SIMULATION - AN APPLICATION IN MARINE TRANSPORTATION SCHEDULING

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Summary

The Tanker Logistics System is a highly interactive, man-machine system for determining feasible tanker schedules on an annual basis. This system provides a basic tool for quickly evaluating alternative schedules due to changing conditions in a highly specified and sensitive network.

The simulation model, based on a time-dependent sequential decision tree approach, is sensitive to the system's many constraints such as product run-out/run-over, voyage length, dry-docking, third party charter/subcharter and idle time.

Introduction

The Agricultural Chemicals Group of W. R. Grace & Co. consists of a fully integrated mining, production, secondary processing and distribution system for agricultural chemicals and fertilizers. Production facilities are located in several widely separated states and three Caribbean Islands. Wholesale and retail distribution networks include the continental United States east of the Rockies and a worldwide export marketing system.

Of the three primary fertilizer components - nitrogen, phosphate, and potash- W.R. Grace & Co. is a basic producer of the first two. Nitrogen, in the form of ammonia, is produced in continuous process plants and requires specialized handling, storage and transportation equipment. Of the W.R. Grace & Co. ammonia plants, two major facilities are located outside the continental United States; namely, Trinidad and Aruba. In order to transport this ammonia from the Caribbean area to market locations, W.R. Grace & Co. owns and operates its own ammonia tankers.

Problem Statement

Production at the ammonia plants is relatively uniform for the entire year with fixed storage capacities at these locations. The demand, in terms of consumption and sales, is highly seasonal and compressed into short periods of time. These demand locations also contain fixed storage capacities.

Based on annual forecasts of production and demand, the problem is one of scheduling vessels such that production facilities are depleted before storage capacity limits are reached, while at the same time, assuring that no demand locations are left unserviced. Because the W.R. Grace fleet has a limited number of ships which carry a single product, a schedule has to be prepared for a relatively large time span to insure that no bottlenecks will occur. For economic considerations, ships must be scheduled to avoid arriving at supply locations before a full cargo of ammonia is available and at demand locations before a full cargo can be discharged.

Because of the cyclical behavior of the ammonia business, extra ships must be chartered during peak demand periods. During slack periods excess ship capacity is available and can be leased to third parties.

A schedule of voyages, once prepared, is valid only as long as every assumption used to develop it remains static. This does not occur for numerous reasons, i.e., demand patterns do not coincide exactly with original estimates, production facilities "go down", vessels require emergency repair, etc. Each time a significant variation occurs, a new schedule must be generated.

Formerly, the tanker schedule was prepared on a manual basis. Because of the excessive time required to generate a schedule, few alternative possibilities could be evaluated.

Objectives obtained with the implementation of the Tanker Logistics System are as follows:

(1) Provides a mechanism for generating a feasible schedule for a full twelve month period based on specified production rates, demand forecasts and system constraints.

(2) Quickly examines the effect of revisions to current schedules when altering one or more of the demands and/or constraints of the system.

(3) Provides a computerized technique for quickly preparing multiple schedules which then can be evaluated on the basis of economic considerations and personal experience.

(4) Determines at which point existing vessels cannot satisfy a supply/demand situation, thereby requiring the chartering of additional vessels.

(5) Determines how many days of free time in the overall schedule vessels would be available for sub-charter.

(6) Recomputes possible schedules resulting from adding chartered ships or sub-chartering an owned vessel for a specified period of time.

Model History

Shortly after the construction of the three Grace ammonia tankers, it became apparent that sophisticated long-range schedules had to be prepared and revised on a continuous basis. The need for long-range scheduling is due to the limited number of available vessels, the demand requirements compressed into a relatively short-time span, the limited, fixed storage facilities and specialized transportation equipment related to ammonia logistics, i.e., low temperature or high pressure, in other words, a highly constrained and interdependent system.

Since fixed operating costs of a single ammonia tanker exceed $4,000 per day, it is imperative that scheduling be done with greatest possible accuracy, and within the system constraints mentioned above, such that vessel idle time is kept at a minimum.

Immediately after the ammonia fleet first became operational, an attempt was made to provide a mechanized scheduling tool. The technique employed at that time was a linear program. From a set of predefined schedules, this model was used to determine the least-cost transportation schedule, as opposed to the generation of the schedules themselves. Since a set of predefined schedules was required by the optimization model, the more basic problem of generating feasible schedules remained unsolved. Therefore, the Tanker Logistics System was developed.

