IMPROVING INVENTORY MANAGEMENT FOR METHANEX

by

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We accept this thesis as conforming to the required standard.

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ABSTRACT

Methanex is a global leader in the production, distribution and sale of methanol. Their extensive supply chain services customers in all parts of the world. Intimately tied to their ability to service customers is their management of inventory. By storing methanol in regional distribution centers, Methanex is able to limit their global shipping costs by transporting methanol in larger ships, while improving their agility in responding to customer demand.

This paper examines the issues surrounding inventory management for Methanex. The goal is to define a methodology to identify target inventory levels for all of their major global inventory storage locations. It also discusses recommendations for changes in current levels of storage capacity. The feasibility of applying standard inventory control approaches such as the EOQ model and the Newsboy model is discussed. Two hybrid approaches involving simulation, combining mathematical techniques and business practices to model the global supply chain, are also discussed.

The Waterfront Inventory Simulation Engine (WISE) model is based one of these hybrid approaches. It is a decision support tool that enables the testing and analysis of a myriad of potential sourcing and inventory scenarios. This paper demonstrates that though supply chain planning for Methanex may be complicated and does not lend itself well to the standard inventory control techniques, there are still many ways in which operations research techniques can be used to conduct useful inventory analysis that will improve efficiency and have a positive impact on bottom line results.

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CHAPTER 1: BACKGROUND

1.1: METHANEX CORPORATE SNAPSHOT

Methanex is a global company, a world leader in the production, distribution and sale of methanol. Methanol is a chemical building block used to produce formaldehyde, acetic acid, fuel additives and a variety of other chemical intermediates. As one of Canada's largest publicly traded chemical companies, Methanex earned more than a billion dollars in revenue in 2001, creating more than $70 million in profits. It was a banner year for Methanex, selling more than 7.4 million metric tonnes (MMT) of methanol, representing 26% of the global market. Strategically, the focus of the company is to "create maximum value [through] low cost, global positioning and operational excellence."[1] The upcoming years will be years of growth, as Methanex plans to open new production facilities in Australia and Trinidad.

At the heart of Methanex and their success is their supply chain.

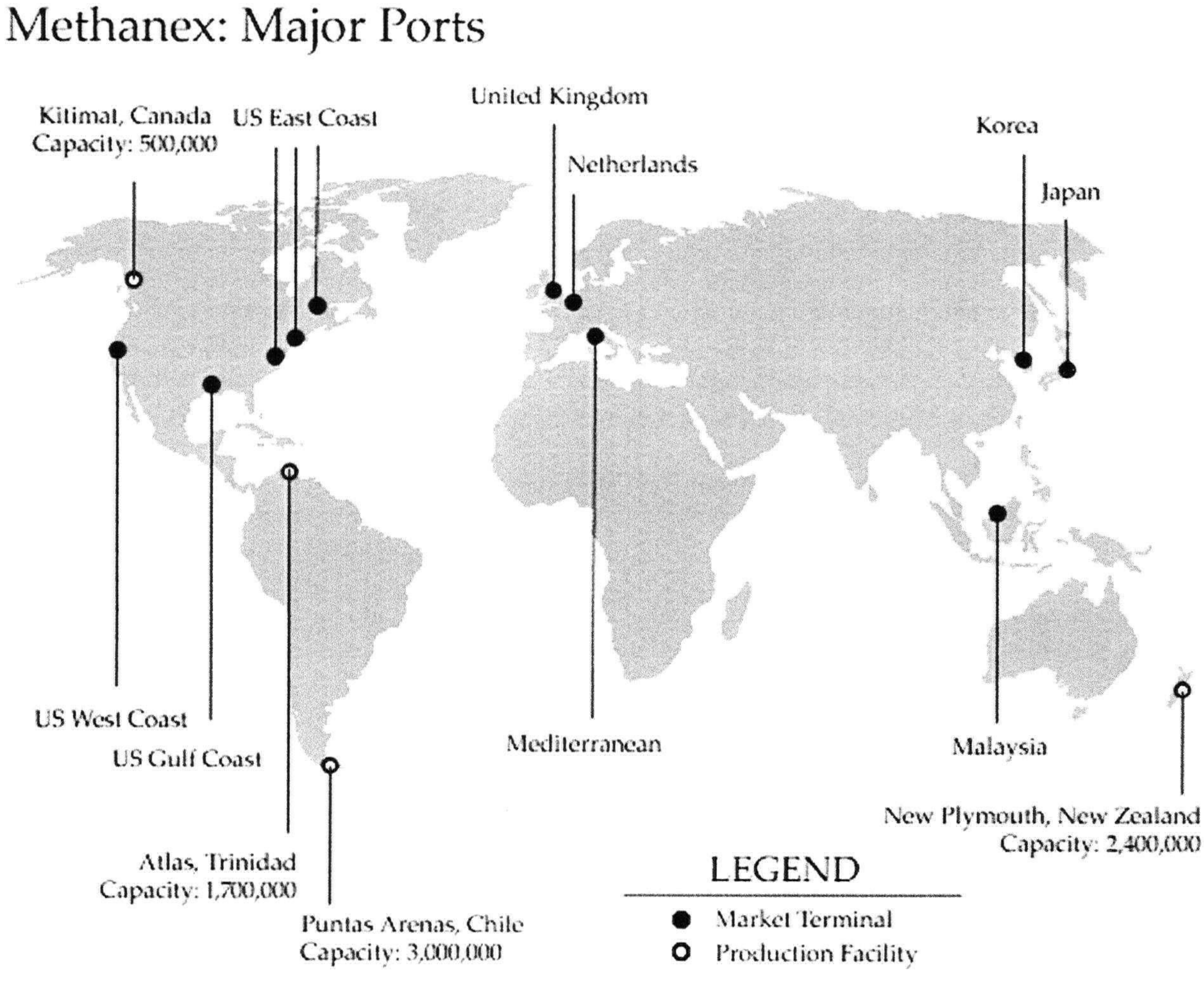

Figure 1: Methanex Major Ports

[1] Quoted from the Methanex 2001 Annual report

1.2: SUPPLY CHAIN FOR METHANOL

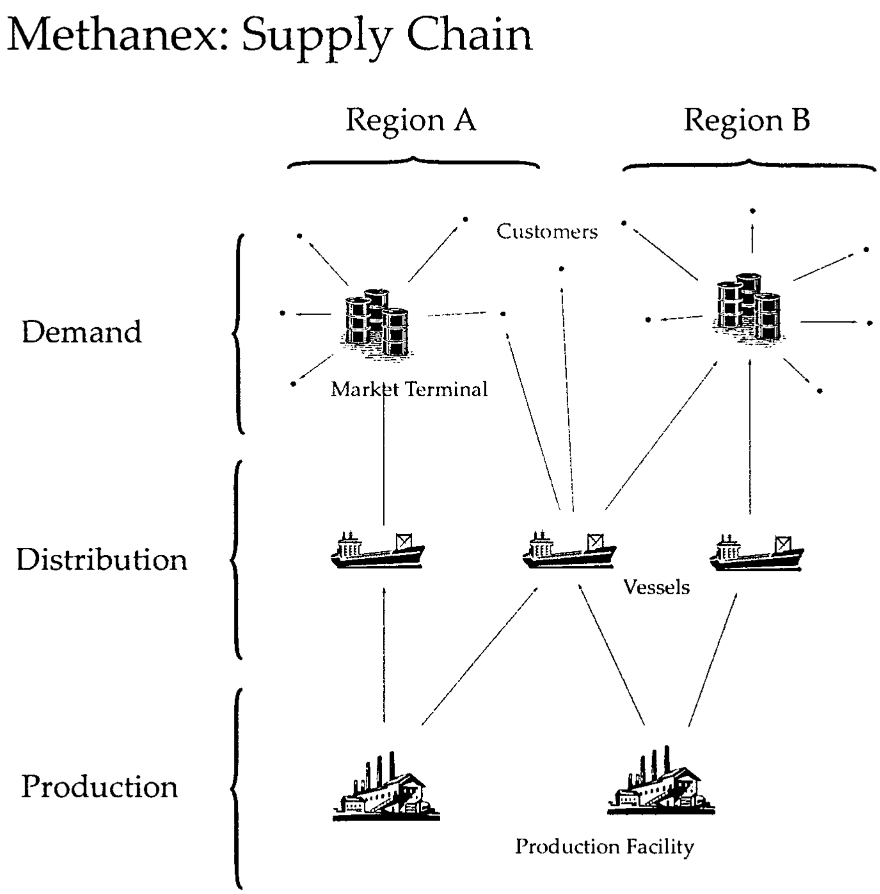

Figure 2: Methanex Supply Chain

PRODUCTION

Methanex operates major production facilities around the world located in Puntas Arenas, Chile; New Plymouth, New Zealand; and Kitimat, Canada. They are nearing the completion of a fourth site in Trinidad, and are beginning construction of a fifth in Australia. Production facilities are located in regions where natural gas feedstock can be acquired at the lowest cost. In 2001, total production was more than 5.3 MMT, making Methanex the one of the largest producers of methanol worldwide. The production facilities in both Chile and New Zealand are recognized as two of the most world's most cost-efficient facilities. As such there is a strong incentive is to produce at the maximum rate.

DEMAND

The vast majority of Methanex methanol sales are in North America, Europe and along the coasts of Asia. Larger customers, and those that are geographically isolated, are served directly from the production facilities, whereas regional distribution networks serve the smaller customers. The global market conditions are marked by demand that is relatively inelastic to changes in price, and only minor seasonal effects. A small part of their customer base represents the majority of their sales.

DISTRIBUTION

The transportation of methanol represents a substantial portion of Methanex's Supply Chain costs. In order to limit these expenditures, a subsidiary organization manages a fleet of time charter vessels, on long-term leases. These ships are ocean-going tankers dedicated to the transportation of Methanex methanol.

The Atlantic fleet consists of primarily of large 40 kMT vessels, and includes the Millenium Explorer, the largest chemical tanker in the world, capable of transporting an incredible 93 kMT. Typical trip durations from Chile to either the North American or European markets are between 25 and 30 days, exhibiting little variance. The Pacific fleet is made up of smaller vessels, ranging in size from 10 kMT to 30 kMT. Though, the trip durations of the Pacific Fleet exhibit high variance across ports, ranging anywhere from 5 to 27 days, variance for any given port is low. The ships are constantly in motion, collecting methanol from the production facilities and delivering it to directly to customers or into storage.

Alternatively methanol can be transported across the ocean on vessels termed "spot vessels" or "Contract of Affreightment vessels", which are chemical tankers that are leased temporarily to make deliveries. The number of suitable spot vessels is limited. Suitability is based on the type of cargo previously carried, size, and availability. The cost of using a spot vessel can vary extensively, but is generally higher than the cost of using an equivalent time-charter vessel.

Once the methanol has arrived at the major market terminals, it is often redistributed via a regional network. These networks include barges, railcars, and tanker trucks. Regional distribution networks were not studied as part of this research project, but may be the subject of a future study.

PURCHASES

In the past several years, Methanex production has not been sufficient to satisfy all of their customer demand. As a result, Methanex has purchased methanol in spot markets[2] to be resold to customers. In 2001, Methanex purchased more than 1.2 million MT of methanol. Spot purchases can be made at a reasonable cost at ports with an active methanol market. Spot purchase costs are higher than Methanex production costs.

SWAPS

A swap arrangement is a contract to exchange methanol between locations or over time. Methanex engages in a number of swap arrangements with other large methanol companies in order to maintain an appropriate inventory level at a given time and place. Swap arrangements represent less than 2% of their total global methanol supply. This thesis does not consider swaps.

STORAGE

Methanex maintains an inventory of methanol in every major hub in their distribution network. This includes all of their production facilities as well as all of their market terminals. Inventory is stored for a number of reasons.

[2] Spot purchases of methanol are purchases from other methanol distributors

- **Limiting Shipping Costs:** Distribution costs represent a sizeable expenditure for Methanex. Shipping with larger vessel reduces per unit shipping costs. However to accommodate loading and unloading of large vessels requires that sufficient inventory capacity is available at both the production and market terminals.

- **Shorter Lead-Times:** By storing inventory in many locations around the world, Methanex moves the methanol closer to customers, improving agility in responding to customer demand.

- **Smaller Customer Delivery Volumes:** Some customers do not have the capacity to accommodate ocean-going methanol tankers. Their inventory capacity only permits smaller deliveries associated with barges, railcars, or tanker trucks. By storing inventory, Methanex is able to satisfy the needs of these customers.

- **Demand Variability:** Keeping methanol on hand allows Methanex to flexibility in dealing with unforeseen demand variability.

The global supply chain strategy involves all six of these fundamental elements: production, demand, distribution, purchases, swaps and storage. Improper planning of any one of these factors could result in costly ramifications such as ship diversion[3], ship demurrage[4], re-working of orders[5], unnecessary spot purchases, or inventory juggling between storage locations.

1.3: INSTITUTIONAL CONSTRAINTS

In studying the Methanex supply chain; there are a number of essential business practices to consider.

Customer satisfaction: Methanex maintains a strong commitment to customers, aiming to maintain a high level of customer service. They have created a "reputation for security of supply and an ability to meet customer demands."[6] Methanex strives for a customer service level of 100%.

Shipping: The fleet of time-charter vessels and suitable spot vessels is known, and as such the selection of delivery parcel sizes[7] is limited. Additionally, the lead times from production facilities to market ports are known and have little variability; the vessels travel at a fixed rate (by contract), and as such it does not vary from significantly across vessels or trips. Vessels are typically fully loaded before they begin their trips. Finally, there is a maximum on the size of the vessel that any port can accommodate. For instance, the Millenium Explorer can only dock fully loaded in two ports, Puntas Arenas, Chile and Rotterdam, Netherlands. This vessel is primarily dedicated to the route between those two ports.

Production: Methanol production is planned to be constant, running 24 hours a day, 365 days a year. As a low cost producer of methanol, Methanex has a strong incentive to produce at the maximum rate. While production outages due to breakdowns and accidents are not entirely preventable, outages due to improper planning can be limited.

Tank Inventory: The volume of methanol in tanks cannot drop below a minimum level called the heel[8]. The effective tank capacity is the difference between the tank capacity and the heel.

[3] Ship diversion occurs when ships are redirected to ports that were not previously on their schedule.
[4] Ship demurrage occurs when a ship sits idle in port, representing an inefficient use of resources.
[5] Re-working of orders is the process of changing contractual terms in customer orders.
[6] Quoted from the Methanex 2001 Annual Report.
[7] Delivery parcel sizes are the volumes of methanol delivered to terminals or customers.
[8] The heel of the tank is the lower portion of the tank. Product stored below this level is not directly accessible.

1.4: PROJECT DESCRIPTION

In the spring of 2002, Methanex undertook an inventory study in partnership with the Centre for Operations Excellence, at the University of British Columbia. The primary objectives of this inventory study were to determine the **target inventory levels**[9] and the **recommended levels of capacity** by location, which included all of the major market terminals and the production facilities. The purpose of establishing a target is to monitor the inventory status to decisively establish the adequacy of a particular inventory level over the long-term. By extending the idea of a target inventory level, the model couldalso be used to monitor acceptable levels of deviation from the current plan, providing a perspective on what constitutes a crisis situation. The plan was to create an analysis that could be easily extended to supply chain policy revision, cost-benefit modeling or what-if scenario planning.

The project was undertaken in two parts. A preliminary study of the variance in both demand and production was conducted, as a foundation for the subsequent inventory study.

1.5: DEMAND AND PRODUCTION STUDY

DEMAND

This goal of studying demand was to gain insight into the nature and predictability of demand. Demand variability is one of the core incentives for holding inventory. Demand data was drawn primarily from Methanex's internal information systems, consisting of total monthly sales by terminal from January 2000 to June 2002. It was found that historically, demand at individual terminals changed from month to month, exhibiting significant variance. The degree of variability, and the shape of the demand distribution, varied extensively from terminal to terminal.

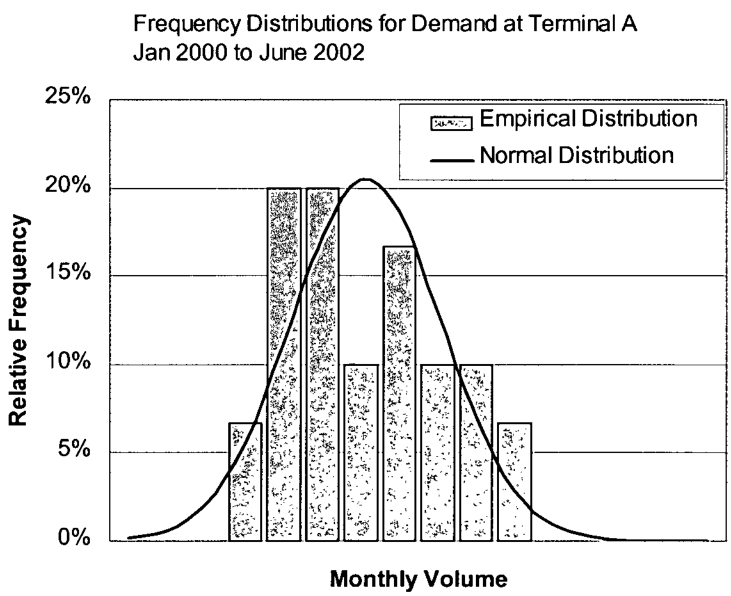

Figure 3: Monthly Demand Distribution at terminal A

[9] Target Inventory level is defined as the 12-month average inventory level

Additional data analysis was conducted relating to demand by specific groupings of customers. This grouping included the end-use of the methanol, and the segment[10] of the customer. The underlying purpose was to explain as much of the variability in demand as possible. Findings of this analysis were inconclusive from an inventory perspective and as a result they have not been included.

