few months, the fleet size will not be adjusted. Currently, on an annual basis the railcar capacity is sufficient to meet demand.

Railcar storage requires that the railcars are moved to locations not used in daily operations. Consequently, tracks required in daily operations can remain available to meet demand for yard capacity. Moreover, there is an avoidance of the yard congestion that would arise if stored railcars were to block the movement of demand railcars. Excess railcars are those not used to meet demand at a hub and also not moved into a storage location. Rather, they are in excess at the hub yard and interfere with daily operations.

Railways commonly use customer order fulfillment as a measure of customer satisfaction. Spieckerman and Voss (1995) discuss both order fulfillment and job tardiness (i.e., delay in filling backorders) as measures of customer satisfaction. The greater the number of unfulfilled orders the greater the customer dissatisfaction. As well, the greater the average job tardiness the greater the customer dissatisfaction. Both measures can be used to determine overall customer satisfaction, although an estimated cut-off point is required to distinguish between satisfied and dissatisfied customers. For the purpose of this aggregate model, order fulfillment and job tardiness can be measured through the amount of railcar shortfall from month to month. Shortfall (or railcar shortage) is the term used to describe any unfulfilled demand from the previous month that is carried into the current month.

## Problem Analysis

The analysis of the problem with storing covered hoppers was undertaken in a multi-step process involving several iterations. First, various groups involved in the storage process were interviewed regarding the current methods used in storing covered hopper railcars, sourcing data, and making decisions. These groups included car management, service design, grain marketing and the operations planning group. The questions dealt primarily with the processes followed and tools used in storing railcars and were exploratory in nature. The responses from these interviews allowed for the development of a process map for placing covered hopper railcars into storage.

Historical data was gathered regarding forecasted railcar orders, costs, railcar fleet sizing, and storage locations. This data originated from various company databases and personnel and required a time consuming process of filtering prior to use. The data presented in this paper has been disguised because of proprietary concerns. The disguised data exemplifies the model without compromising company information. This data was then used as a source of input in a spreadsheet model for analysis purposes. The objective of this model was to provide insight into the aggregate planning process for storing railcars.

Problem Description

## Due to the complexity of the model, a simplified version of the model had to be constructed so that the problem formulation could be tested and its validity ensured. The three type of nodes utilized in the movement of empty covered hopper railcars are 1) origin nodes, 2) demand hub nodes and 3) destination storage nodes. Each type of node operates in a distinct fashion in order to allow for the tracking and movement of empty railcars throughout the network. Figure 1 shows the network model consisting of two origins, fifteen demand hubs and eighty storage destinations.

 **Insert Figure 1 about here**

1. Origin Node

Origin nodes are the source points for empty covered hopper railcars entering into the model at the beginning of each month. These railcars are either empties unloaded at the port or additional railcars added to the railcar fleet through new leasing arrangements. Origin nodes also act as a holding point for empty covered hopper railcars used to meet non-grain demand during the month such as the demand for covered hopper railcars to move potash product.

#### Demand Hub Node

Demand hub nodes are the source points for customer demand as expressed in empty railcars required to load product. Demand hub nodes also act as an exit point for loaded railcars to be removed from the model at the end of the month. A demand hub node can also be a holding point (or storage point) for empty railcars.

#### Destination Storage Node

Destination storage nodes are the source points for railcars available to meet demand at a demand hub node by the end of the month. Available railcars are those empty railcars stored at the location from the previous month; they are pulled from the destination storage location at the beginning of the month. The destination storage nodes are also a holding point for excess railcars not used to meet demand during the month.

The network diagram (Figure 1) shows how the origins (O1 and O2), demand hubs (H1, H2, … H15) and storage destinations (D1, D2, … D80) are interconnected, so that a railcar can move from one point to all other points on the network through multiple paths. Logically and in practice, there is a direct linear relationship between the distance travelled and the cost of the movement. For example, to move a railcar from O1 to H15 would cost $201 and to move a railcar from O1 to D79 would cost $645. The costing assumes the use of the shortest or least cost route to travel.

Demand is expressed in terms of railcar requirements, that is, empty railcar demand, not demand for product. Any demand that cannot be met in a given month is carried forward into the next month as additional demand to the forecasted demand for that month (as customers in general do not have alternate carriers and will wait, though the government can force CPR to reimburse customers for losses due to poor customer service). Capacity limits the railcar movements into the destination storage locations, through demand hubs and origins.