The Tanker Logistics System provides a computerized system for scheduling voyages of the W.R. Grace & Co. ammonia tankers along with the ability to review and evaluate updated schedules as a result of changing conditions.

Model Design And Structure

The Tanker Logistics System is designed primarily to determine feasible tanker schedules for a full twelve month period or portion thereof from given supply availabilities, demand requirements storage limitations, vessel capacities, and ship voyage times. The simulation technique employed is a time-dependent sequential decision tree examination. Decisions are made each time a vessel reaches a supply location or a demand location, i.e., a decision point. Although not designed as an optimization model, the system has the capability to direct or restrict the decisions at various points in the iteration process so that the effect of decisions can be monitored and alternative schedules evaluated. However, no attempt has been made to incorporate economic considerations in the present model.

The following four components are used to define the structure of the Tanker Logistics System:

(1) Supply Points: A supply point is any geographical location having

product available for shipment to a demand location. Production facilities have depletion requirements based on a combination of fixed storage capacity and variable production rates. Production rates which can vary during the scheduling period can be specified for any inclusive time period from one day to one month and are not necessarily continuous.

Purchases and product exchanges with co-producers have specified quantities of product available but only during predetermined periods of time. For a valid schedule, the total volume of product must be shipped during the specified available period.

Product availability at a supply point is constrained by maximum and minimum storage tank capacities; however, incremental capacities over the nameplate maximum may be specified for any desired period of time. For a feasible schedule, these upper (including incremental) and lower storage limits are not violated at any time during the scheduling process.

Loading times (to the nearest one-half day), as a function of ship class, are required at supply points. These times determine the loading period required for each class of ships.

Dry-docking facilities may also be specified at supply points where such facilities exist. When a ship reaches a supply point and is permitted to dry-dock, the ability to dry-dock the vessel for a predefined period of time becomes an alternative in the decision-making process.

(2) Demand Points: A demand point is any geographical location requiring product delivery by a vessel. This includes our own internal system demands plus contract and "spot" sales locations. Demand points have product requirements based on predetermined consumption/demand rates. Analogous to supply points, these rates can vary during the scheduling period and may be specified for any time period from one day to one month. Unloading times as a function of ship class, storage limits, incremental capacities, as well as dry-docking facilities may also exist at demand locations.

(3) Vessels: The vessels used in the simulation are the W.R. Grace & Co. tanker fleet together with all additional ships which may be required for peak demand periods. Each vessel must be defined in terms of its cargo capacity, availability times (used primarily for charter), sub-charter availability times, ship class (required for loading and unloading times at supply and demand locations. In addition, non-porting constraints are required for those supply and/or demand points at which a particular vessel cannot port, and vessel dry-docking times, i.e., the earliest date that the vessel can dry-dock, the latest date, and the number of days required in dry-dock.

(4) Voyage Links: Voyage links are used to establish the possible routes and voyage times between supply and demand locations. Also, voyage links between demand locations are used where two-porting is permitted. Ships may pass along these links in both directions or may be restricted to a single direction. The sea times are independent of the size class to which the vessel belongs and is not a function of the season of the year during which the voyage takes place. However, sea times may be modified during the simulation process by setting appropriate "break-points."

Given the basic system structure of supply points, demand points, vessel data, and voyage links, the simulation begins by dividing the scheduling period into half-day increments. The scheduling process commences at a specified date with the specific location of each vessel, in terms of days out from its destination point, the vessel cargo and the inventory levels at all supply and demand storage locations.

From this specified date, the system is updated by half-day increments (performing inventory adjustments, ship movements, etc.) until a decision point is reached. This occurs when a ship reaches a supply or demand locstion, loads or unloads, and is ready to go.

When a decision point is reached, the determination of the feasible alternative destinations together with the process of destination selection takes place. The following decision rules have been incorporated into the Tanker Logistics System for supply decision points and for demand decision points:

Supply Decision Points: When a ship reaches a supply point, the ship is always empty and automatically receives a full cargo.

The demand point to which the ship is to be sent must have sufficient storage capacity available to accept a full cargo on projected arrival date. At the same time, the ship must arrive at the demand point before the lower storage constraint is reached. Where two porting is permitted, the above constraints apply to the combined demand locations.

In determining the feasible demand points, projected inventory levels based on demand point depletion rates, ship voyage times, and unloading times must all be taken into consideration. Once the set of feasible demand points has been determined, the system directs the loaded ship to that demand location that will first reach its lower limit constraint.