PRODUCTION

The goal of studying production was to measure the impact of production outages on the supply of methanol. Production outages are important to inventory management because they can have far reaching implications for system-wide inventory levels. The production data was drawn from an internal report covering a period from January 1999 to June 2002. As shown by Figure 4, historical monthly production is periodically affected by months of low productivity.

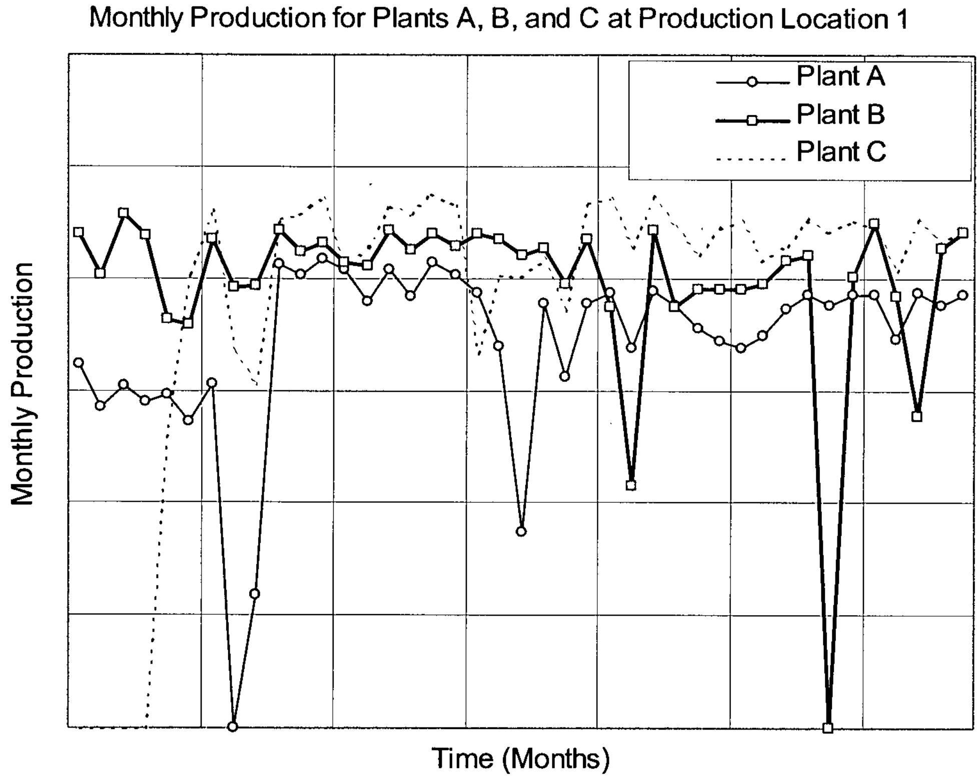

Figure 4: Monthly Production at Production Location 1

Production outages occur for a number of reasons

- **Planned outages** occur for plant maintenance and upgrading.
- **Unplanned outages** occur are the result of plant failure.
- Outages caused by **business restrictions** occur when the production is interrupted for reasons that are not caused by plant failure or planned shutdown. Examples include interruptions in production because the tank is full, or a decision to shutdown because changes in the price of methanol make production unprofitable.

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[10] Customer segments are internal Methanex segments created for marketing purposes

Further, the nature of these unplanned outages was investigated. For the most part, unplanned outages are short in duration. A histogram of the duration of the unplanned outages reveals that outage durations are explained reasonably well by an exponential distribution, as shown by Figure 5.

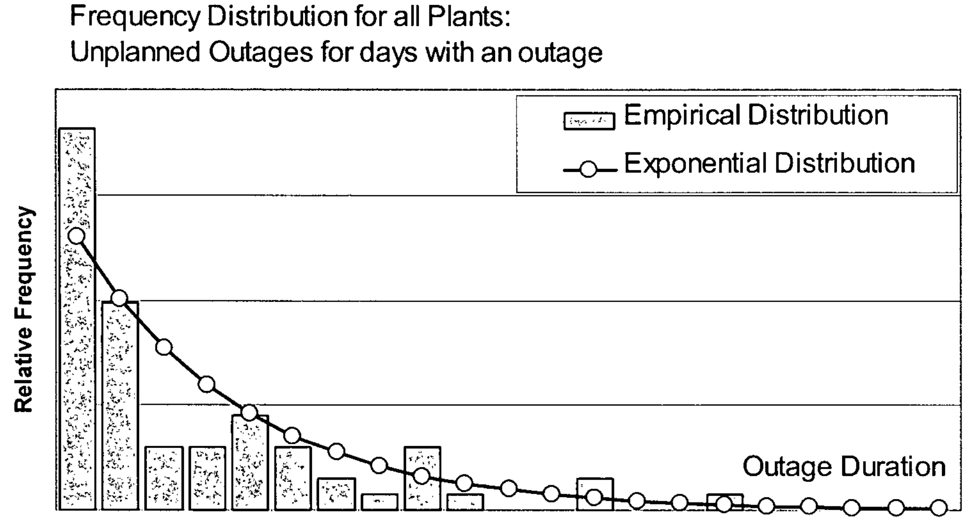

Figure 5: Unplanned Outage Durations for All Plants

1.6: INVENTORY STUDY

The inventory study took place between August and October 2002. The process of generating inventory targets was more difficult than originally anticipated. The root cause of this difficulty is the concept of modeling the system as a whole, as opposed to modeling a single location at a time. Treating the system as a whole is the only way to appreciate the impact of sending methanol to one location as opposed to another. Any sourcing decision must carefully balance the tradeoffs carrying too much or too little inventory at any affected locations. Unfortunately, modeling the system is considerably more complicated than modeling its components. The standard academic models cannot be applied directly to this problem without making unrealistic assumptions, as described more thoroughly in the Chapter 2: Standard Inventory Control Approaches.

Alternative approaches using simulation were considered. The main challenge associated with modeling of the Methanex environment through simulation is deciding how to take shipping into account. Two options were evaluated. One approach considered the analysis of the proportion of production sent to each terminal, while the other considered the implementation of a partially fixed vessel schedule, supplemented with spot vessels and spot purchases. The primary differences between the models are the degree to which shipping is abstracted, and the potential for subsequent analysis. Both models are discussed in greater detail in Chapter 3: Hybrid Inventory Control Approaches.

CHAPTER 2: STANDARD INVENTORY CONTROL APPROACHES

Inventory control policies are widely studied in the field of Operations Research. Heuristics and optimization approaches for storing stock have been developed for the better part of the last century. This section discusses the foundation and use of some of the most fundamental inventory models and their degree of applicability to this project.

2.1: ECONOMIC ORDER QUANTITY MODEL

The EOQ model is one of the simplest and most widely used of all inventory models. It is also referred to as the economic lot-size model, fixed order quantity, and the Q-model. It describes the importance of the tradeoff between fixed order costs and holding costs and is the basis for the analysis of more complex systems.

PARAMETERS AND ASSUMPTIONS

1. The demand rate is known and constant (a).
2. Shortages are not permitted.
3. There is no order lead-time.
4. The costs include:
    - A setup cost (K), incurred when an order placed
    - A proportional order cost of (c), incurred per unit ordered
    - A holding cost (h), incurred per unit held per unit time

The objective is to choose the quantity (Q), which minimizes the average cost per unit time. This is illustrated in Figure 6.

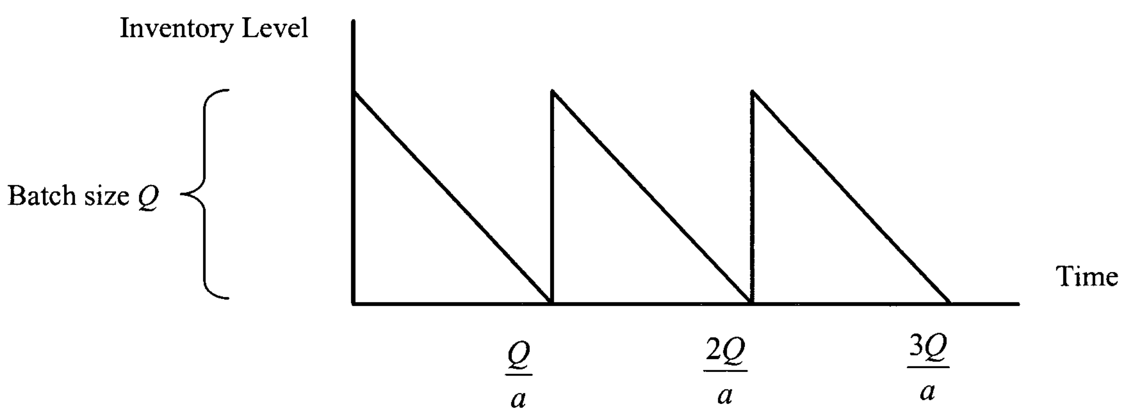

Figure 6: EOQ Model

In each cycle the total fixed plus proportional order cost is:

$$C(Q) = K + cQ$$

To obtain the order cost per unit time we divided by the cycle length T.

Average total cost: $$\frac{K + cQ}{Q / a} + \frac{hQ}{2}$$

The resulting average inventory cost is made up of a ordering costs and holding costs. The ordering costs over a single time period will be made up of the fixed ordering costs and the incremental ordering costs, while the holding costs will be the average amount of inventory held, multiplied by the holding costs. Under the EOQ assumptions, the inventory will vary evenly between a maximum (Q) and a minimum of zero. Therefore, the average inventory held will be half of the order quantity.

Because this is a convex function, it can be minimized by taking the derivative and setting it equal to zero.

Optimal order quantity: $$Q^* = \frac{\sqrt{2aK}}{h}$$

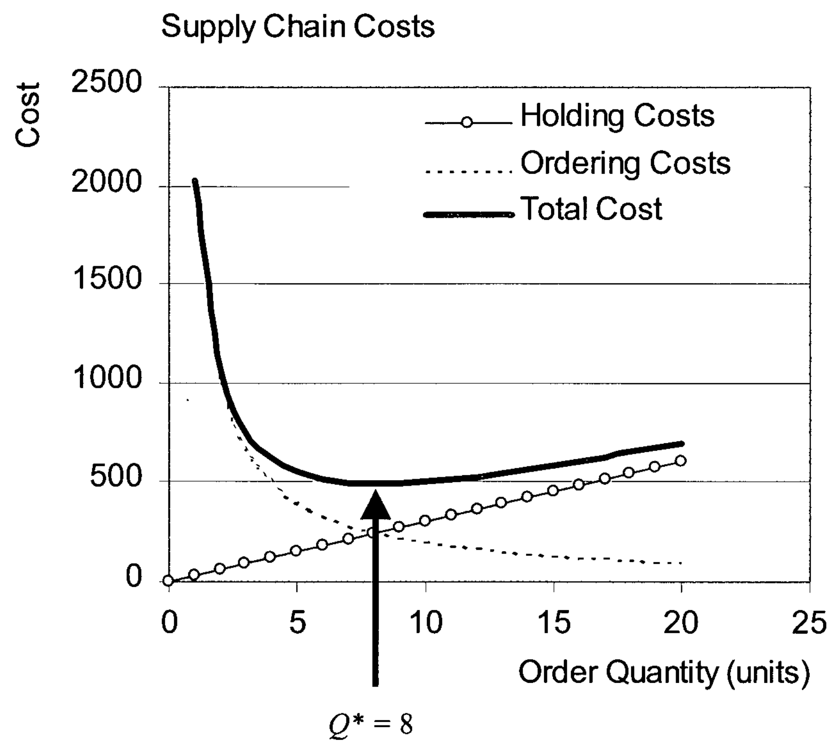

Figure 7: EOQ Costs

Under the EOQ, the optimal order quantity chosen will represent the minimum of the total cost line. In this system, the optimal order cycle is determined to be:

Order cycle = Q* / D

where Q* is the optimal order quantity and D is the demand over a single time period.

METHANEX EOQ PARAMETERS

Applying the EOQ methodology to Methanex requires a set of costs. The ordering costs can be determined by examining the shipping costs per trip to a given destination. Using linear regression, these costs can be split into fixed ordering costs (K) and proportional ordering costs (c).

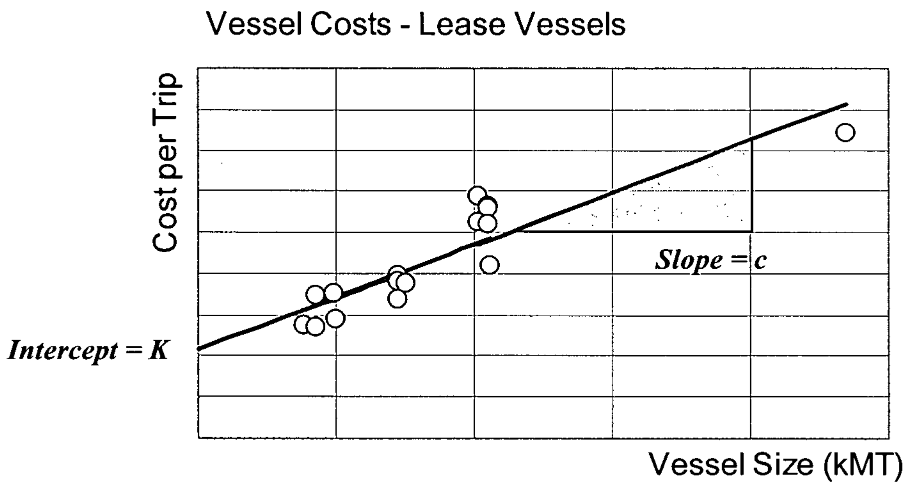

Figure 8: Methanex EOQ Ordering Costs

Demand (a) is defined as the monthly demand forecast at a given terminal.

Holding costs (h) are difficult to determine. Methanex does not always incur a specific, incremental charge for holding additional inventory. While they do incur charges for renting and maintaining a tank, and additional charges for managing and insuring their inventory, most of these costs are fixed as opposed to incremental. That is to say, as long as the tank capacity is not exceeded, there is no charge for holding more methanol. As a substitute, it is reasonable to use the opportunity cost of the capital invested in inventory. Should the inventory be sold and the proceeds re-invested, they would earn some rate of return. This rate of return can be used as a lower bound of to approximate holding costs.

SAMPLE RESULTS FROM EOQ

Table 1 (shown below) is a set of sample results using an EOQ methodology. These results represent the optimal ordering quantity for each terminal given different holding costs. Each level chosen represents a different but plausible interpretation of what the holding costs should be. For all levels chosen, the value of methanol is assumed to be $200 per MT.

- 3.5% is the annual compound interest that Methanex earns on the investment of cash, otherwise known as their risk free rate. By selling inventory, Methanex is converting their investment in methanol to an investment in cash. This in turn can be invested at the risk free rate. The lower bound for the cost of capital is the opportunity cost of investing cash at 3.5%. That is to say, instead of holding $10 of methanol for a year, the $10 could be invested and earn a rate of 3.5% a year. A holding cost of 3.5% represents a cost of $0.57/MT/month.

- 8.75% is Methanex's cost of long-term (10-year) debt. Methanex could use funds from a bond issue to subsidize inventory storage activity, in which case, the storage activity would have to earn a return of no less than the cost of debt. A holding cost of 8.75% represents a cost of $1.40/MT/month.

- 12% represents the industry standard cost of capital. In a publicly traded company such as Methanex, every asset, including inventory, should earn the cost of capital. The cost of capital is related to the profitability of the company. Any assets or projects that do not earn the cost of capital should be dismissed in favor of more profitable ventures. A holding cost of 12% represents a cost of $1.90/MT/month.

- 20% implies that there are other incremental material costs associated with holding inventory, beyond the opportunity cost of investing the value of the methanol. These types of costs could include storage tank rental fees, methanol insurance costs, incremental taxes, and any administrative overhead attributable to inventory decisions. A holding cost of 20% represents a cost of $3/MT/month.

- 25% is an arbitrarily large holding cost, chosen strictly for comparative purposes.

	Economic Order Quantity: Optimal Order Quantity				
	Holding Costs				
Terminal	3.5%	8.8%	12%	20%	25%
1	372,956	152,641	112,840	69,938	57,046
2	136,720	55,956	41,365	25,638	20,912
3	129,039	52,812	39,042	24,198	19,738
4	237,801	97,326	71,948	44,594	36,373
5	380,961	155,918	115,262	71,440	58,271
6	446,003	182,538	134,941	83,636	68,220
7	157,734	64,557	47,724	29,579	24,127
8	169,364	69,316	51,242	31,760	25,905
9	170,309	69,703	51,528	31,937	26,050
10	157,868	64,611	47,764	29,604	24,147
11	259,117	106,050	78,398	48,591	39,634
12	227,079	92,937	68,704	42,583	34,733
13	289,284	118,397	87,525	54,248	44,248

Table 1: Economic Order Quantity Results

WHY NOT USE EOQ?

1. **Perspective – Single Terminal versus System:** The EOQ model examines a single terminal in isolation. It treats all of the terminals as if they are unrelated when in fact; they are part of a system. In this respect, they may share the fixed order cost, or gain some advantage by making multi-stop deliveries.

2. **Demand:** The EOQ model is based on known demand. The preliminary demand analysis revealed that long-term demand at the storage terminals is relatively volatility.