Several types of costs need to be accounted for, including railcar movement costs between nodes, railcar storage costs at nodes, excess railcar costs at demand hub nodes and railcar shortage costs at demand hub nodes. These costs may differ by railcar type as well as by the direction of railcar movement.

Railcar storage costs at nodes are those costs associated with holding railcars at a node. These tend to be fixed monthly costs associated with the railcar type, due to the structure of railcar leases. These costs drive the movement of certain railcar types into storage locations, because different railcar types carry different storage costs.

Excess railcar costs are incurred when a railcar is not required to meet demand at a demand hub node and remains in the demand hub node in order to meet future demand, rather than being stored, creating congestion costs and operational inefficiency within a demand hub node. Railcar shortage costs are incurred when a railcar is not available to meet demand at a demand hub node in the month when demand occurs. These shortages are carried into the subsequent month as additional demand to be met in that month.

Fleet size data records the total number of empty railcars available to move through the network in a month in order to meet demand. The fleet size is proactively adjusted for mechanical failures and changes to leasing agreements in order to more accurately reflect empty railcar availability. Fleet size data is based on historical data based projections for future needs. CPR’s existing fleet sizing model is used to determine fleet size, which assumes that 98% of the railcars are mechanically available at any given time.

#  Current Practice

A review of the current storage process brought several important issues to light. First, the use of multiple departments to make storage-related decisions results in confusion and frustration with the responsibilities for decision-making associated with the storage process. Each department feels they are entitled to a larger part of the decision-making process due to their subsequent involvement in the process. For example, car management determines the fleet size and number of railcars requiring storage, so want cars placed into storage as soon as possible. Marketing wants sufficient railcars available to meet demand and so they want to delay storage for as long as possible, to ensure all demand is met on time. Second, the communication between these departments needs to improve in order to ensure that all parties understand the need to store railcars and that a coordinated plan is executed. Third, the process is hampered by the use of last minute decision-making rather than planning. This is true particularly with respect to determining the storage locations, the number of railcars to store, and when to begin storing railcars. These issues have resulted in intuitive decision making and negotiation between departments with conflicting priorities. As a consequence, fleet efficiencies have been lost and costs have increased.

Model Assumptions

Several assumptions allow the model to function. It is assumed that railcars arrive at the end of the month in the destination storage location or the hub location. Further, it is assumed that railcars are pulled out of storage at the beginning of the month. Both these assumptions are used in practice in the sizing of railcars fleets. Further all destination storage locations are networked together through the hub locations. This means that railcars travel from the origin locations through a hub and then into a destination storage location, so that a hub is part of the sequence of movement. It also means that a railcar from either origin can end up at the same destination storage location via different routes. This imitates the fashion in which the rail network works in reality.

It is also assumed that demand in a given month is met at the end of the month by the cars moving at the beginning of the month. This is similar to how CPR plans railcar fleet sizing and forecasting demand. The model assumes that all railcars will end up at one of the origin locations at some point within the month, which is also true in practice.

There are several assumptions about capacity including the following: origin capacity is essentially unlimited in a month, since all railcars must cycle through the origin locations; hub capacity in a month is based on the movement of railcars through the hub in that month. In other words, the capacity of a hub location is an operational capacity, not a fixed capacity such as exists at the destination storage locations.

The assumptions made with respect to costs may result in an excessively high total cost; therefore, the model may not determine the overall true cost of storage to CPR. However, it can provide a guideline as to what costs may need to be calculated in the effort to better understand the impact railcar storage has on overall costs. As well, several of the assumed costs included in the model, such as shortage and excess railcar costs, are not used by the company; however, these costs are essential in managing railcar flows within the model. When excess and shortage costs are assumed to be zero, then railcars travel the least cost routes, and the result is shortages at hubs farther from origin (i.e., those with higher movement costs) and excesses at hubs closer to origin (i.e., those with the lowest movement costs). This is not, in reality, how railcars move to meet demand. Thus, this model is intended as a future decision support system for managing the storage of railcars on CPR rail lines, providing feedback to management regarding the effectiveness of railcar storage practices and gaining insight into potential longer-term decisions, such as future track abandonment.

## Data Acquisition

Some costing data was missing from the system used to determine railcar costs. CPR’s Accounting Centre deals with these missing pieces of information through the use of a highest cost substitute. Thus the same convention was followed in this paper.