In certain instances, no feasible destinations may exist. Because the simulation process does not automatically modify the original data such as voyage times, the option of allowing ship idle time to a maximum specified by the user has been incorporated into the model. This feature provides a buffer such that the scheduling process may continue when only minor impasses are encountered. In addition to idle time, the ship can be sent to sub-charter or dry-dock if these options are permitted at the location and/or during such a period.

Demand Decision Points: When a ship reaches a demand location, the ship cargo is unloaded (or partially unloaded for two-porting). If the vessel after unloading is empty, a decision must be made as to which supply point the ship should be sent. The potential supply locations must have available inventory such that a full cargo can be loaded when the ship arrives. Also, the vessel must arrive before the inventory level exceeds the storage tank capacity at the supply point.

Analogous to supply decision points, the feasible supply points are obtained by projecting inventory levels based on production rates or product availabilities, ship voyage times, and ship loading times. Once a set of feasible supply points has been determined, the system directs the unloaded ship to that supply location that will first reach its upper limit constraint.

In the case of two-porting, the partially unloaded ship is sent directly to the second port, and at that time, the ship is fully unloaded. When the ship unloads at the second port, the ship is empty and at that time the evaluation and selection of a supply point destination is then determined. Ship idle time, subchartering, and dry-docking options are handled at demand decision points in the same fashion as at supply decision points.

When a decision at a supply or demand point is made, the effects of that decision on the associated demand/supply points are projected (i.e., run-out time in the case of demand points and overflow time for supply points), and the system is updated to the time at which a ship reaches the next decision point. Hence, all future effects of decisions made at decision points are immediately accounted for in the simulation model. Decisions made at succeeding decision points are influenced by the effect of all commitments made at prior decision points, i.e., the effect of all ships underway is considered in making a decision at any time.

Utilizing the time-dependent sequential decision-making process, the scheduling continues until a feasible schedule is generated or an impasse condition reached, i.e., storage capacity exceeded at supply point, product run-out at demand point, etc. When such an impasse condition is reached, the reason is identified, and the user can either return to any previous point in the decision tree at which an alternative decision was possible and proceed along an alternative branch of the decision tree, or the user can modify the original data such that the impasse condition is alleviated.

Illustrative Example

The representation of a simplified set of supply and demand locations illustrates the decision-making process which takes place at the supply and demand points and demonstrates the time-dependent sequential decision tree algorithm of the Tanker Logistics System. To illustrate the decision-making process at a supply point, assume that a ship has arrived at supply point S_2 and is fully loaded at time t = 2 (Figure I).

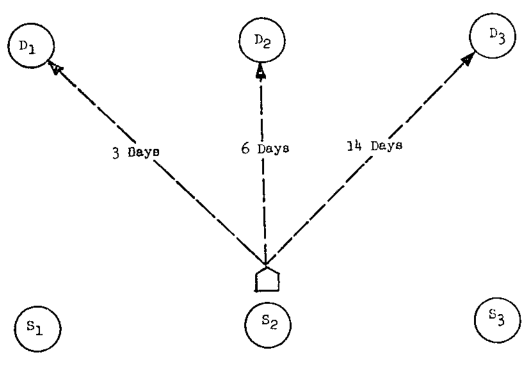
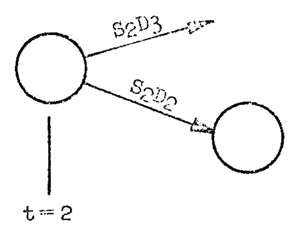


Figure I

Furthermore, assume that the inventory and rate of consumption at demand point D_1 are such that D_1 cannot accept a full cargo before t = 7 and the rate of depletion is such that a delivery is required before t = 17. For demand point D_2, assume the earliest date for delivery is t = 6 and the latest date is t = 16. The demand point D_3 is a "spot" demand, i.e., a specified cargo is required to be delivered between two specified dates. Assume that the earliest date for the "spot" delivery is t = 1 and that the latest date is t = 17. For the voyage links S_2D_1, S_2D_2, S_2D_3 assume voyage sea times of 3, 6 and 14 days, respectively. The following table shows that there are two demand points D_2 and D_3 to which the ship may be sent with zero idle time; the arrival date is between the earliest and latest date.