3. **Holding Costs**: The EOQ model is dependent on holding costs. Until a conclusive methodology for measuring holding cost of inventory is resolved, the EOQ results cannot be validated.

4. **Lead times:** The EOQ model estimates an optimal order quantity that does not account for lead times. Since most of the lead times are already known, the EOQ model may generate order quantities that are not feasible for the standard vessel rotation.

5. **Volume:** Optimal order quantities may be unrealistic based on the vessel availability and ship scheduling constraints.

2.2: (R,Q) POLICY

The deterministic EOQ model can be modified to account for stochastic demand, lead times, and safety stocks in an "(R,Q) policy". This modification involves defining two specific parameters:

1. A re-order point (R)
2. An order quantity (Q)

PARAMETERS AND ASSUMPTIONS

1. The **average** demand rate is known and constant (a)
2. Shortages are permitted, and a shortage cost (p) is incurred per unit backlogged per unit time
3. There is an order lead time
4. The costs include:
   - A set up cost (K) is incurred when an order placed
   - A proportional order cost of (c) is incurred per unit ordered
   - A holding cost (h) is incurred per unit held per unit time

The objective is to choose the re-order point (R), and order quantity (Q) that minimizes the average cost per unit time. In this case, the optimal order quantity is defined by the formula:

$$Q^* = \sqrt{\frac{2aK}{h}}\sqrt{\frac{p+h}{p}}$$

Notice that this formula is almost the same as the EOQ formula, with the exception that it includes a multiplier that accounts for shortages.

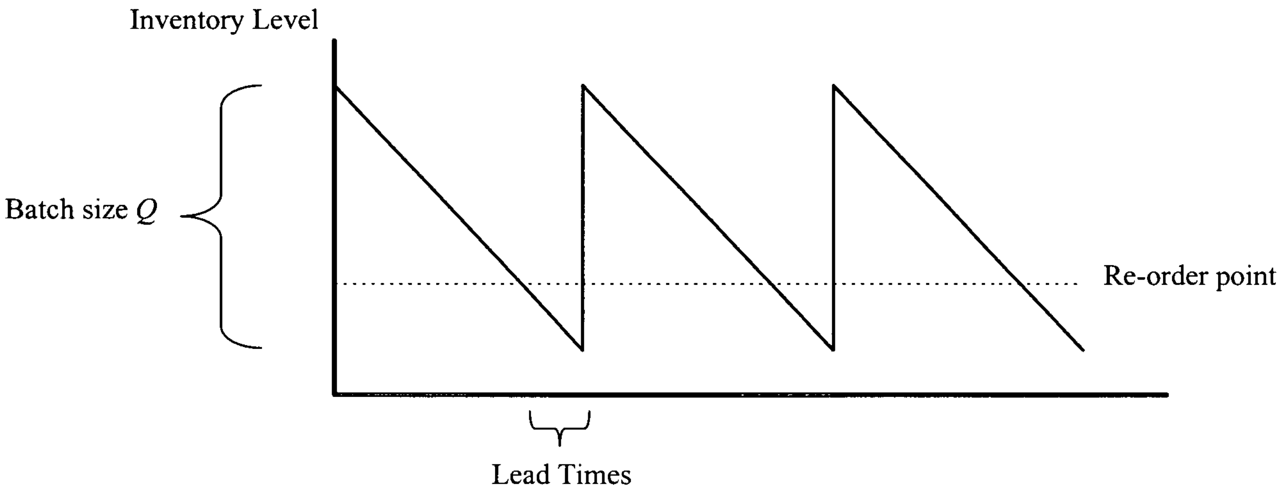

Figure 9: (R,Q) Policy

Defining a re-order point depends on the required service level, and the distribution of the demand.

In the case of uniformly distributed demand between two points, x and y, the re-order point R can be calculated as:

$$R = x + P(a_L \leq R)(y - x)$$

a_L	the expected demand over the time between deliveries "L"
$P(a_L \leq R)$	the desired service level, otherwise described as the probability that demand over the lead time exceeds the expected demand

In the case of normally distributed demand with mean μ and variance σ^2, the re-order point R can be calculated as:

$$R = \mu + z\,\sigma$$

z	the z-score associated with a desired service level: $P(a_L \leq R)$

METHANEX (R,Q) POLICY PARAMETERS

The mean demand will be the same as the EOQ formulation, while the standard deviation must be defined using a combination of historical and forecast data. The holding costs and ordering costs can be carried over from the EOQ formulation.

The shortage costs of the (R,Q) policy are difficult to measure. Methanol sales contracts are drawn up months prior to delivery and have built in flexibility, allowing contracts to be managed in such a way that inventory is rarely completely depleted. Some combination of contract revision, demand deferral, and spot purchase costs could be considered as the basis for shortage costs.

SAMPLE RESULTS OF AN (R,Q) POLICY

Table 2 (shown below) is a set of sample results using an (R,Q) policy. These results represent the optimal ordering quantity given a set of potential backorder costs. Each level chosen represents a different but plausible interpretation of the backorder costs. The value of methanol is assumed to be $200 per MT, and holding costs assumed to be $3/MT/month. For the re-order points in Table 3 (shown on the following page), the time between deliveries are assumed to be the typical lead time between the terminal and the nearest production facility.

	(R,Q) Policy: Optimal Order Quantities				
	Shortage Costs per MT per month				
Terminal	$1	$3	$5	$10	$20
1	140,955	99,417	88,807	79,932	75,101
2	51,672	36,444	32,555	29,302	27,531
3	48,769	34,397	30,726	27,656	25,984
4	89,874	63,389	56,625	50,965	47,886
5	143,980	101,550	90,714	81,647	76,713
6	168,562	118,888	106,201	95,587	89,811
7	59,614	42,046	37,559	33,805	31,763
8	64,009	45,146	40,329	36,298	34,104
9	64,366	45,398	40,554	36,500	34,295
10	59,664	42,082	37,591	33,834	31,789
11	97,931	69,071	61,700	55,534	52,178
12	85,822	60,531	54,071	48,667	45,726
13	109,332	77,113	68,884	61,999	58,253

Table 2: (R,Q) Policy Optimal Order Quantity Results

	(R,Q) Policy: Re-order Points			
	Service Level			
Terminal	80%	90%	95%	99%
1	54,427	58,436	61,747	67,957
2	7,790	8,577	9,228	10,447
3	9,488	11,522	13,201	16,352
4	25,331	27,107	28,573	31,324
5	50,238	52,959	55,206	59,421
6	70,170	74,585	78,232	85,072
7	8,261	8,880	9,392	10,351
8	9,558	9,901	10,185	10,717
9	11,950	13,100	14,050	15,831
10	4,087	4,538	4,912	5,612
11	14,294	15,414	16,338	18,072
12	11,605	12,793	13,774	15,614
13	17,756	19,120	20,246	22,358

Table 3: (R,Q) Policy Re-Order Point Results

WHY NOT USE (R,Q) POLICY?

1. **Perspective – Single Terminal versus System:** The (R,Q) policy examines a single terminal in isolation. It treats all of the terminals as if they are unrelated when in fact; they are part of a system. In this respect, they may share the fixed order cost, or gain some advantage by making multi-stop deliveries.

2. **Long Lead times**: For Methanex the order lead times are relatively long. In accounting for these long lead times, some of the re-order points suggested are higher than the tank capactities. This would imply that in some cases, the demand to lead-time ratio is so high that the reorder point would be more than one full delivery cycle away from the point at which the order is received.

3. **Holding Costs**: The (R,Q) policy is dependant on holding costs. Similar to the EOQ approach, until a conclusive methodology for measuring the per unit cost of holding inventory is determined, the results of the (R,Q) policy cannot be validated.

4. **Shortage Costs**: The (R,Q) policy is dependant on shortage costs. Again, a conclusive methodology for measuring potential shortage costs must be determined in order to validate the results.

5. **Volume:** Optimal order quantities may be unrealistic based on the vessel availability and ship scheduling constraints.

2.3: NEWSBOY MODEL

Otherwise known as the Newsvendor model, and the single period stochastic model, this is a method typically used for managing inventory policies of perishable products[11]. Examples of perishable products might include newspapers, flowers, or dairy products. In those cases, the model is a single period model, where period length is defined as the expiry time of the perishable product. As an example newspapers have an expiry time of one day. The model can also be applied to other situations, involving non-perishable products, under the following 2 conditions:

1. Only a single stocking decision is allowed
2. The financial consequences can be expressed a function of the difference between the initially chosen stock level and the realized demand[12]

The objective is to optimize the order size in order to maximize the difference between expected revenues from sales and the combination of shortage costs and overage costs.

PARAMETERS AND ASSUMPTIONS

1. The demand (ξ) is observed over the single time period
2. The costs include:
   - An overage cost (c_0) is incurred for the excess amount ordered each time period
   - A shortage cost (c_u) is incurred for the unsatisfied demand each time period

Let Q be the amount ordered, and let C represent the cost function of ordering.
For a single time period:

$$C(\xi) = \begin{cases} (Q-\xi)*c_o, & \xi < Q \\ (\xi - Q)*c_u, & \xi > Q \end{cases}$$

This means that the cost per period is either the quantity over-ordered, multiplied by per unit overage cost, or the quantity under-ordered, multiplied by per unit shortage cost. The ordering cost depends on whether the quantity ordered is either too much or too little.

Applied to the case of normally distributed demand, with mean μ and variance σ^2, the optimal order quantity is defined by the following equation:

$$\Phi\left(\frac{Q^* - \mu}{\sigma}\right) = \frac{c_u}{c_o + c_u} = \text{Optimal Service Level}$$

where Φ is the cumulative distribution function of the demand. This fraction represents the optimal service level, where total costs are minimized. It is sometimes referred to as the critical fractile. This approach balances the costs of carrying too much inventory against the costs of carrying too little.

[11] Perishable products are products that lose value over time
[12] Porteus, Foundations of Stochastic Inventory Theory, 2002 p.7

METHANEX NEWSBOY PARAMETERS

Demand parameters for the Newsboy model can be determined from a combination of historical and forecast information. In this case, the demand parameters must be scaled from monthly data to the length of the time period used to evaluate each terminal. Again, the costs are very difficult to determine, since there is no specific charge incurred for carrying additional inventory (overage costs) or for stocking out (underage costs). Similar to holding costs, overage costs can be approximated using some variant of the cost of capital, as described earlier in the chapter. Similar to shortage costs, underage costs could be made up of some combination of contract revision, demand deferral, and spot purchase costs. At those terminals where spot market purchases of methanol are not available, the underage costs would be higher to compensate for the fact that is difficult to acquire methanol, though how much higher they should be is difficult to determine. Alternatively, instead of defining specific overage and underage costs, it is possible to approximate the relationship between overage costs and underage costs by assuming an optimal service level. The length of the time period will be assumed to be twice the typical lead-time from the most likely production facility. This would be equivalent to assuming that a single vessel makes round trips to each terminal.

SAMPLE RESULTS OF A NEWSBOY MODEL

Table 4 is a set of sample results calculated using the Newsboy model. The optimal order quantities for a variety of service levels are shown.

	Newsboy Model: Optimal Order Quantities			
	Optimal Service Level			
Terminal	80%	90%	95%	99%
1	104,360	110,030	114,712	123,496
2	14,697	15,811	16,730	18,455
3	16,697	19,573	21,948	26,403
4	48,671	51,183	53,257	57,147
5	97,427	101,275	104,453	110,413
6	135,391	141,636	146,793	156,466
7	15,828	16,704	17,427	18,784
8	18,730	19,216	19,618	20,370
9	22,611	24,238	25,581	28,100
10	7,667	8,306	8,834	9,824
11	27,334	28,917	30,224	32,676
12	21,880	23,559	24,946	27,548
13	33,984	35,913	37,505	40,493

Table 4: Newsboy Model Optimal Order Quantity Results

WHY NOT USE THE NEWSBOY MODEL?

1. **Perspective – Single Terminal versus System:** The Newsboy model examines a single terminal in isolation. It treats all of the terminals as unrelated when in fact; they are part of a system. In this respect, they may share some fixed order cost, or gain some advantage by sharing deliveries.

2. **Overage Costs**: As in the cases of both the EOQ model and the (R,Q) policy, the Newsboy model is dependant on holding costs. Again, until a methodology for measuring the per unit cost of holding inventory is determined, the results of the Newsboy model cannot be validated.

3. **Underage Costs**: As seen in the (R,Q) policy, the Newsboy model is dependant on shortage costs. Again, a concrete methodology for measuring potential shortage costs must be determined in order to validate the results.

4. **Volume:** Optimal order quantities may be unrealistic based on the vessel availability and ship scheduling constraints.

5. **Fixed Ordering Costs**: In this case, there are no ordering costs. In reality, fixed ordering costs actually make up a large proportion of the actual ordering costs, this model is less reliable.

6. **Period Length:** The optimal order quantity will be based on the selection of the period length. In this case, it has been assumed that the period length is twice the typical lead-time from the most likely production facility. This assumption is only valid in rare circumstances. Selection of a period length is critical to determining the results.

2.4: ALTERNATIVE STANDARD APPROACHES

An alternative approach might be to apply a fixed-time period model to account for the known lead times between locations. Examining other such standard approaches would be desirable and may in fact be more applicable to the Methanex supply chain than some of the models discussed. Instead, Chapter 3: Hybrid Inventory Control Approaches discusses the use of models that employ simpler analytical techniques while operating within the business constraints.

CHAPTER 3: HYBRID INVENTORY CONTROL APPROACHES

The complex Methanex Supply Chain does not lend itself well to the classic academic models seen in Chapter 2: Standard Inventory Control Approaches. To create a model that incorporates both the nuances of their business practices, and generally accepted operations research techniques, a unique approach must be employed. The most appropriate way to approach the problem is to construct a hybrid model integrating the academic and standard business approaches.

3.1: SIMULATION

As a tool, simulation is used to imitate the operation of a real world process. It is especially useful in cases where a process is too complex to be modeled effectively using strictly mathematical methods, or problems involving uncertainty. In many cases, a simulation does not require simplifying assumptions (necessary for optimization techniques) that might impair the validity of the model. As an approach, simulation easily allows a user to test "what-if" scenarios and facilitates the evaluation of potential decision-making policies.

Academically, simulation has strengths and weaknesses. Modeling through simulation produces meaningful results, and is capable of maneuvering around some of the complex constraints of a particular situation. However, in contrast to optimization techniques, simulation methods may not yield provably optimal results. Scenario analysis can allow a modeler to evaluate the impact of certain decisions, but unlike linear programming there are no dual values to assist with sensitivity analysis. Introducing random variation into a model allows stochasticity to be introduced, but at the same time it may increase the modeling error.

To successfully model a system or process using simulation, it should be replicated an appropriate number of times. The number of replications required is determined by the distribution of the results. This concept is explored further in Chapter 4: Results.

The preliminary part of the project studied the variation in two major processes: demand and production. Historically, variation played a significant role in each of these two aspects. By simulating these two variables the model more accurately represents the uncertainties in the real system and can effectively test different levels of production and demand. For each replication of the simulation, the demand and production at each facility is slightly different, which will affect the choices that the model makes, and will ultimately determine the resulting inventories.

The main challenge associated with modeling of the Methanex supply chain using simulation is deciding how to treat shipping. Two approaches were seriously considered: a production proportion model and a partial vessel schedule model.

3.2: PRODUCTION PROPORTION MODEL

The basis of this model is to determine the proportion of total plant production to be sent from each production facility to each market terminal. This would entail simulating both demand and production at their respective locations. The decision variables would be the proportion of production sent from each production facility to each market terminal. Demand not sourced by Methanex production would be sourced by spot purchases. For each replication of the simulation, a cost function would produce an objective value. Using a non-linear solver, these results could be used to determine the optimum production proportions to send to each market terminal.

Scenarios could be developed using a combination of forecast and historical demand and production parameters. By making assumptions about vessel scheduling, this model could provide a perspective on the range in which inventory should be held. It could also suggest alternate provisioning strategies based on regional spot price differences. However, this model is an abstraction of reality for all aspects of vessel scheduling and as such, the recommendations are not directly actionable. That is to say the sourcing plan used by the model may or may not be feasible within Methanex's business constraints.

3.3: PARTIAL VESSEL SCHEDULE MODEL

An alternative method of dealing with vessel scheduling is to explicitly create a vessel schedule. Starting with a partially fixed vessel schedule and supplementing it with spot vessels and spot purchases where necessary, the system inventories can be examined at any location at any point in time. A key advantage of this type of approach is that it operates on a vessel schedule that can be implemented. It allows the testing of a partial vessel schedule, which respects many of the complicated constraints of the system, while creating a complementary spot vessel schedule. On the other hand, using a pre-determined vessel schedule is somewhat contradictory to an optimization approach, since the model does not have the opportunity to try to improve on the decisions made in the creation of the fixed portion of the vessel schedule.

The two main challenges with this approach are:

1. How to create the decision rules associated with spot vessel assignment and spot purchases
2. How to create a partial vessel schedule.

This model would include all major inventory storage locations and would make decisions on a daily basis. Instead of only generating a target inventory level, this model will also generate a probability distribution for inventory for each day in the simulation. This in turn allows the model to make recommendations about the capacity at each location. The tracking of daily inventory through each run of the simulation also allows the model to generate acceptable inventory ranges for specified time periods, which can be used to identify times when inventories are out of range. This approach takes into account different shipping rates, lead times, and vessel capacities. Additionally it makes use of information about future vessel scheduling which may be pre-determined.