Railcar storage costs were calculated using the associated leasing costs as the basis for the cost of storing railcars. Those railcars that are government owned can be stored without a cost to the railway and are considered to have zero cost associated with storage in the model.

Shortage costs are difficult to calculate. They not only result in penalty charges from the customer to CPR; they can also potentially be associated with future lost revenues due to lost market share or goodwill (i.e., the customer moves to another transportation company where they have a choice). It is generally accepted that a certain amount of shortage will be acceptable to the customer; however, it is considered a negative long-term risk to the company. Thus, an artificially high cost is associated with shortage in the model. The model does still allow railcar shortages to occur, particularly in periods of high demand resulting from the seasonal nature of the demand.

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#  The Spreadsheet Model

For reasons of brevity only a description of the mathematical programming model implemented is provided (Figure 2). The actual model can be found in Espey (2007). The model is built similarly to a network flow model with the “unused” arcs, such as destination to destination moves, defined as cost prohibitive in nature. Thus, the model could include these movements at a later date, if required.

The objective function of the model is designed to minimize the total cost of all railcar movements between origins, hubs and destinations; all storage of railcars at destinations; all excess railcars at hubs; and all shortages of railcars at hubs. Constraints (categories of constraints can be seen in Figure 2) included inventory balance calculations designed to calculate the current inventory from beginning inventory plus incoming railcars less outgoing railcars for each origin, demand hub and destination storage location. These equations work in conjunction with the capacity constraints at each location type to ensure that maximum capacity is not exceeded. An excess (shortage) railcar calculation is used to determine the number of excess (or shortage of) railcars in the fleet. This calculation was necessary for the creation of a linear model (Winston and Albright, 2009; pp 157-159) and to allow any shortages to be carried over into the following month’s demand without having unmet demand in other months carried over as well. The forecasted railcar demand calculation is used to determine the forecasted number of railcars required to meet demand for the month, including any carryover demand from the previous month, which is required to determine the number of excess (or shortage of) railcars. Another set of constraints calculates the starting inventory at origin based on the month’s railcar fleet size and taking into account railcars in storage at destinations and in excess at hubs.

 **Insert Figure 2 about here**

Origin capacity constraints ensure that an origin location does not contain more railcars than the track can operationally handle at that location at the end of a given month. Demand hub capacity constraints ensure that a hub location does not contain more railcars than the track can operationally handle at that location at the end of a given month. The destination storage capacity constraints ensure that a destination storage location does not contain more railcars than the track can handle at that location at the end of a given month.

The mathematical model was translated into an Excel spreadsheet to allow for linear programming analysis. The model uses a closed network system that allows railcars to move from any point to any point within the system. Two railcar types were allowed to move within this system, each with differing cost properties. Once completed, the model had 226,536 variables and 4573 constraints. The railcar movement variables included two origin locations by fifteen demand hubs by eighty destination storage locations by twelve months by two railcar types. The demand variables included fifteen demand hubs by twelve months by two railcar types by two status types (excess or shortage). The large size of this linear programming (LP) model required the purchase of the Premium Solver Platform and the use of a free trial version of the Large-Scale LP Solver from Frontline Systems, Inc. (2005). Once completed, the model required approximately two hours of run time on a DELL Inspiron 600M with a Pentium processor and 512 MB RAM, this included running three analysis reports; a sensitivity report, a limits report and an answer report.

Excel Solver could solve an LP model only if the decision variables, including the changing cells, objective function and constraints were all contained within one worksheet. The number of variables in this model necessitated the separation of calculations and data inputs from the decision variables. Thus, the resulting spreadsheet contained nine worksheets, so that there could be a separation of the various data, the calculations as well as any assumptions required. Table 1 provides a breakdown of the worksheets and their size as determined by the rows and columns used on each worksheet.

 **Insert Table 1 about here**

This separation of data, calculations and assumptions into separate worksheets also aided in debugging the model as it allowed for easy visibility of potential problem areas. Figure 2 outlines the overall layout of the model. For reasons of brevity, only example screen prints of some of the worksheets are included in this paper. More detail on the worksheets can be found in Espey (2007).

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# Analysis of Results

An analysis of the model’s results provides considerable insight into the storage of covered hopper railcars at CPR. A comparison of the previous year’s actual storage plan with the model’s suggested storage plan for the same year shows that the storage plan developed by the model would have saved a significant amount of money compared to the current process. This higher cost can be attributed to the costs associated with moving railcars inefficiently instead of placing them in storage locations.