VOYAGE	SEA TIME	ARRIVAL DATE	EARLIEST DATE (FULL CARGO)	LATEST DATE (RUN-OUT)
S_2D_1	3	5	7	17
S_2D_2	6	8	6	16
S_2D_3	14	16	1	17

The criteria for the selection of the preferred demand point is that demand point whose inventory is depleted first (the earliest projected run-out time). In the above case, the demand point D_2 with the first run-out date (t = 16) would be chosen. After the selection has been made, the earliest and latest dates for the demand point D_2 are updated to account for the influence of this cargo movement. Looking at this decision in the form of a sequential decision tree, a decision point (node) at time t = 2 will contain two branches; the branch S_2D_3 representing the feasible alternative which was not selected and the branch S_2D_2 representing the selected voyage.



It should be noted that the illustration contains only a single ship whereas the simulation model accounts for numerous ships simultaneously.

The next decision point occurs after the ship is unloaded at D_2 at time t = 9 (assuming a one day unloading time). Figure II shows the position of the ship at t = 9 and the available voyage links and sea times.

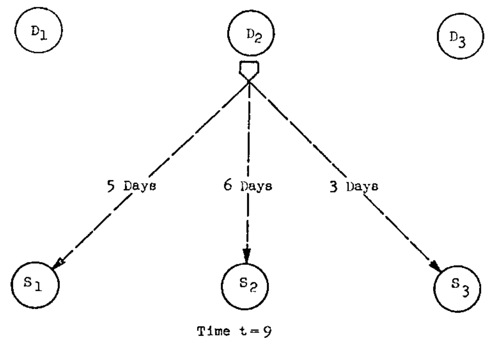
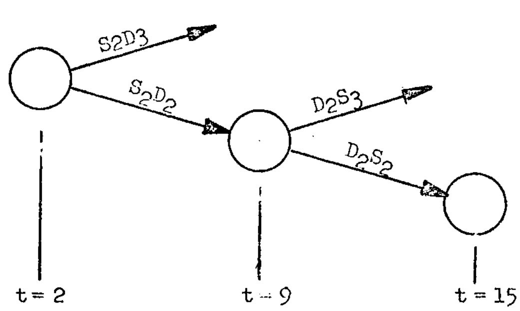


Figure II

Assume that the production inventory at S_1 will not be sufficient for the ship to pick up a full load before t = 18 and that storage capacity will be exceeded at t = 30. For S_2 the earliest date for a full cargo pick up is t = 14 and the latest date t = 26. For S_3 the earliest date is t = 11 with t = 34 the latest date. The decision table at time t = 9 would be as follows:

VOYAGE	SEA TIME	ARRIVAL DATE	EARLIEST DATE (FULL CARGO)	LATEST DATE (OVER FLOW)
D_2S_1	5	14	18	30
D_2S_2	6	15	14	26
D_2S_3	3	12	11	34

The above table indicates that there are two supply points S_2 and S_3 which can provide a full cargo and have zero vessel idle time. The simulation logic selects from all feasible supply points that supply point which will overflow first, i.e., the earliest projected overflow time; S_2 would be chosen. Refer to the decision tree illustration below.



The decision node from the branch S_2D_2 is at t = 9. Since two permissible voyages with zero idle time are possible at t = 9, two branches emanate from this node. The branch selected is D_2S_2 which connects to a node representing the next decision point, i.e., at t = 15 assuming a one day loading period.

This iterative procedure continues until the scheduling period is completed or until an impasse condition is reached, e.g., demand location inventory runs dry, overflow at supply point, etc. If an impasse is reached, the impasse is noted and the user either directs the system to a previous decision point (node) where an alternate selection exists or modifies existing data and continues along the present branch. Whichever alternative is chosen, the system again performs sequential decision-making iterations until a schedule is obtained or another impasse condition reached.

The above illustrative example does not include multiple vessels, vessel cargos, inventory levels, idle times, chartering of additional ships, sub-chartering of owned vessels or dry-docking. These factors are included as an integral part of the selection process at supply and demand points in the Tanker Logistics System. However, for the sake of simplicity and clarity these options have not been included in the illustrative example.

Mode of Operation/ Communication Techniques

The model was designed to be used in an interactive environment by people having little or no knowledge of computer operations and techniques. The successful use of the model necessitated its being as simple as possible in structure with an operational language which was easy to understand.

The most practical communications technique was one by which the personnel responsible for tanker operations would be able to visually monitor the scheduling process as decisions were made, either by the user (in an interactive mode) or by the computer (in an automatic mode). As a result, the model was implemented using an in-office CRT with an attached hard copy, non-impact printer.