3.4: MODEL SELECTION

Though both approaches have merit, neither of the two contender models is clearly superior. Internal debate among the COE project team, along with numerous consultations with operations and logistics faculty, was not able to completely resolve which of the two candidates would generate the most appropriate results.

The proposed production proportion model and the partial vessel schedule model were presented to Methanex. Upon review, it was decided that the ability to directly test a potential vessel schedule made the partial vessel schedule model more attractive. Over a three-month period the Waterfront Inventory Simulation Engine (WISE) was created to implement the partial vessel schedule approach.

3.5: WISE MODEL

Waterfront Inventory Simulation Engine (WISE), is a discrete event simulation model, built to simulate one year in the Methanex Supply Chain. Demands at each terminal and production at each plant are treated as random variates with known statistical properties. An existing partial vessel schedule is applied against the simulated demand and production and then supplemented by a series of spot vessel shipments and spot purchases of methanol.

The decision-making process for allocating spot vessels and making spot purchases is guided by a greedy heuristic. By embedding the heuristic within the simulation, it is able to mimic the business process logic.

HEURISTICS

A heuristic is a solution strategy to an optimization problem that iteratively selects choices that drive it closer to optimal. A "greedy" heuristic is a subset of the heuristic family that is constantly choosing the decision that has the greatest local impact on the final solution. A common example might be a knapsack problem, where someone needs to pack food for a picnic into a knapsack. Each food item occupies a specific volume and holds some level of preferable to the picnickers. The optimal strategy to maximize the picnickers' satisfaction in this scenario is to iteratively select as much of the food with the highest level of preference as possible. When that type of food is exhausted, the food of the next highest level of preference is selected. This process continues until the knapsack is full. Heuristics are often used in decision making because they are relatively easy to implement and understand.

SIMULATION PARAMETERS

In order to run any simulation, many assumptions and parameters are required. These are described in the pages that follow.

DEMAND

Demand is simulated at each terminal for each month and is assumed to be continuous throughout the month. Demand parameters in the model are determined for each terminal, and have been estimated based on a combination of sources including Methanex's 2003 budget, and the Preliminary Demand and Supply study. Where necessary, direct customers were grouped together regionally, and treated as separate terminals.

The simulation user has the option to use a blend of three potential demand values.

1. A deterministic value from the Methanex 2003 budget.

2. A normally distributed random demand, using the Methanex 2003 budget demand to determine the mean monthly demand and the historical standard deviation computed in the Preliminary Demand and Supply study.

3. An empirical demand treats the demand as a uniquely distributed random variable, making use of the historical demand distribution from the Preliminary Demand and Supply study, modified by a multiplicative scalar to reflect the forecasted increase or decrease in demand.

The example shown in Figure 10 shows the effect of combining the probability density function of a normal distribution equally with the probability density function of the historical information for Terminal A.

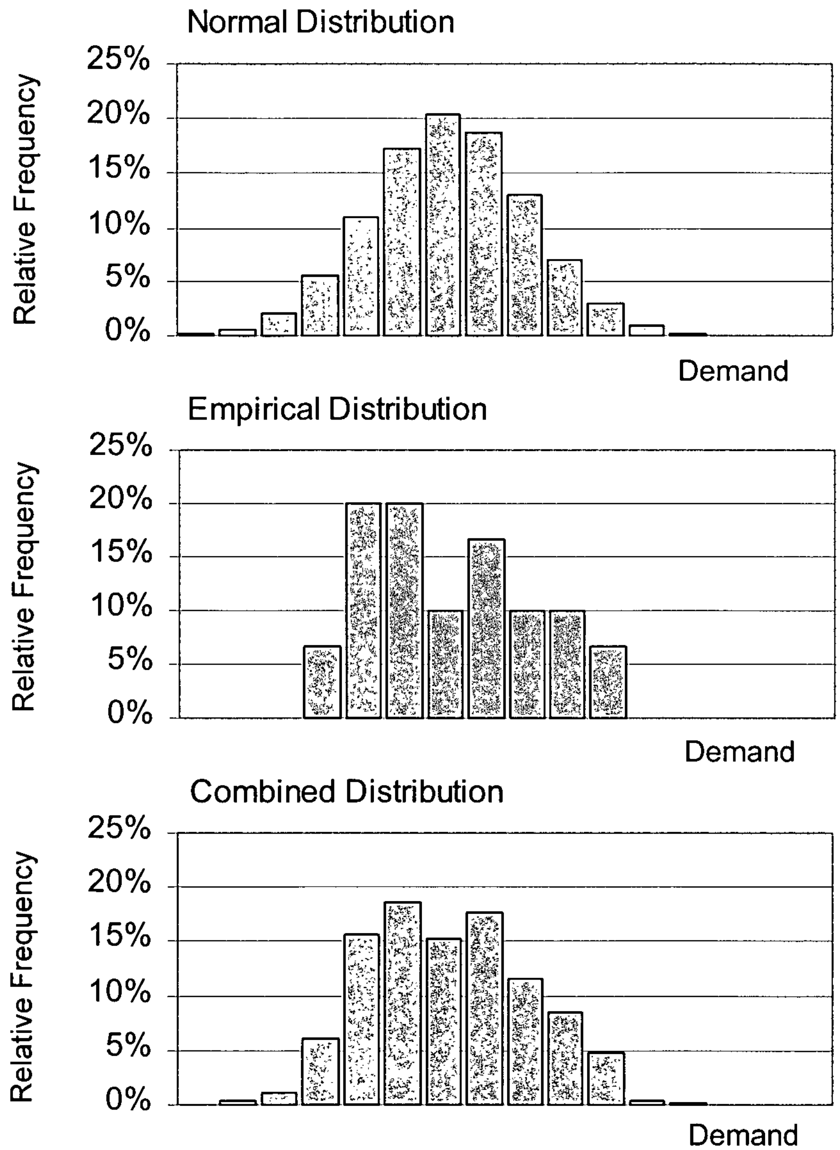

Figure 10: Combining Demand Distributions

This resulting combined distribution represents a sampling range for demand that balances the advantages of the properties of both the normal distribution and the empirical distribution. Modeling using the empirical distribution limits a simulation from selecting demand that is excessively far from historically observed values, while modeling using a theoretical distribution helps to smooth the peaks and valleys associated with sample data.

PRODUCTION

Production is simulated at each plant at each production location for each day of the year. Potential daily production is treated as a normally distributed random variable. **Planned outages** are scheduled outages for maintenance and upgrading. These are deterministic based on the current plan. **Unplanned outages** are outages that occur due to some sort of breakdown, and occur stochastically, with a certain probability and a simulated duration. The duration is modeled using an exponential distribution, as seen in Chapter 2: Background. All parameters were determined based on future plans and historical data examined in the Preliminary Demand and Supply study. It is possible to set the parameters such that unplanned outages do not occur, which would provide insight on the cost of unplanned outages and their effect on inventory.

The example shown in Figure 11 is an exaggerated example the combination of the frequency distributions for the days without outages and the days with outages. The result is a non-standard frequency distribution for realized production. In this case days without outage are 9 times more likely.

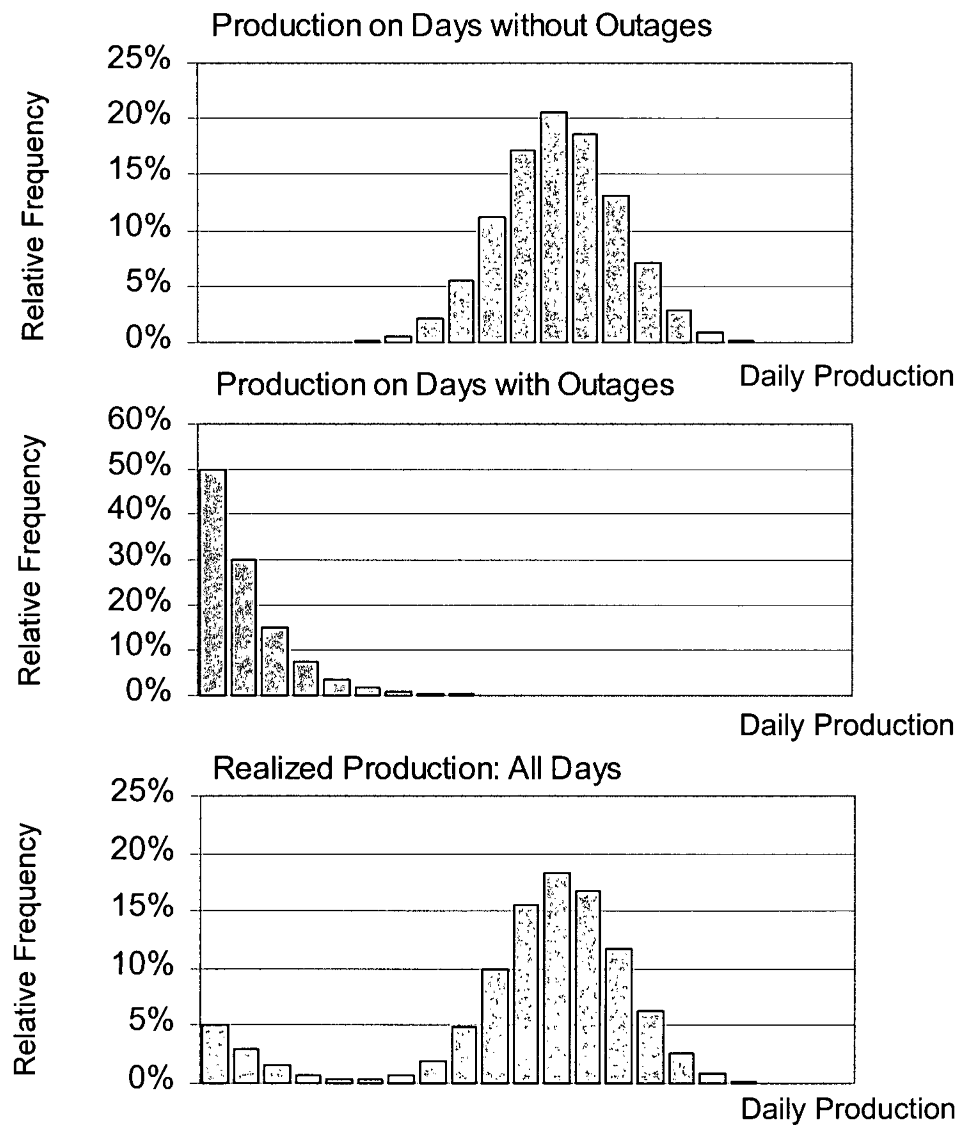

Figure 11: Combining Production Distributions

LEASE VESSELS (TIME CHARTERS)

The schedule for the time charter vessels is treated as a fixed input for the simulation. Methanex created this input. It is their best forecast of the future vessel schedule. Vessels are assigned to specific routes over the course of the year. Shipping costs assumed for the lease vessels are assumed to be the daily lease rate. Daily lease rates are calculated based on the average billing rate of several 2001 voyages, divided by the average trip durations.

SPOT VESSELS

A specific set of potential spot vessel routes are pre-defined. These options are chosen based on the known gaps in the lease vessel schedule, and on current practices. They are a fixed set of options that the model can use. While multiple options can exist for a given terminal, they are all pre-determined based on a user's selection. A given option might have as many as three stops in its route. Spot vessels are always assumed to be available, and there are no restrictions on the number of times a particular spot vessel route may be used.

SPOT PURCHASES

At some individual terminals, spot purchases are planned to make up as much as 50% of their planned supply. The model allows spot purchases to occur at designated terminals. The purchase quantity is set to a relatively small volume, enough to cover the immediate needs in order to prevent excessive purchasing. It is assumed that delivery of spot methanol is instanteous and that spot methanol is always available.

STARTING INVENTORIES

The inventory positions at all of the terminals are estimated for January 1, 2003. Where possible, the inventories were estimated by the regional logistics managers.

CRITICAL THRESHOLDS

Critical thresholds are defined as the safety stock levels below which inventory is not allowed to drop. These can be set as low as the heel of the individual tanks.

DEMAND DEFERRAL

Demand deferral parameters represent the number of days that demand can be deferred without penalty at each storage location.

MODEL PHASES

The model goes through a number of phases in each replication.

1. Simulate Demand
2. Simulate Production
3. Implement partial vessel schedule
4. Initialization of the Greedy Heuristic

Both demand and production are determined at the outset of each replication of the simulation. Subsequently, the fixed component of the vessel schedule is overlaid upon the production and demand schedules. This will immediately identify those areas that will require additional assistance, based on whether or not the forecasted inventory ever drops below the level set by the critical threshold parameter.

In times when forecasted inventory is below the critical threshold, some alternative action must take place. These types of decisions are controlled by the greedy heuristic.

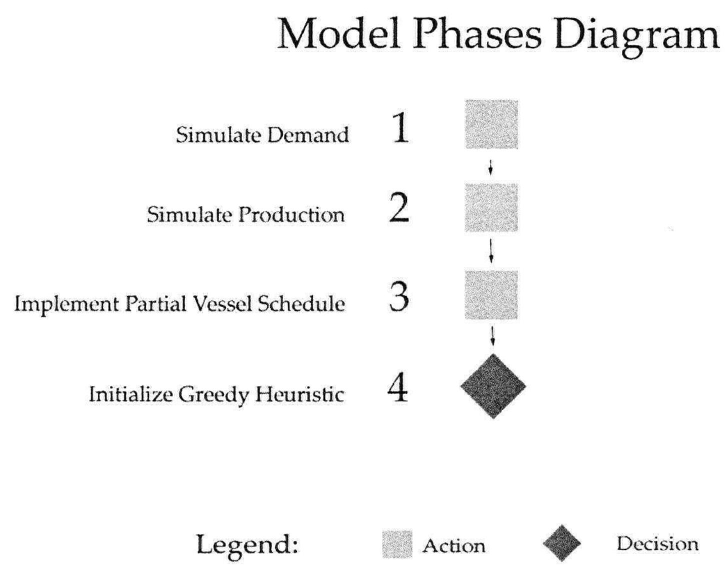

Figure 12: WISE Model Phases

GREEDY HEURISTIC

The heuristic in this model was developed specifically for this project. It involves a series of logical steps for making decisions with respect to the distribution of the methanol that has not been allocated by the fixed vessel schedule, and for making decisions about purchasing and demand deferral. This process has been modeled as closely to the current business practices as possible.

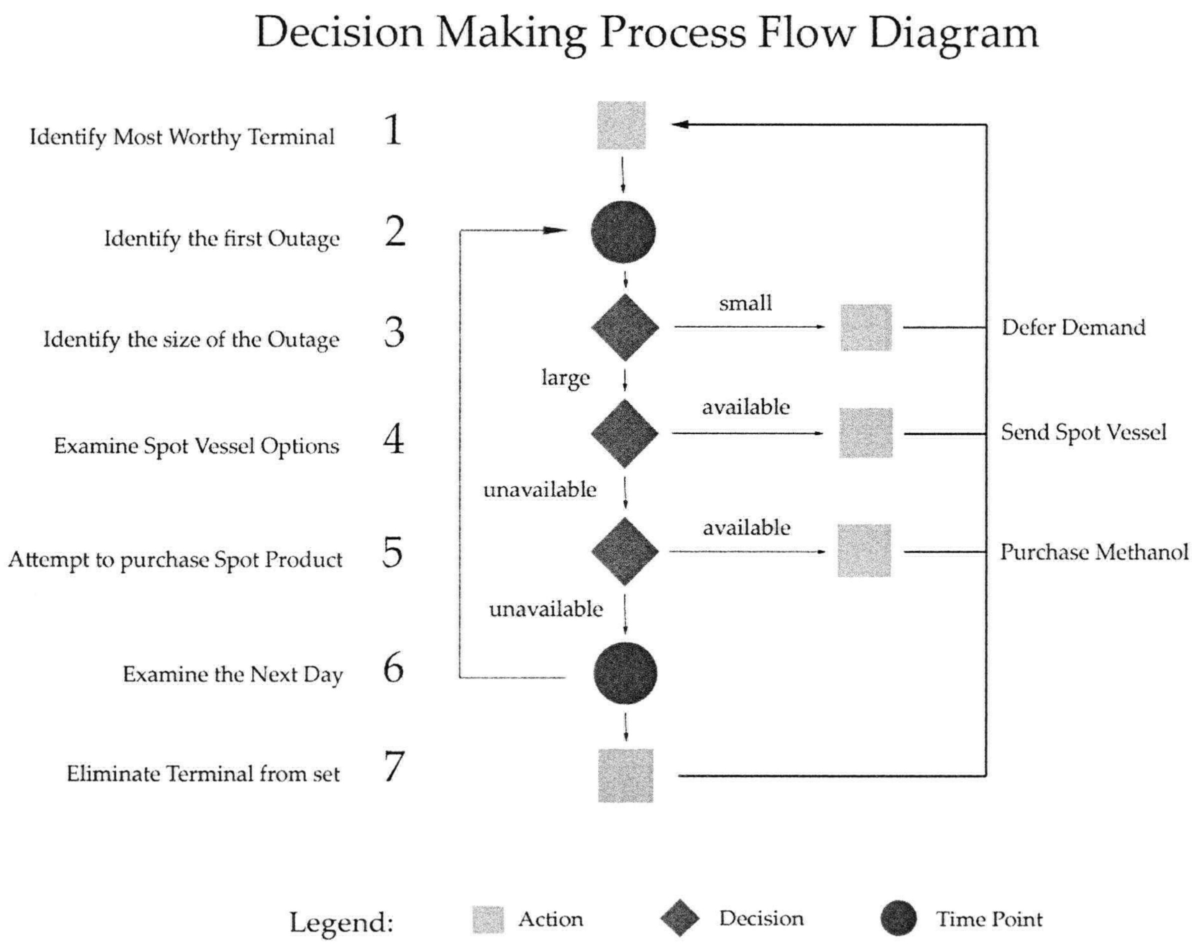

Figure 13: WISE Decision Making Process Flow Diagram

STAGE 1: IDENTIFY THE MOST WORTHY TERMINAL

There are two factors used in determining which terminal is the most worthy:

1. The number of days that the terminal's inventory is below the critical threshold.
2. The terminal's outage score.

Each terminal is assigned an outage score. The outage score is meant to represent an index for the severity associated with the shortage of inventory at a specific terminal. It is used to differentiate those terminals where methanol can be purchased on the spot market and those where it cannot. In the scenarios evaluated, all of the terminals that could acquire methanol on the spot market were given an outage score of 1, where all others were given an outage score of 10. This implies that an inventory outage at a terminal that can't acquire methanol via the spot market is 10 times worse than an outage at a terminal where methanol can be acquired on the spot market. This score can also be used to preferentially order the terminals, so that terminals are always examined in a specific order. In economic terms, the magnitude of the outage score would be related to the utility of the outage. The outage score is multiplied by the number of days below the critical threshold to create a ranking mechanism that takes into account the outage duration and weights it by the severity of the outage. In the event of a tie, the terminal that has been selected as the most worthy terminal the fewest times will be selected.