The costs associated with these excess railcars and the railcar shortages in the actual storage plan versus the model’s storage plan shows that the suggested storage plan would have reduced these costs. The actual storage plan had 4793 more excess railcars at hubs compared to the proposed plan, which are the biggest contributors to the higher cost. This actual plan also had 519 more railcars of shortage, another significant contributor to the higher cost. As well, the actual storage plan indicated excess railcars in many months; the model’s storage plan placed these excess railcars into storage locations or to meet demand at hubs rather than incurring the high costs associated with excess railcars.

It was seen that the model’s solution was very sensitive to the per unit cost of excess and shortage of railcars, which could not be accurately estimated in the time frame available. This result indicates that is it important for CPR to determine the cost of an excess or short railcar accurately. Figure 3 shows an example of the excess/shortage costs from the model results.

 **Insert Figure 3 about here**

An analysis of the detailed railcar movement section of the model provides information related to the number of railcars of each railcar type in storage. It also highlights the preference for railcar type in meeting demand. As can be seen in the ending inventory numbers in Figure 4 (costs associated with the car movements can be found in Figure 5), the model shows that railcar Type 1 (government owned) is the preferred railcar for storing. This preference for using railcar Type 2 to meet demand is due to the lower cost of Type 2 railcar movements as well as the lower storage costs for railcar Type 1.

 **Insert Figures 4 and 5 about here**

An analysis of Figure 5 also showed that initially some railcar movements to the hubs were not directly from an origin location, but via destination storage locations. This action indicated that it is less expensive to move these railcars from origin to destination and then to hub instead of directly to the hub to meet demand. As these broken segment movements are ones that the company avoids in practice due to the set-up costs, the costs in the model associated with the moves may be too low. When the costs for each of these broken segments were increased, the model moved the railcars directly to the demand hub location. This change in railcar movement indicates that the costs for the broken segments need to be investigated.

The model also provided insight into the relationship between demand and the cost of moving and storing railcars near demand locations. For example, the model did not store railcars near the areas of highest demand or nearest to the origins; instead the railcars were stored at intermediate points between the origin and areas of highest demand. This was due to the trade off between meeting demand and reducing transportation costs.

The model did provide several anomalous situations in which railcars were moved into a final storage location only to be pulled back into a hub in order to meet demand in the same month. Analysis of these situations showed that moving the railcars in this manner was less costly than moving the railcars directly into the hub to meet the demand. This result seemed counter intuitive, as the cost for multiple movements would naturally be higher than the cost of a single movement, in view of the set-up costs. As well, the constraints did not require or prevent this type of movement in order to allow the free movement of railcars between all locations. Further analysis of the costing information is required to ensure the costs used in the model accurately capture the costs of movements.

The analysis also highlights potentially unused locations (fifty eight destinations were unused for storage of grain covered hoppers) that could either be used for storage of other railcar types or eliminated from the rail infrastructure. In both situations, there are benefits to the company in reduced costs as well as improved operational efficiency. Locations that could be used for storage of other railcar types may allow for the reduction of other railcar fleets, so that operational efficiency improves in currently congested yards, and fleet management costs may decline. Eliminating some location from the rail infrastructure would allow for the reuse of rail, ballast and ties in other locations that require capital improvements. It would also free up the land to be sold to outside interests or used in another manner by the railway.

The number of variables resulted in considerable sections of the model holding zero values; thus, a summary table (Figure 6) was generated to provide an overview of the results of the storage plan for easier communication of the results.

 **Insert Figure 6 about here**

In general, the pattern in results from the model provided validation evidence. For example, the model did store and withdraw railcars in the expected months. Thus the movements in the model mirrors what should happen in practice. In addition the cars that were less expensive to store and withdraw were stored first. Further anomalous results could be explained by the cost structure. When the structure (as mentioned, some costs had to be assumed) was changed, the results became intuitive. So we can be confident that the model will provide valuable insights and decision making information for the CPR.

A sensitivity report of the hub summary decision variables as well as the constraints provides several insights into the available storage capacity on the rail network. The negative shadow price of some storage locations (Figure 7) indicates that if several destination storage locations were expanded, then additional railcars could be stored at these locations with a decrease to overall costs. Furthermore, the marketing department could use incentives to entice customers to ship railcars during periods of low demand from a specific hub near the lower cost destination storage locations.