Prior to the preparation of a schedule, the user makes all required modifications in the four "static" data files; namely,

1. Supply Location File
2. Demand Location File
3. Vessel File
4. Voyage Link File

Having set these data files, the user then establishes an "Operations File" which initiates the scheduling for the desired period. When creating this file, the Tanker Logistics System program automatically requests the following data:

1. Scheduling to start at (Month/Day).

2. Inventory level in storage tanks at each location at time indicated in (1) above:

   Supply Location #1________(tons)
   "   "   etc.________(tons)

   Demand Location #1________(tons)
   "   "   etc.________(tons)

3. Vessel location. Sea time of each ship to next destination at time indicated in (1) above:

Ship Name	Destin-ation	Days from Destination	Cargo Tonnage
M. P. Grace	London	5.5	14,250
J. P. Grace	Trinidad	2.0	0

After the files have been loaded, the user may specify either location or time break points. These break points generate a program interrupt at either the specified times or when ships arrive at specified locations.

When commencing the schedule preparation, the user has three optional modes of operation which can be changed at any decision point during processing. These modes are automatic, semi-automatic, and manual.

(1) Automatic Mode - In this mode, the scheduling is done entirely by the computer using the program logic explained in the prior section of the paper. Processing continues until either the schedule is complete, an impasse condition encountered, or a specified time or location break point reached. The user then can review the schedule, and, returning to any desired decision point, start the scheduling anew by selecting any of the alternate decisions not chosen by program logic.

(2) Semi-Automatic Mode - In this mode, processing is automatic only for those decision points where no alternate choices exist without violating constraints imposed on the system by the "static" data files.

(3) Manual Mode - In this mode, scheduling is stopped at each decision point. The preferred program choice is indicated on the CRT as well as alternate choices which can be considered. The user can also interrogate the files at this point for inventory levels, demand requirements, supply point availabilities, and ship locations. If the user is satisfied with the program choice, a "continue" command is all that need be given. If an alternate decision is preferred, this can be implemented with a simple command such as "send to (location)".

In the interactive mode the user has three classifications of commands, namely retrieval commands, action commands and system commands. These commands can be executed at any point during the scheduling process.

Retrieval commands are used to obtain data relative to ship locations, current inventory levels and all other statistical information relative to the entire network at any given point of time in the scheduling algorithm. This information can be obtained selectively or in total using one of five available commands.

Action commands are used in the interactive mode to activate the scheduling process. These can be used either to continue the processing under program logic or make any desired modifications. These actions are initiated using one of five available commands. Included in these action commands is the capability to override parameters contained in the "static" files. These modifications affect only a specific decision point.

System commands are used for file maintenance and for establishing mode of operations/breakpoints/etc.

The Tanker Logistic System provides a log of all decisions that have been made. This log is available as a reference for tracking the sequence of decisions as the scheduling progresses.

Decision Point Number	Time	Action Status
(21120)	12/4 PM	JPG sent to S01 with 0 tons Tank level at D04 is 13413 tons after transfer at 12/4 PM 12/9 PM WRG arrives at S02 with 0 tons
(21121)	12/10PM	WRG sent to D02 with 9350 tons Alt. Dest: D15 Tank level at S02 is 3047 tons after transfer at 12/10 PM 12/14 AM MPG arrives at S01 with 0 tons 12/14 PM WRG arrives at D02 with 9350 tons
(21122)	12/15PM	MPG sent to D15 with 14250 tons tank level at S01 is 15016 tons after transfer at 12/15 PM 12/16 AM JPG arrives at S01 with 0 tons

In addition to the log report, once an acceptable schedule has been generated, three reports are available. These are the actual schedule, a ship utilization report and monthly activity report.

Resources to Develop and Implement the Model

All the basic design work was performed by W. R. Grace & Co. personnel. The effort involved approximately eight man-months. After the design work was completed, manual calculations were performed to validate the design criteria.

Because of the complexity of the system, it was decided to award the implementation of the model to a software consultant. The Tanker Logistics System was programmed by Dr. H. E. Zellnik using the PDP-10 timesharing computers of On-Line Systems, Inc. Implementation of the Tanker Logistics System was completed in a period of five months.

The testing and validation of the Tanker Logistics System required two people for two months to input data and verify the model results.

Conclusion

The Tanker Logistics System is a highly interactive, man-machine system for determining feasible tanker schedules for the W. R. Grace & Co. ammonia fleet. In addition, this system provides a basic tool for quickly evaluating alternative schedules due to changing conditions in a highly specified and sensitive network.