STAGE 2: IDENTIFY THE FIRST OUTAGE

To rectify the inventory shortages of the most worthy terminal, the heuristic examines the daily inventory level at the first point that it crosses the critical threshold. This is the first point at which demand cannot be satisfied by the existing sourcing.

STAGE 3: IDENTIFY THE MAGNITUDE OF THE OUTAGE

The size of the outage will determine how it is treated. Outages of periods shorter than a deferral parameter are defined as being manageable, because in some cases demand can be temporarily deferred. This is the preferential treatment of outages, since it is the least costly. If the outage can be "managed" then the demand will be deferred, and the heuristic will begin again by selecting the most worthy terminal. If, on the other hand, the outage will last longer than the deferral parameter, then the model progresses to stage 4. A example is shown below in Figure 14.

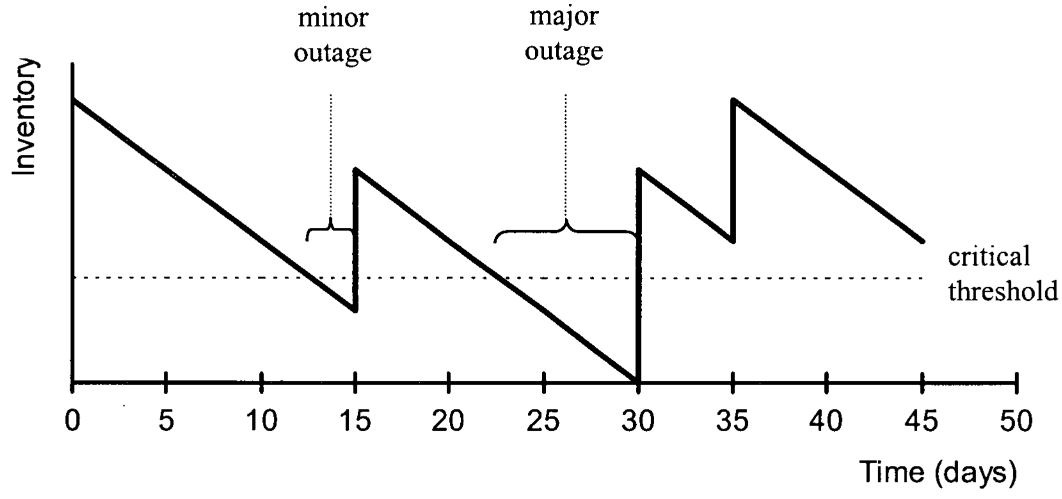

Figure 14: Identifying Inventory Outage Duration

STAGE 4: IDENTIFY SPOT VESSEL OPTIONS

If an outage cannot be eliminated by demand deferral, the next least costly alternative is to insert a spot vessel into the vessel rotation. The heuristic checks a list of pre-defined list of potential spot vessel options and tests their feasibility. It begins by selecting the option with the greatest volume to be moved to the destination. As shown in Figure 15, to test the feasibility of a particular option, the model examines the future inventory of the appropriate production facility to see if there is an amount at least as large as the amount required to fill the vessel that has not been allocated for later shipments. If such a volume exists, then a spot vessel is booked, and the heuristic starts again at stage 1. If such a volume does not exist, then the heuristic will attempt to use the next largest spot vessel option. When it has exhausted all of its options, it proceeds to stage 5.

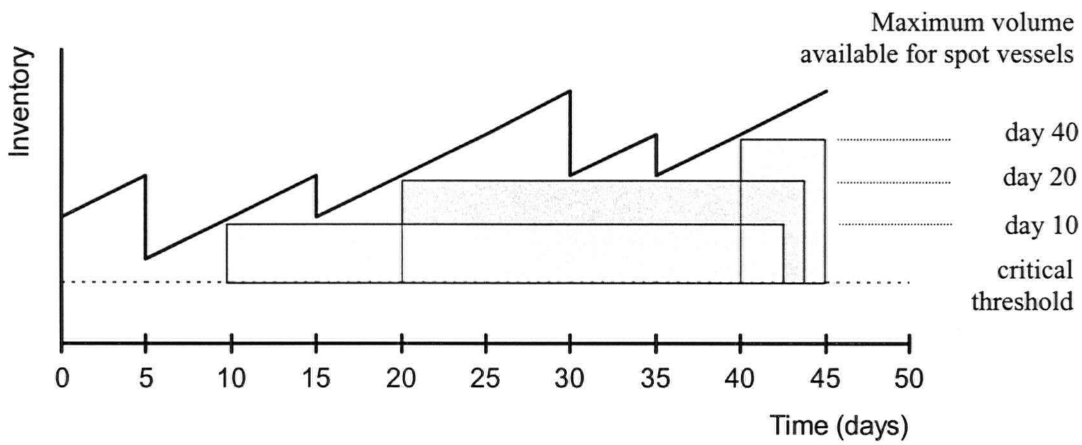

Figure 15: Identifying Volume Available at a Production Facility

The above figure shows the volume of unallocated methanol at a production facility at different points in time. The unallocated volume will be equal to the minimum level of inventory for all ofthe remaining time periods. This is the maximum amount of inventory that can be transferred out via spot vessel. Simply put, the model cannot send methanol that is required to meet future shipping commitments.

STAGE 5: MAKE A SPOT PURCHASE

If WISE cannot find a suitable spot vessel, it will attempt to make spot purchases of methanol to try to improve inventory positions. This stage is only relevant to those terminals where spot purchases are permitted. If methanol is purchased then the heuristic begins again at stage 1.

STAGE 6: EXAMINING THE NEXT DAY

If WISE cannot make a spot purchase, the next level of recourse is to attempt to rectify the outage the following day. The model's next iteration will examine inventory of the same terminal.

STAGE 7: ELIMINATION

As soon as the terminal's inventory options have been thoroughly exhausted, it is removed from the list of eligible terminals, and can no longer be selected as the most worthy. At this point it is placed on a Taboo list. The heuristic will iterate until all the terminals reach the elimination stage and are on the Taboo list. Depending on the number of spot vessel options that are provided, this could involve thousands of iterations. In some instances, based on the input parameters, it may not be possible to source demand completely.

As a last resort the heuristic will defer any demand that has not been sourced, regardless of the magnitude of the demand deferral parameter.

ASSUMPTIONS

Inherent to this model are a number of fundamental simplifying assumptions. The following are the most critical assumptions:

1. Demand is continuous across a month
2. Demand is meant to capture all outgoing shipments from a terminal, including transshipments to lower echelons of the supply chain.
3. Demand can be deferred for short periods at no penalty
4. Demand occurs in non-negotiable volumes
5. Direct customers are grouped regionally and treated as collective terminals
6. Spot vessel are always available
7. Shipping costs and the price of methanol are fixed
8. There is no variability in the lead-times
9. Spot purchases are made instantaneously
10. Reaching the current storage tank capacity of any storage location does not prevent it from acquiring more inventory. That is to say, there is no explicit upper bound on inventory. Instead, the simulation uses the maximum simulated levels as a guide to determine recommendation for tank capacity. This is supported by the fact that the system incurs more demand than supply, coupled with the fact that the parcel sizes being tested have been selected based on past practice.

MODEL IMPLEMENTATION

The WISE model described was created in Microsoft Excel, making extensive use of Visual Basic for Applications (VBA) programming. It was used primarily because of prevalence of Excel use at Methanex. The model is capable of running up to 180 replications of a single scenario, though file sizes may grow prohibitively large. The spreadsheet begins at approximately 4 MB, and grows to just over 20 MB after 50 replications. It is recommended that it be run for a maximum of 100 replications at a time. The model is split into two complementary workbooks: one to model the simulation, and one to collect and display the results. Splitting the model into two increases the speed of the simulation. The simulation is computationally demanding. Using the original parameters, it takes anywhere from 45 seconds to 3 minutes to run a single replication[13]. Variability in run times are due to the stochasticity in the model.

[13] Based on an Athlon 1700 processor (1.47 GHz) running Microsoft Office 2000 professional on a Windows XP operating system.

GENERATING RESULTS

In order to generate meaningful results, a set of parameters was chosen and agreed upon by Methanex. These parameters included all aspects of production and demand, as well as assumptions regarding potential spot vessel routes, starting inventories, and outage scores. The most difficult inputto collect was the vessel schedule for time charter vessels. The process of selecting a partial vessel schedule that properly accounted for both production and demand is difficult. After testing, the final vessel schedule selected required minor manipulation to improve results. Though vessel scheduling is a major bottleneck in the process of the preparation of final results, it is of crucial importance to the model.

A user guide and brief tutorial were provided in order to help the team at Methanex implement the system and interpret the results. Several scenarios were examined, in addition to the original benchmark case. Selected anonymous results are presented in Chapter 4: Results.

CHAPTER 4: RESULTS

The WISE model generates a series of useful quantitative results for planning purposes. These results are related to many aspects of the Methanex Supply Chain, including inventory, shipping, demand, production, and purchasing. This section discusses the major findings of the study, and how they relate to the current benchmarks at Methanex. It also discusses additional uses for the tools, and some of the technical issues related to the results.

The results generated can be divided into seven major groups. Listed below are the descriptions for the each of the results categories.

Inventory Targets: These are the average inventory level per location of all of the replications of the simulation. Target inventory levels can be used for long range planning.

Inventory Capacity recommendations: Tank capacity recommendations identify areas where current tank capacity may be too high or too low, given the sourcing strategy. If the 95th percentile for the simulated level of inventory exceeds the current tank capacity, then we recommend that tank capacity be increased. If the 95th percentile for the simulated level of the inventory does not exceed 75% of the current capacity, then we recommend that capacity be reduced, if possible.

Demand Deferral Days: The average number of days in which demand was deferred is tracked at each demand location, to quantify the managerial effort required at those locations. Because deferring demand is the heuristic's preferential method for dealing with inventory shortages, there will typically be some deferred demand at each demand terminal. This represents the amount of time that must be spent negotiating with customers and re-arranging delivery plans. This is tracked in order to understand how often the inventory is at a critical threshold of the tank.

Sourcing: For each of the demand locations monthly details of time-charter shipments, spot vessel shipments, and spot purchases are tracked in order to ascertain potential plans for the future. While the timing of specific spot vessel shipments and spot purchases will likely differ in each run of the model, understanding the average amounts shipped and purchased allows Methanex to plan more progressively.

Costs: For each of the demand locations monthly breakdowns of shipping costs, purchase costs, and holding costs are tracked and tabulated to enable the comparison of separate scenarios.

Production: The monthly average production is tracked at each plant at each production facility.

Demand: The monthly average demand is tracked at each of the market terminals.

4.1: MAJOR FINDINGS[14]

The model identified the discrepancies between the existing internal benchmark inventory targets and the proposed targets, as shown by the table below. The relative WISE target is the ratio comparing the WISE target to the current benchmark.

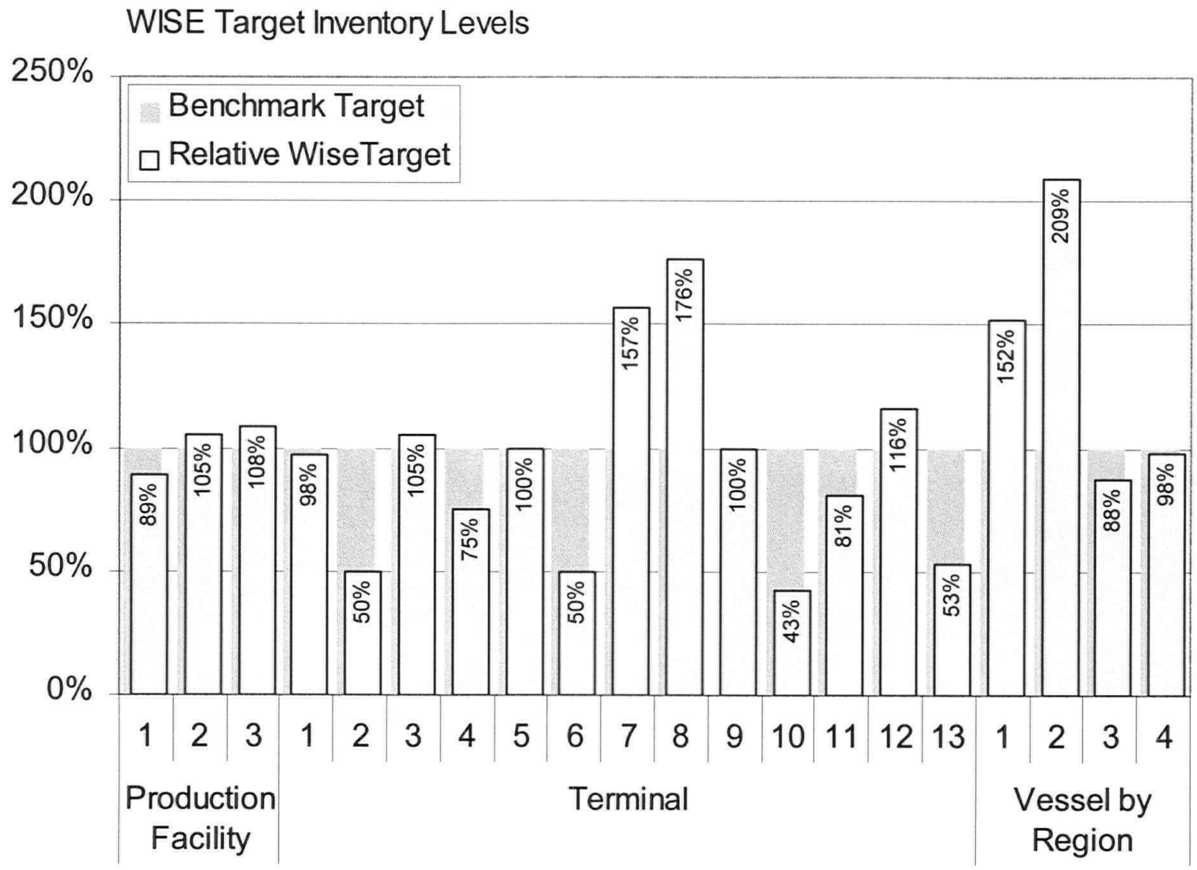

Figure 16: Relative Target Inventory Levels

Figure 16 demonstrates the difference in simulated Target Inventory levels to current benchmarks. The current benchmarks were part of an inventory analysis done by Methanex one-year prior. A thorough comparison of the two models is included later in this chapter.

Inventory targets for the 3 production facilities were relatively close to the internal targets, with ratios ranging from 89% to 108%.

The inventory targets for the 13 major market terminals ranged from 43% of the internal targets up to 176% of the current targets. The major differences in the two sets of targets are primarily due to different vessel scheduling assumptions and the inclusion of spot purchases.

[14] To protect Methanex confidentiality, total inventory volumes are not provided.

The vessel inventory appeared to be much higher in total, though regional levels ranged from 89% of the internal target up to 209% of the target. This is primarily attributable to the fact that the current targets were based on historical data. In contrast, the WISE targets are set through forecast data. Recent changes in two of the four regions have increased the amount of inventory that will be in transit.

Location	WISE Target	Difference
Production Facilities	97%	- 3%
Terminals	87%	- 13%
In transit	125%	+ 25%
Other[15]	100%	0%

Table 6: Grouped Target Inventory Results

This summary table shows that the model recommends a **major inventory reduction of 13% at the market terminals**. It also shows that the inventory target for methanol in transit has been under estimated by 25%. Though the model does not recommend a major change in global inventory levels, it does suggest that the previous targets may have inadequately described the position of the inventory.

[15] Other includes smaller terminals which were not simulated

4.2: COMPARISON TO CURRENT BENCHMARKS

Part of the motivation for undertaking this study was to validate an internal inventory analysis done by Methanex one year earlier. This internal analysis also used simulation, treating both shipping and demand as random processes. Notable differences between the internal benchmarks and the WISE targets as shown in the previous figures are due to the different assumption inherent to each model.