 **Insert Figure 7 about here**

# Conclusions and Areas for Future Research

The results showed that the model provided a cost effective solution for removing excess railcars temporarily from the fleet, while still meeting customer demand. The model can also provide managers with many insights into the relationship between movement and storage of rail cars, thus improving CPRs decision making capabilities.

The spreadsheet model was also set up with a high shortage cost assumption designed to force demand to be met ahead of storage of the railcars. This shortage cost was based on management’s assumption that meeting customer demand had to take precedence over the operating needs of the organization. In fact, this assumption may not be correct, since customers have limited transportation alternatives for the long-haul movement of grain. The unmet demand in one month may simply be pushed into another month, thus so that demand is smoothed over the long run and a more static fleet size is achieved.

The model also highlighted fifty eight locations not being utilized for storage of railcars. Management now had a decision point regarding these locations and the potential to utilize them for other purposes such as storage of other railcars, or to eliminate the sites as storage locations and use the materials (e.g., ties, track, and ballast) to replace worn track in the remaining network. Since the original analysis was completed, CPR has either sold off, leased or removed track from five of these locations. As well, the results from the model were used to adjust the Three-Year Plan that is published publicly to indicate what locations CPR is considering eliminating from their network.

Most managers are comfortable with spreadsheet applications such as Excel, due to the pervasiveness of Microsoft applications in an office environment. The familiarity of CPR managers with the look and feel of Excel information makes this application an ideal tool for building, solving, and communicating an aggregate storage planning model in a practical manner. It also allows managers to easily make manual changes to the results where required.

This study did not consider the variability of demand and its impact on cost, customer satisfaction or operating efficiency. Because demand can be extremely variable, particularly in the case of grain movement, this would be an important area for further development of the spreadsheet model. The model’s sensitivity to the cost of excess railcars or a shortage of railcars, along with other internal reporting limitations, has resulted in CPR pursuing alternative costing methodologies in order to better assess these costs. Once complete, the new costing methodology can subsequently be inputted into the model and further analysis done to improve storage decisions.

Overall, the development of the storage process map as well as the storage planning model provided considerable insight into storage practices at Canadian Pacific Railway. This information has been be a valuable aid to management during monthly as well as yearly storage planning decisions. It has also allowed management to eliminate unnecessary steps within the storage process and realign responsibilities between the various departments to ensure accountability in storage planning and execution. This realignment has resulted in reduced complexity and sign-offs, increased automation of billing to storage, and a more accurate list of potential storage locations for all commodities which has improved execution of the storage plan. The potential for additional model development may allow CPR to use the storage planning model for all commodities in order to better manage their railcar fleets.

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**Legend**

Origin

Hub

Destination

Type 1 railcar to Origin

Type 1 railcar to Hub

Type 1 railcar to Destination

Type 2 railcar to Origin

Type 2 railcar to Hub

Type 2 railcar to Destination

Figure 1: Network Diagram

| **Worksheet Name** | **Number of Rows** | **Number of Columns** |
| --- | --- | --- |
| Model | 2748 | 202 |
| Assumptions | 21 | 2 |
| Cost Calculations | 1367 | 201 |
| Railcar Type 1 Costs | 102 | 100 |
| Railcar Type 2 Costs | 102 | 100 |
| Capacity | 105 | 9 |
| Fleet Size | 49 | 30 |
| Demand | 199 | 38 |
| Starting Inventory | 201 | 14 |

Table 1: Breakdown of Worksheets

**MODEL**

**ASSUMPTIONS**

**CAPACITY**

**FLEET SIZE**

**DEMAND**

**STARTING INVENTORY**

Costs

Capacity

**COST CALCULATIONS**

Summary Costs

Movement and Storage Costs

Excess and Shortage Costs

Railcar Type 1 Costs

Railcar Type 2 Costs

Objective Function

Hub Summary

Detailed Railcar Movement

Capacity Constraints

Availability Constraints

 Excess and Shortage Constraints

Excess Non-negativity Constraint

Hub Demand Constraint

Moving Railcar Constraint

**Legend**

Worksheet

Cells

Figure 2: Layout of the Spreadsheet Model



Figure 3: Demand Related Costing Calculations

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Figure 4: Detailed Railcar Movement Changing Cells



Figure 5: Movement and Storage Railcar Costs



Figure 6: Summary of Storage Plan Results



Figure 7: Sensitivity Report