1. **System-wide modeling vs. Single-terminal modeling:**

By examining the system as a whole the WISE model makes decisions about where to best allocate the fixed amount of Methanex methanol production. The model must consider the tradeoff between moving methanol to one location as opposed to moving it to another. In effect the individual terminals are competing for spot shipments of methanol. In contrast, the internal model examines one inventory terminal at a time, which precludes the analysis of the choice between servicing demand at separate locations that actually occurs. It also limits the ability to measure the availability of methanol at the production facilities.

2. **Spot Purchases:**

The WISE model uses spot purchases to source demand at some terminals while the current benchmark does not. Because spot purchases represent acquisition in relatively small package sizes, their inclusion tends to decrease the average inventory at terminals where spot purchases occur.

3. **Vessel Scheduling:**

The WISE model is constructed based on the forecasted partial vessel schedule. This fixed portion of the vessel schedule will reflect the most accurate plans for the future. This initial schedule is supplemented by appropriate spot vessels. While the realized vessel schedule is unlikely to match the fixed partial vessel schedule plan, it is likely to bear a close resemblance to it.

In comparison, Methanex's current model dedicates ships to cyclical routes with random start times. As in the WISE model, gaps in the schedule are supplemented with spot vessels. One critical difference between the methods of vessel scheduling is that in the internal model does not allow inventory to run over the tank capacity. Shipment scheduled to arrive when the tank is full are not allowed to discharge methanol into the tank. Instead they are simply dismissed. Because the internal model does not fully account for all shipments, it may be underestimating target inventory levels.

4. **Demand Deferrals:**

The WISE model defers demand within an acceptable range, allowing demand to be realized later than originally scheduled. In contrast, the internal Methanex model does not defer demand. Instead it always assumes that a spot vessel will be available to service demand from a production facility. The net effect is that the demand deferrals drive inventory targets lower.

4.3: INVENTORY CAPACITY RECOMMENDATIONS

The WISE model generates capacity recommendations based on the simulation. The recommendations are computed as follows:

- If the 95th percentile for the simulated level of inventory exceeds the current tank capacity, then we recommend that tank capacity be increased.
- If the 95th percentile for the simulated level of the inventory does not exceed 75% of the current capacity, then we recommend that capacity be reduced, if possible.

Though the parameters of 95th percentile and 75% of capacity are both subjective, it would be easy to re-calculate using other values. The capacity difference shown in the Table 7 represents the difference between the current capacity and the 95th percentile for simulated inventory levels.

Location	Capacity difference	Recommendation
Production Facility 1	-13%	
Production Facility 2	-32%	Excess Storage Capacity
Production Facility 3	+44%	Shortage of Storage Capacity
Terminal 1	0%	
Terminal 2	-52%	Excess Storage Capacity
Terminal 3	-6%	
Terminal 4	-24%	
Terminal 5	+17%	Shortage of Storage Capacity
Terminal 6	-43%	Excess Storage Capacity
Terminal 7	+53%	Shortage of Storage Capacity
Terminal 8	+31%	Shortage of Storage Capacity
Terminal 9	+28%	Shortage of Storage Capacity
Terminal 10	-34%	Excess Storage Capacity
Terminal 11	+1%	Shortage of Storage Capacity
Terminal 12	+18%	Shortage of Storage Capacity
Terminal 13	-5%	

Table 7: Inventory Capacity Recommendations

This clearly identifies the locations where inventory capacity is an issue. In most cases, the recommended changes in capacity are located at the same terminals where a mismatch of target inventory levels has been identified.

4.4: SHORT-TERM PLANNING OF INVENTORY LEVELS

The identification of an inventory target can be useful for long-range planning. Unfortunately from a day-to-day perspective, the target gives very little information about whether or not current inventory levels are too high or too low. The operational problem faced at the demand terminal is of the form: "Based on the current inventory level, the rate of demand, the next scheduled vessel arrival, and the spot purchase options, is there reason for concern?" To address this specific question the minimum inventory level should be time-specific.

The model output from multiple replications can be summarized to support such a decision. The observed variability on each simulated day across multiple replications will reveal a range of expected inventory levels. When actual inventory levels are outside of this recommended range for a specific day it should be cause for concern. Figure 17 shows a sample of the expected inventory levels at production facility 3. The shaded region represents the middle 50% of the replication results, and the region within the end of the whiskers[16] represent the middle 90%.

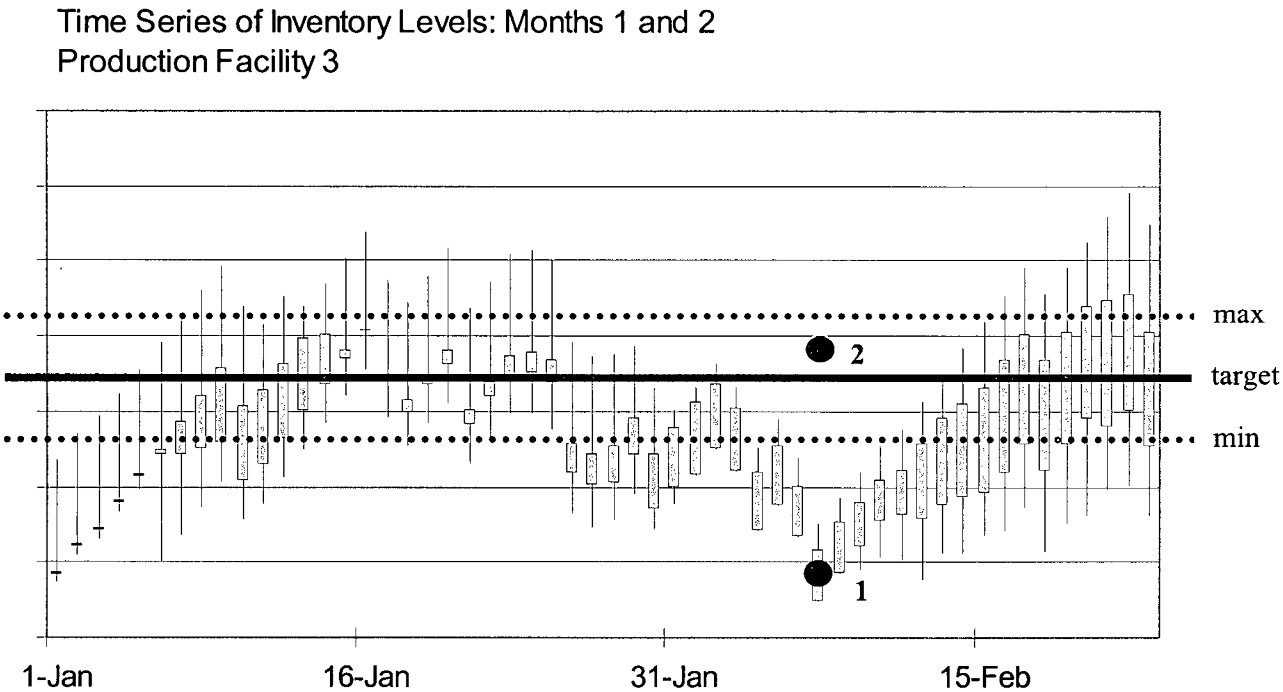

Figure 17: Short-Range Planning – Inventory Boxplots

The current method of identifying when there is "reason for concern" is to create a static maximum and a minimum around the inventory target. In the past, the practice has been to set these levels one standard deviation away from the target. If inventory levels deviate outside of the range set by the minimum and maximum, then alternative measures for inventory management such as demand deferral, spot purchases or spot vessels are examined.

[16] The whiskers are the vertical lines that extend out from the top and bottom of the boxes

In contrast, the WISE model outputs time sensitive inventory distributions. It is expected that even the best plans will result in an expected daily inventory level that is outside of the range defined by long-term minimum and maximum levels during specific periods of time. These are periods shortly before or after the arrival of a vessel. This is the normal operation of the system. Planners should only be concerned when the actual inventory level is beyond the expected range depicted by the time series of boxplots.

As seen by the dot marked "1" in Figure 13, there is a period in early February where the simulated inventory levels drop below the minimum. In this case, the inventory levels observed below the static minimum are expected, and are a function of the production plan and forecasted vessel schedule. They are not a reason for concern.

The dot marked "2" in Figure 13, identifies an inventory level which is between the inventory maximum and minimum. At the same time, this dot is well outside the range defined by the boxplot. This means that inventory is much higher than expected. Despite the fact that this inventory level is within the static range defined by the minimum and maximum, is outside of the assumptions set out by the plan, and as a result, it is a cause for concern.

4.5: SCENARIO ANALYSIS

The most useful capacity of the WISE model is its ability to model scenarios. By modifying the parameters, a user is able to monitor the impacts of changing assumptions related to demand, production, vessel scheduling, spot purchases, inventory safety stocks, and demand deferral. Depending on the parameters modified, the results may affect a single terminal, or several locations in the supply chain. Several example scenarios are included to demonstrate this functionality.

INCREASING A SPOT VESSEL PARCEL SIZE

Terminal 10 is a special case, which is serviced strictly by spot vessels that drop off a parcel and continue to a second destination to discharge the ship's remaining volume. In the initial runs of the simulation, this terminal was consistently running out of methanol, and had a target inventory level that was lower than expected. The following scenario models the impact of increasing the parcel size delivered to Terminal 10. Increasing the parcel size will increase the target inventory level and should decrease the number of days that demand is deferred.

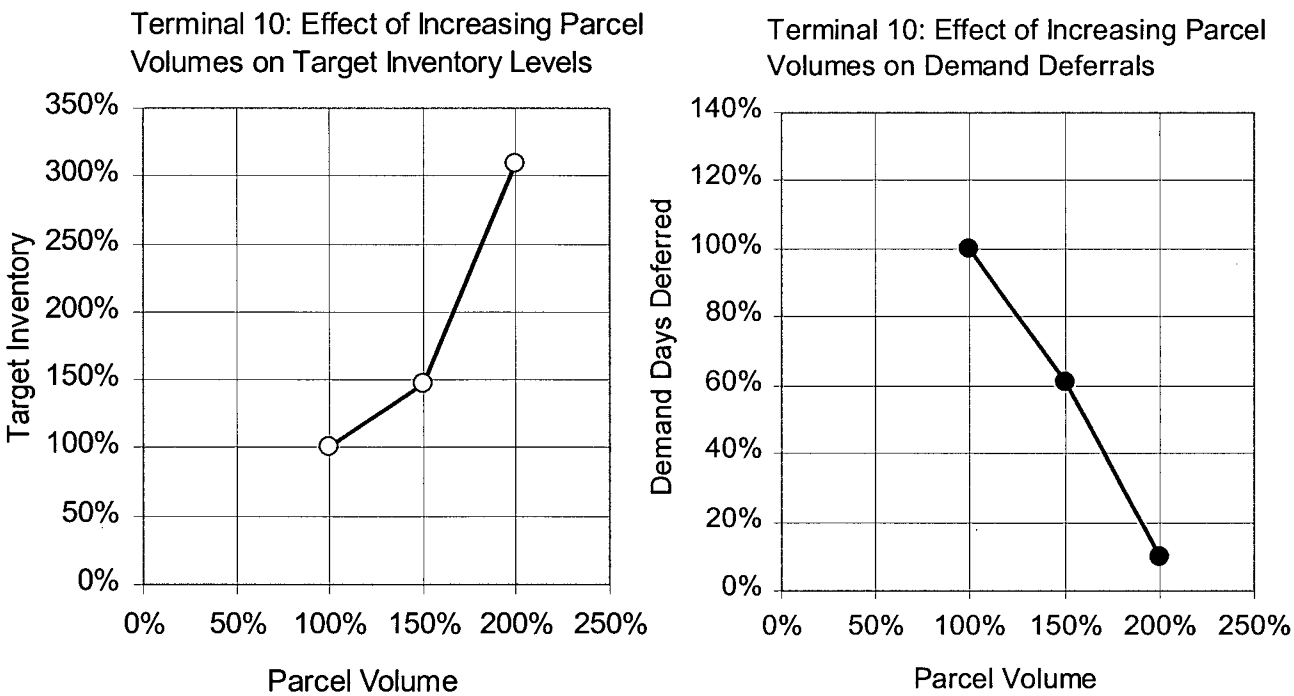

Figure 18: Scenario Analysis – Increasing Parcel Size at Terminal 10

As the parcel size increases, the target inventory level increases. As seen in Figure 18, there appears to be an increasing return in target inventory levels for increases in parcel size. This demonstrates a non-linear relationship between the parcel size and the target inventory level.

Similarly, as the parcel size increases, the average number of demand days deferred decreases. Figure 18 shows how increasing the parcel size has an increasing effect on decreasing the average number of demand deferral days.

While these effects are predictable, quantifying their magnitude assists us to understand them more completely thereby improving the inventory analysis.

INCREASING SPOT PURCHASE VOLUME

Terminal 6 is a terminal that purchases a high volume of methanol on the spot market. As a result, the target inventory level from the simulation is significantly lower than the current benchmark. A series of scenarios were conducted to examine the sensitivity to spot purchase volume. At terminal 6, the spot purchase volume for each purchase in the original scenario was set to be a small volume. The objective of setting a small spot purchase volume is to encourage the model to purchase only as much spot product as necessary. To test the impact of changing the spot purchase volume, four separate scenarios were examined at Terminal 6. In each scenario, the spot purchase volume per purchase is increased.

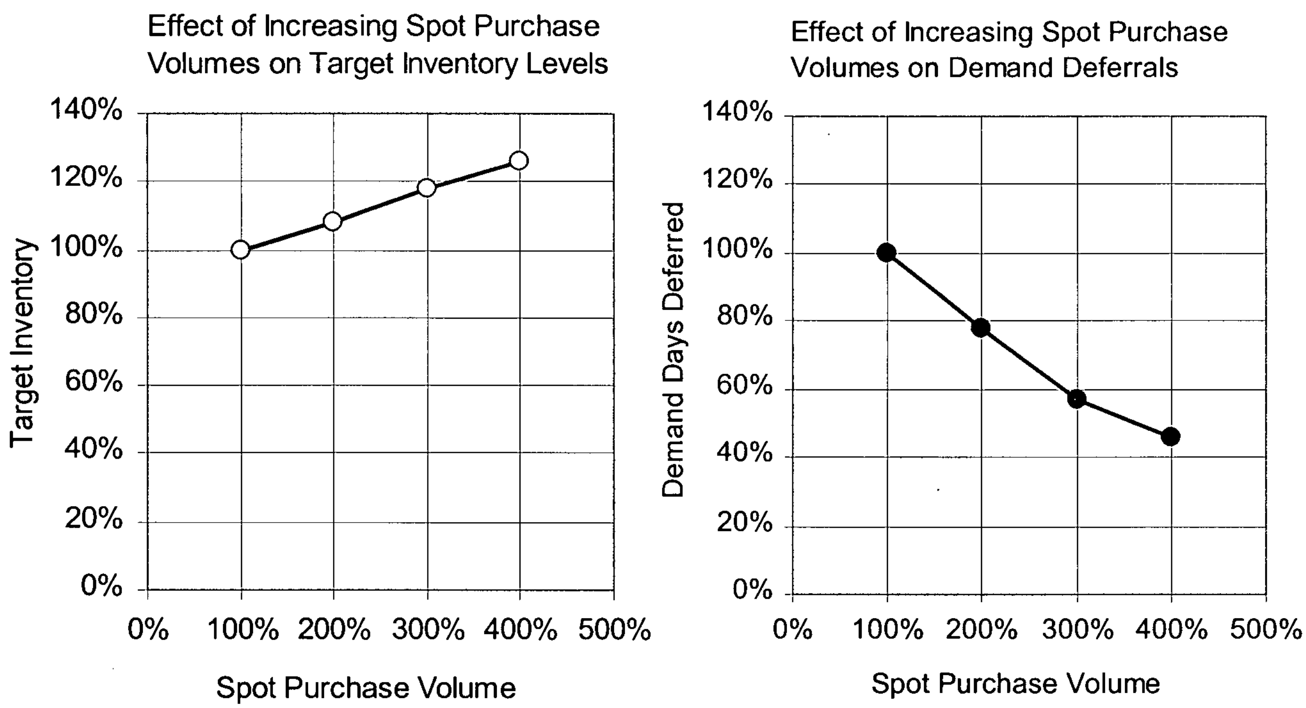

Figure 19: Scenario Analysis – Increasing Spot Purchase Scenarios

As shown in Figure 19, as the spot purchase volume increases, the target inventory increases. In this case it appears that increasing the spot purchase volume has a positive linear effect on the target inventory level.

Also shown in Figure 19, as the spot purchase volume increases, the average number of demand days deferred decreases. For larger spot volumes, there is evidence of a decreasing return in average number of demand days deferred. This is attributable to the fact that deferring demand is the preferable method of dealing with minor inventory outages caused by gaps in the fixed vessel schedule. As a result, some demand deferral is likely to occur at all terminals. After some point, increasing the spot purchase volume will have a decreasingly negative effect on the average number of demand days deferred.

REMOVING DEMAND VARIABILITY

One of the reasons for using a simulation approach is that it enables the inclusion of demand variability. As a separate scenario, it is possible to test the effect of the demand variability on target inventory levels, by removing it from the model. The chart shown in Figure 20 illustrates the ratio of the inventory targets with deterministic demand to the inventory targets with stochastic demand.

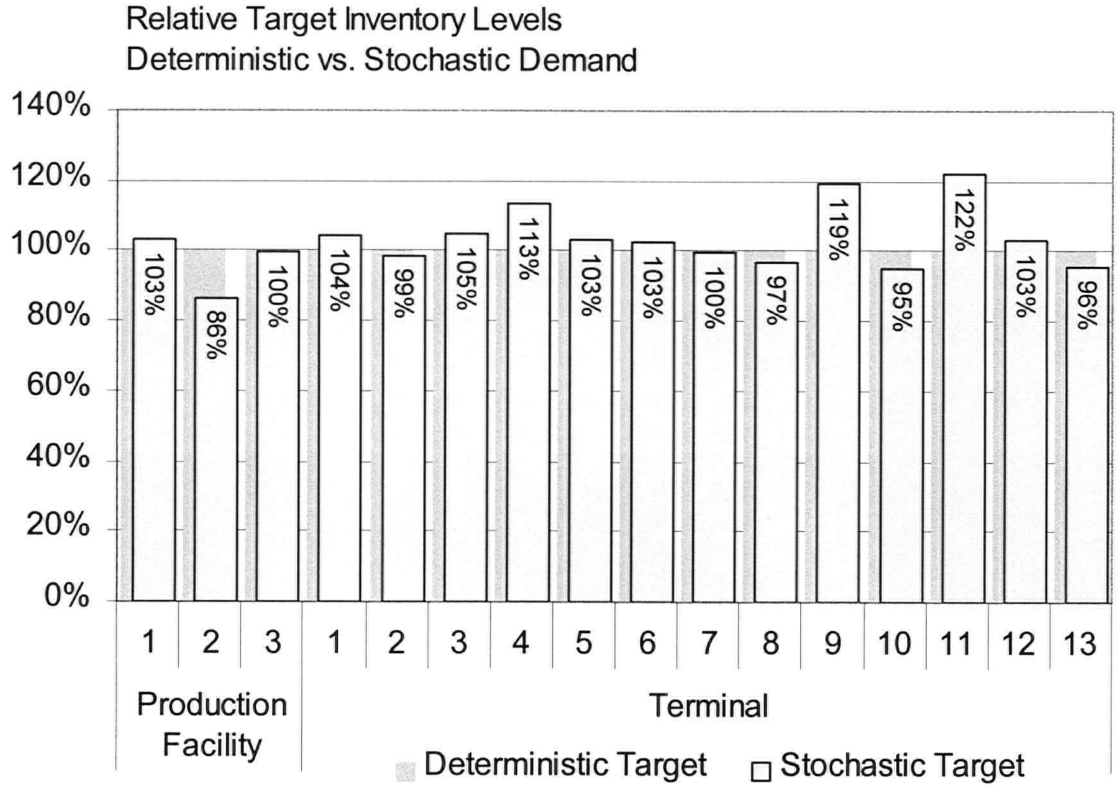

Figure 20: Scenario Analysis - Removing Demand Variability

While most of the inventory targets are similar under stochastic and deterministic demand conditions, 9 locations experienced an increase in targets inventory level of more than 1%, 3 locations experienced a change in target within 1% of the deterministic target, and 4 locations experienced a decrease in inventory target of more than 1%.

The target inventory level **decreases** were seen in locations with a relatively high proportion of spot vessel shipments. In stochastic scenarios, other terminals compete for the spot shipments. Depending on the differences between simulated demand and the partial vessel schedule, different terminals could receive spot shipments. As a result, those terminals with a high dependence on spot shipments suffer under conditions of system wide variability, as the spot shipments are allocated to other less dependant terminals. These less dependant terminals are the terminals that will observe an **increase** in target inventory levels under stochastic conditions.

The net result is that by removing demand stochasticity, the global inventory target for all locations is almost 2% lower.

CHANGING DEMAND DEFERRAL THRESHOLD

The demand deferral threshold is set to distinguish those outages that are short enough to manage by deferring demand from longer outages. In the initial runs of the simulation, the value chosen for the demand deferral threshold was 5 days. This implies that demand can be deferred without penalty for a period of up to 5 days. A scenario was created to ascertain the sensitivity of the inventory targets to changes in this demand deferral threshold, by testing a deferral threshold of 1 day.

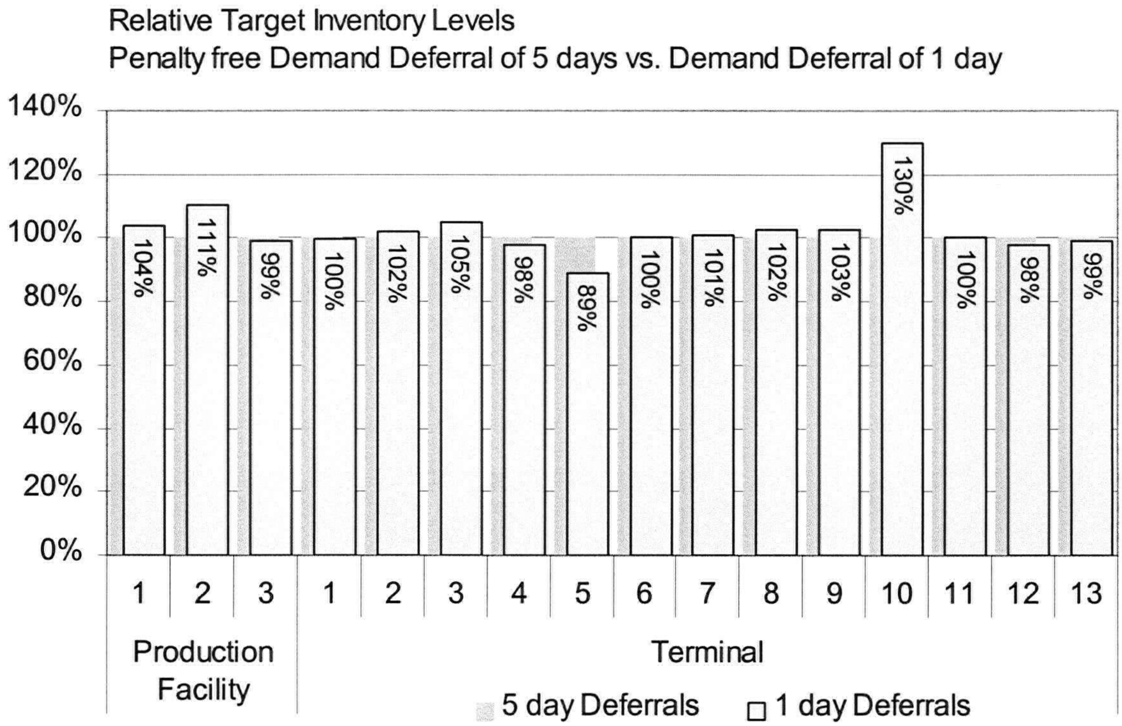

Figure 21: Scenario Analysis - Modifying Demand Deferral Threshold

This change has the highest impact at locations where demand deferral occurs often. While 7 of the 16 locations experienced an increase in target inventory levels greater than 1%, 4 locations experienced a decrease in target inventory levels greater than 1%. The remaining 5 terminals stayed within 1% of their initial target inventory level. It is expected that decreasing the demand deferral threshold will force the terminals to acquire more methanol, increasing their target inventory levels. This is not always the case. Of those terminals experiencing a decrease, the largest was observed at terminal 5. Terminal 5 is a terminal that can acquire methanol on the spot market and as a result it is less likely to receive spot shipments. By decreasing the demand deferral threshold, all terminals will experience an increased demand for spot shipments. However, those terminals with higher outage scores are more likely to receive them. As a result, the terminals with higher outage scores are better equipped to compete for the scarce resource of spot shipments. Terminal 5 loses some of the spot shipments it was receiving in favor of spot purchases.

The other notable change occurs at Terminal 10. Terminal 10 is one of the smallest terminals. While it experiences the largest relative growth in target inventory level, the change in absolute terms is small.

There will always be a tradeoff between the amount of inventory that is carried and the number of times that inventory will be deferred. By restricting the number of demand deferral days, the net change to the system is an increase in the global target inventory by less than 1%. Though inventory targets change very little, the total number of days of demand deferral drops by 46%.

4.6: CONFIDENCE INTERVALS FOR INVENTORY TARGETS

It is possible to describe a confidence interval for the mean target inventory level, based on the distribution of simulation results. This will describe the precision of the analysis, and the sensitivity of inventory levels to stochastic demand and production effects. The formula for calculating a confidence interval for the mean is as follows:

$$\bar{x} \pm t^* \frac{s}{\sqrt{n}}$$

where:

$\bar{x}$ is the simulated target inventory level

t is a t-statistic based on the appropriate level of confidence and degrees of freedom

$\frac{s}{\sqrt{n}}$ is the standard error of the simulated inventory target

Using a confidence interval of 95% and 50 replications, results are calculated for the base scenario in Table 10. The upper and lower limits are the limits for the confidence interval for the inventory target with respect to the current tank capacity. The "margin of error" is the width of the confidence interval, which is shown as a ratio to the target inventory level, to provide a relative measure of certainty on the results. The "replications" is the number of replications required to have the margin of error of 5%.

Location	Lower Limit	Upper Limit	Margin of Error	Replications
Production Facility 1	47%	51%	8%	114
Production Facility 2	34%	35%	3%	23
Production Facility 3	54%	62%	15%	433
Terminal 1	48%	54%	11%	254
Terminal 2	24%	26%	6%	84
Terminal 3	43%	53%	20%	800
Terminal 4	33%	36%	10%	199
Terminal 5	51%	55%	7%	99
Terminal 6	26%	27%	5%	57
Terminal 7	82%	91%	10%	218
Terminal 8	67%	75%	11%	239
Terminal 9	96%	109%	13%	316
Terminal 10	23%	25%	8%	137
Terminal 11	43%	49%	11%	248
Terminal 12	64%	72%	12%	308
Terminal 13	43%	47%	9%	161

Table 8: Relative Confidence Intervals for Inventory Targets

The variability of the target inventory determines the number of simulation replications required to obtain an acceptable margin of error. Since the standard error is inversely proportionally to the square root of the number of replications in the sample, the more replications in the simulation, the narrower the confidence interval. Ultimately the number of replications tested should be determined by a tolerance for the precision of the target. The number of replications required is calculated as:

$$n = \left(\frac{2ts}{m\bar{x}} \right)^2$$

where:

m = acceptable margin of error

4.7: PRESENTATION OF RESULTS

The primary methodology and results of the WISE model were presented to Methanex in October 2002. Both the methodology and results were well received. Differences to current benchmarks were understood and supported. The general consensus was that the model produced useful analytical information. Subsequent training sessions were conducted to assist with model transitioning and implementation.

Continued operations research opportunities at Methanex are discussed in Chapter 5: Synthesis, along with a discussion regarding potential improvements to the model, and a comparison of the WISE results to results of the standard academic approaches seen in Chapter 2: Standard Approaches.

CHAPTER 5: SYNTHESIS

The WISE model that was developed represents one possible way to analyze Methanex supply chain policies. There are a number of potential refinements to the WISE model that might make it more effective. These refinements are listed in section 5.1. The list is not comprehensive, but it does demonstrate the room for improvement in the WISE model.

Additionally the results from the inventory study described in Chapter 4: Results could be audited by comparing them to the analytical results from the standard academic approaches described in Chapter 2: Standard Inventory Control Approaches. This comparison is discussed in section 5.2.

Finally some further potential projects at Methanex are discussed. As a large-scale company with an extensive supply chain, it is an excellent source of attractive projects in the field of Operations Research.

5.1. REFINEMENTS TO METHODOLOGY

Listed below are potential enhancements to the WISE model.

1. "MINIMUM" DELIVERIES: A SEMI-FIXED VESSEL SCHEDULE

Instead of using a fixed vessel schedule for all of the leased vessels, it is possible to create a heuristic that is based instead on a semi-fixed vessel schedule. This semi-fixed vessel schedule would include the source and destinations of all lease vessel trips, but it would not have complete delivery volume information. Instead it might have minimums for all of the multi-stop voyages.

For instance, a single vessel on a given voyage might make three stops. As opposed to allocating the entire package, this policy would allocate a portion of the total, perhaps 75%, and use a set of decision rules to distribute the remaining 25% to those terminals that need the methanol the most at the time of delivery.

This would decrease the dependence on the fixed vessel schedule as an input. It would allow the model to react with more agility to variations in demand at the market terminals. It would also represent a closer tie to the existing business process by emulating the last-minute decision-making that is required to properly balance supply and demand in smaller markets.

2. RACK PRICING

To mitigate the price volatility of methanol, Methanex has begun to implement a rack pricing strategy, which will allow them to set a listed price for methanol. This protects them from extraordinary swings in price, while enabling them exert a higher degree of influence over a larger portion of their customers.

Introducing rack pricing may have a serious impact on how demand is realized. Once the effect of the rack pricing strategy has been measured and studied, it should be incorporated into the WISE model to ensure that the target inventory levels are representative of the current business practice.

Though the effect of the rack pricing strategy is not known, it would be possible to use the WISE model to test different potential demand scenarios. This type of testing could provide decision makers with insight into the system-wide impacts of fundamental strategic decisions.

3. INCLUSION OF SCHEDULED SPOT PURCHASES AND SWAPS

The model can be modified to include scheduled spot purchases and swaps. Currently swaps are excluded and spot purchases only occur through the decision making process described in Chapter 3: Hybrid Inventory Control Approaches. By explicitly scheduling known spot purchases and known swap contracts, the model would be able to take them into account when deciding where spot vessels, spot purchases, and demand deferral are required. This inclusion would help align the model's results with the actual business process.

4. USE OF ACTUAL DEMAND DATA

The model is based on the demand and supply study, which examined realized demand data. To add value to the analysis, it would more appropriate to use the uncensored demand information. Uncensored demand information would include the sales that had to be deferred or turned away.

There are several ways to collect the uncensored demand information. The customer service representatives, who deal with the actual customers, could make some sort of estimate as to levels of the uncensored demand. Going forward, it might be possible for them to note the requested demand and track it against the actual fulfillment of demand. Alternatively, the data could be collected by surveying the customers directly. This data collection process would require additional resource commitments.

5.2. COMPARISIONS TO STANDARD APPROACHES

The WISE model generates inventory targets that were compared to the current Methanex benchmarks in Chapter 4: Results. As an alternative measure, it is possible to compare the simulation results from Chapter 4: Results to those discussed in Chapter 2: Standard Inventory Control Approaches.

In each of the three models discussed in Chapter 2: Standard Inventory Control Approaches, an optimal order quantity is selected. Under normal circumstances, the inventory would vary primarily between the order quantity and zero. In this case however, the heel of the tank represents the lowest possible level of inventory, so the level actually varies between the heel of the tank and the optimal order quantity plus the heel of the tank. As a result, the target inventory level would be equal to the half of the optimal order quantity plus the heel.

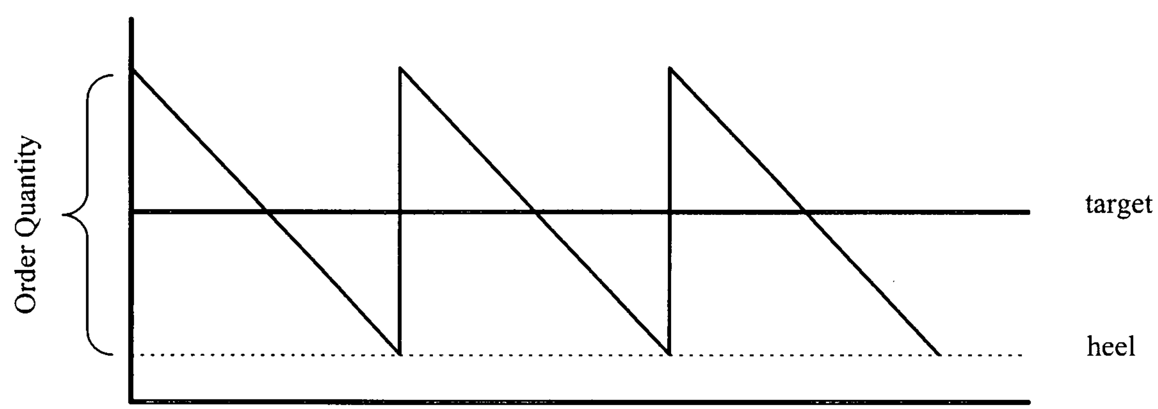

Figure 22: Defining Target Inventory Levels

Using this assumption, it is possible to construct a chart to compare the results. The inventory targets shown are displayed relative to the WISE inventory targets.

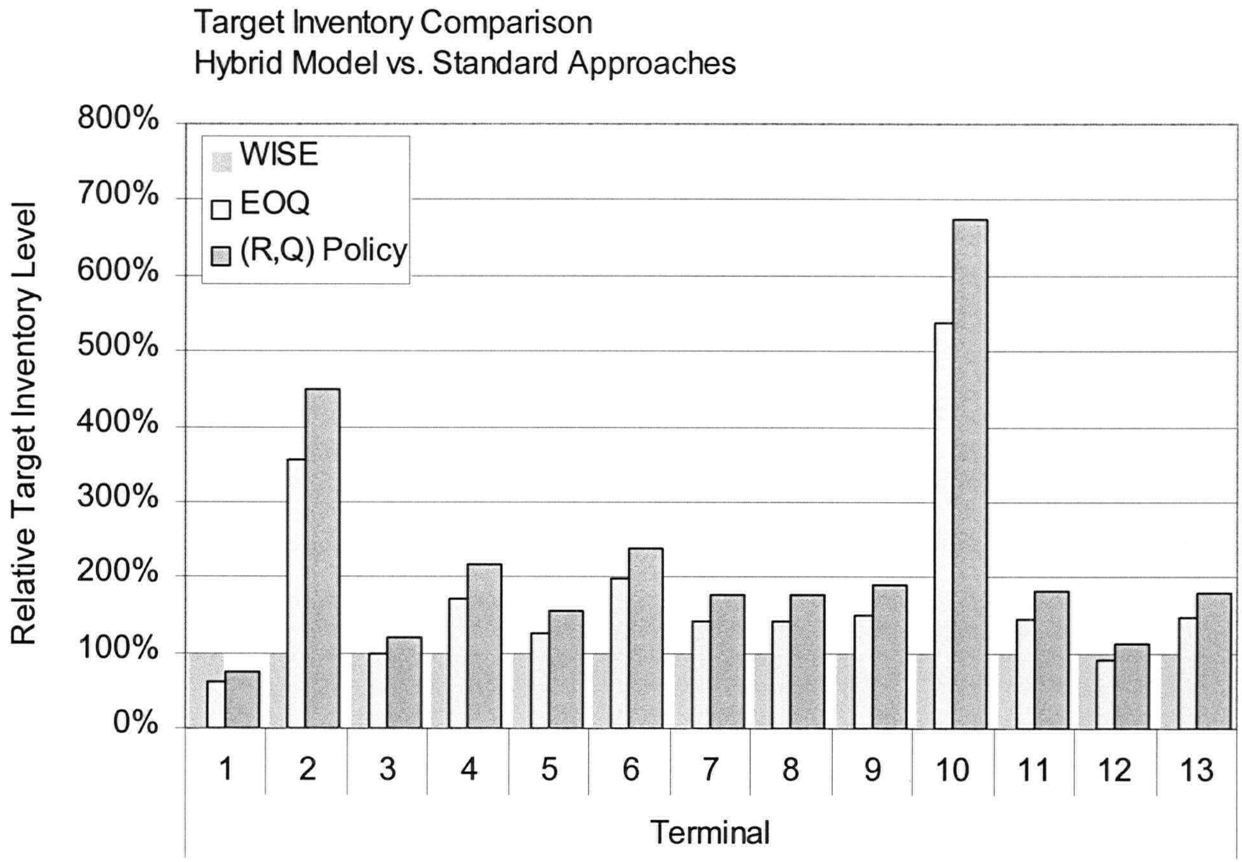

Figure 23: Comparing Target Inventory Levels – EOQ, RQ models

Figure 23 illustrates the relative inventory target predicted by the EOQ model[17], and the (R,Q) policy[18]. In comparing these results, it is important to note that for a given set of EOQ parameters, the (R,Q) policy will always generate a higher target level. The (R,Q) policy is modification of the EOQ model, where the optimal order quantity is always multiplied by a factor which will always be greater than one (see Chapter 2: Standard Inventory Control Approaches).

Using the estimated parameters, in 11 out of 13 cases, the standard models predict a higher target inventory level than the simulation. This is due to a host of reasons:

- The two standard models assume that orders are made from an infinite supply. In reality, Methanex produces a finite amount of methanol. The inventory policy must account for the scarcity of methanol in the system by sending smaller volumes.

[17] EOQ assumes are based on a methanol price of $200/MT, and a holding cost of $3/MT/month
[18] The R,Q policy results shown assume the same parameters as the EOQ model, and a shortage cost of $5/MT/month

- These two standard models acquire inventory via a single delivery parcel size, whereas the simulation can acquire methanol in multiple parcel sizes. This effect is most prevalent at terminals where spot purchases are possible, making some of the parcel sizes relatively small. By acquiring inventory in smaller parcel sizes the target inventory level is reduced.

- These two standard models do not permit backorders (demand deferral); a process that will invariably have a negative effect on target inventory levels.

- These two models do not account for the system-wide aspect of the problem. That is to say, they examine the problem myopically, investigating a single terminalat a time. In reality, there can be interaction amidst the system, whereby a single fixed order charge might be incurred one time to make several deliveries on a single trip. By consolidating these deliveries, overall system-wide charges can be limited.

- These two models do not account for the actual constraints relating to parcel sizes, which are established based on vessel availability and port accessibility. The parcel size constraints are built into the WISE model. These constraints will put an upper bound on the optimal order quantity and have a negative impact on target inventory levels.

These reasons are the primary reasons that the inventory targets of the EOQ model and the (R,Q) policy might be higher than the WISE targets.

The lower target inventory levels seen at Terminal 1 imply that the order quantity / parcel size used to service Terminal 1 is actually larger than the optimal size.

Generally, the results suggest that using larger delivery vessels and dropping off larger packages can limit supply chain costs of a single terminal.

It is possible to use the WISE results to explore the uncertainty around the holding cost in the EOQ model. Treating the holding cost as a decision variable and minimizing the difference between the EOQ targets and the WISE targets can accomplish this. Minimizing the sum of the squared differences across all of the inventory targets results in a holding cost of $3.90/MT/month (equivalent to a 26% annual compound rate of return). Alternatively, it is possible to minimize the sum of the absolute differences in inventory targets, which results in a holding cost of $4.70/MT/month (equivalent to a 32% annual compound rate of return). This second approach will put less weight on larger differences.

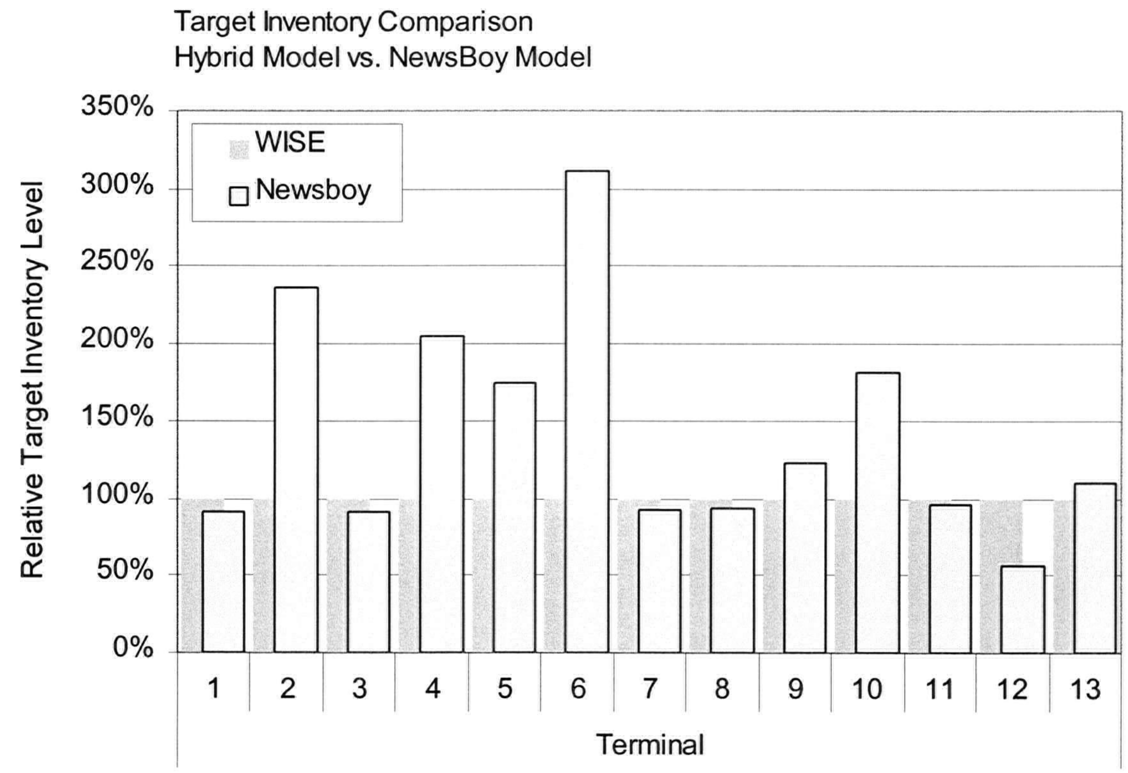

Figure 24: Comparing Target Inventory Levels - Newsboy model

Similarly, the WISE model results can be compared to the target inventory levels suggested by the Newsboy model[19]. In contrast to the EOQ and (R,Q) policies, the inventory targets for the Newsboy model are higher only 7 times out of 13, while the other 6 are lower than the targets suggested by the WISE model (as seen in Figure 24).

In 4 out of the 6 cases where the Newsboy model selects a higher inventory target, the terminal in question is a terminal where spot purchases are permitted and make up a significant portion of the methanol supply. One way to make these results more consistent with the others would be to decrease the cost of underage. Since it is possible for these terminals to avoid underage by making a spot purchase, it is arguable that they merit a different underage cost than the other terminals.

In the Newsboy model the lead-times have been used to construct the demand parameters. This assumption implies that individual vessels constantly deliver along the same routes. This does not hold in most cases. The makeup of the current fleet makes this infeasible.

[19] These Newboy results suggest an optimal service level of 95%, where underage costs are 19 times larger than overage costs.

One way to investigate this further is by manipulating the period lengths in the Newsboy model to minimize the difference between the WISE inventory targets and the Newsboy Inventory targets. The results of such a test are shown in Figure 25.

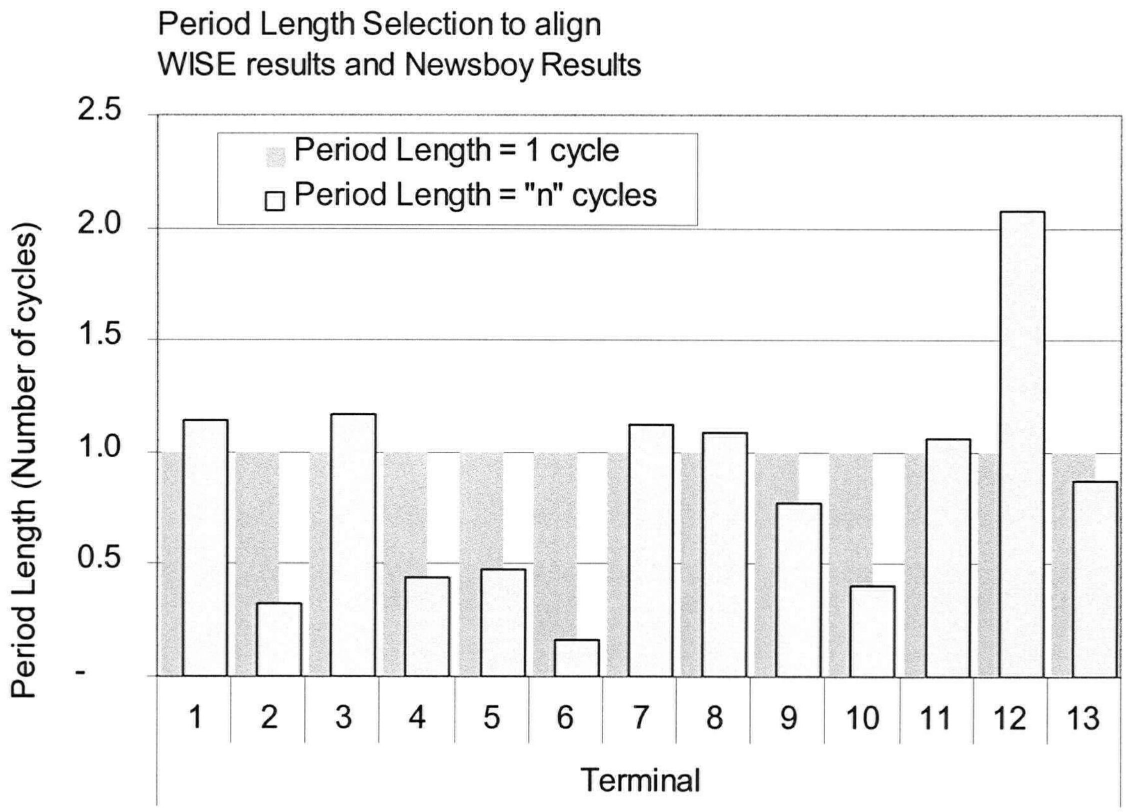

Figure 25: Comparing Period Lengths – Newsboy model

This is a sample interpretation of Figure 25. For Terminal 1, the Newsboy results will generate similar target inventory levels to the WISE model at a service level of 95% when the time period used is roughly equal to 1 cycle[20]. This is the equivalent of a vessel traveling to and from a destination. This implies if a single vessel traveling from the production facility to Terminal 1 drops off the optimal order quantity from the Newsboy model, then the target inventory level will be similar to the target generated by the WISE model. At Terminal 2, the number of cycles required to change the periods so that the Newsboy and WISE results align is near 0.25. This implies that in the space of a single cycle, four vessels must deliver the optimal order quantity for the Newsboy results to match the WISE results.

One criticism of the application of the Newsboy model to the Methanex Supply Chain is that is does not account for the fixed ordering costs. The inclusion of high fixed order costs in other inventory models encourages large parcel sizes and high target inventory levels.

Comparing the results of the standard inventory control models to the hybrid approach that was employed provides a helpful insight into the mechanics of the supply chain. This type of analysis articulates some of the specific details that make this Methanex supply chain complex.

[20] A single cycle is defined as twice the lead time

5.3. NEW DIRECTIONS

As a major production and distribution company, Methanex has a wealth of potential Operations Research projects. Over the course of the project a number of interesting operational issues were brought to the forefront.

1. REFINEMENT OF NETWORK FLOW OPTIMIZATION

Currently Methanex employs linear programming to solve a standard network flow problem to provide a reference point for proper planning. There are a number of ways this optimization process could be revised and improved. Its current incarnation is a complicated and cumbersome Excel spreadsheet. With the recent and ongoing implementation of a new supply chain information system, it might be possible to automate and improve this process. It may also be possible to introduce alternate formulations and to perform sensitivity analysis.

2. OPTIMAL VESSEL SCHEDULING

Underlying this network flow model is a very interesting and very complicated integer programming puzzle. The current network flow model ignores some shipping constraints. It may possible to formulate a model to minimize the supply chain costs by explicitly scheduling each shipment and purchase. That being said, depending on how many simplifying assumptions are made, the problem may be so complex that it might prove unsolvable in practical terms.

3. REGIONAL DISTRIBUTION NETWORKS

The focus of this project has been the ocean going vessel network that distributes methanol from the production facilities to the major market terminals. Within the North American and European markets, there exist regional networks using trucks, trains, and barges to redistribute the methanol to customers and other inventory storage locations. There is potential for regional logistics optimization or for more detailed inventory analysis.

4. CUSTOMER SEGMENTATION

Considering that Methanex incurs large distribution costs, it may be worth examining some type of profitability optimization related to the revenues and costs associated with servicing regions, groups or even specific customers. This analysis may provide insight as to whether, for example there is correlation between customers in the same industry that can improve planning. It could be useful in considering a potential strategy revision, or a contingency plan in the event of a business crisis. A more thorough customer demand analysis may reveal the potential benefits of a Vendor Managed Inventory system.

5.4: VALUE OF THE MODEL

Estimating the value of this type of analysis involves a combination of factors. These might include the potential savings from improved efficiency resulting in cost aversion, reclamation of capital tied up in inventory and the intangible value of learning from this type of project.

Methanex can become more efficient by redeploying resources to change the current storage terminal capacity in accordance with the recommendations of the WISE model. This transformation will align the physical capacity with the current plans. Ultimately, the goal of matching the capacity with the plans is to avoid unnecessary expenditures associated with ship diversion, ship demurrage, re-working of orders, unnecessary spot purchases, and inventory juggling between storage locations.

Historically the global level of methanol storage has been higher than the recommended targets. It may be possible to reduce inventory and reclaim capital that was previously invested in inventory. Additionally, savings may be realized by avoiding unnecessary purchases methanol to support an erroneously high level of inventory.

Finally, there is inherent value in the process of engaging in this type of collaborative project. The application of different statistical analyses, new concepts such as the "probable range for inventory", and the introduction of heuristics all hold intangible value to Methanex.

CHAPTER 6: CONCLUSIONS

As seen in the Chapter 4: Results, the base case highlights discrepancies between the current target inventory levels and the current capacities. This information is potentially useful to supply chain planners at Methanex, who have the ability to implement changes in sourcing and inventory capacity. It could allow a more efficient allocation of resources, which could lead to improved shareholder returns.

The project gives Methanex control of a new tool, which will help them in monitoring and planning inventory. It provides a new perspective on inventory monitoring, by introducing the concept of a "probable range for inventory" for short-term inventory management. The adoption and promotion of analytical techniques such as these is a progressive step for Methanex. It is also valuable to always consider that supply chain decisions in any part of the system will have an impact on other parts of the system, which can now be quantified and studied.

The results presented are based on the current supply chain plans. The true potential of the model lies in its ability to simulate new decisions and events prior to their implementation. This could prove useful investigating a host of decisions, including:

- Re-examining the current fleet decisions such as the mix of time charter vessels to spot vessels, the sizes of new vessels, and the routes of current time charter vessels
- Changing terminal sourcing plans by introducing new vessel schedules, allowing new spot vessel options, or changing the allowable spot purchase volume
- Modifying inventory parameters, such as tank capacities and safety stocks
- Implementing major system-wide changes such as opening or closing a terminal, or introducing a new production facility
- Estimating the impact of production factors, such as the rate of production, the inventory capacity at production facilities, planned production outages, or changes in the likelihood or duration of unplanned outages
- Changing demand assumptions to simulate extraordinarily high demand, or extraordinarily low demand

Though supply chain planning for Methanex may be complicated and does not lend itself well to the standard inventory control techniques, there are still many ways in which operations research can have a positive impact on bottom line results.

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