SunRay V - An Intelligent Container Trucking Operations Management and Control System

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Abstract

This paper describes SunRay V, an intelligent system designed to support the container trucking companies in the management and control of their operations, especially during the planning. The purpose of the paper is to describe briefly the business domain, the motivation for computerisation, some of the main design considerations of the system and the constraint programming approach. The paper also presents some of the problems encountered during deployment, how they are overcome and the lessons learned from the process. Finally, it discusses some of the benefits that resulted from the operational use of the system.

Introduction

[1]Container trucking is a complex business due to the requirements imposed by the shipping agents, customers and the port. Due to the complexity of the business, usually only a few individuals in a container trucking company are skilled in deploying vehicles to truck containers, bearing in mind the constraints imposed by the various parties as well as the company itself.

SunRay V is a successful attempt to computerise this complex business using constraint programming to assist the human planner. The system incorporates all the constraints imposed by the various parties and seeks to optimise the scheduling based on a set of criteria imposed by the company.

The Domain

The container trucking business essentially provides a service for the transportation of containers by road. Container trucking companies, known as hauliers, are responsible for the whole process of container movement, and must co-ordinate the movement and documentation requirements of all the different parties involved: container depot operators (who lease out containers), customers (who pack containers with goods), shipping agents/lines (who transport containers by sea), port terminal operators (who provide vessel discharging and loading services) and other hauliers (who provide subcontracting services).

A typical order from a customer to a haulier is either export, import, transhipment or local delivery. The trucking company then has to create the order, plan, execute and monitor the container deliveries. The process is more complex if, as is frequently the case, the container is destined for (export) or originates at (import) the port, as vessel estimated times of arrival and container status must be monitored closely to ensure that departure closing times (export) or port clearing times (import) are respected.

Interaction with customers also plays an important role in the business process. Customers may call up the haulier to check the delivery status of containers or report the readiness of containers at their premises. Sometimes, customers may call up the haulier to cancel the order or make changes to the order. Moreover, most orders require that containers go through a sequence of movements (or 'legs') before reaching the final destination. For example, an empty container is moved from a container depot to a customer site, where the customer packs the container. The packed container is then transported to the port. Thus in this case, two separate legs are required. In other cases, containers may require temporary storage at warehouses, thus requiring further legs. The haulier thus has to monitor port-related information, container readiness and ensure that the deliveries conform to the deadlines imposed.

The operations process involves the delivery of the containers to different places with limited resources and meeting requirements. The resources used by the haulier to provide transport services are trucks (or towheads, or prime-movers) and trailers. The latter are used to carry the container during transport but may also be retained for a time at sites (usually customers) where there is no container mounting equipment. As a result of trailer retention, hauliers typically operate with trailer-towhead ratios of between 5:1 and 7:1 depending on the average trailer retention period. Trailers which are not in use are parked at one or more sites called trailer parks. Trailers, like containers, come in a number of lengths usually 20' (foot), 40' and 45'. A truck may have to draw, deposit or exchange trailers at a trailer park in order to configure itself properly for the next job, depending on whether the container is already on-trailer and the container size.

In capacity planning a haulier tries to determine how many jobs (or legs, or paid-trips) he can handle using his own fleet in the planning period (typically the next day). Depending on the resource availability and the job deadlines, some of the jobs may have to be sub-contracted to other (usually smaller) hauliers. The principal objectives of the haulier in pre-operations planning is to sub-contract as few jobs as possible and where necessary only the lower paying jobs (e.g. empty containers).

In operations scheduling a haulier dispatches jobs to the towheads (typically by voice radio). The dispatched jobs cannot follow a pre-planned schedule for any extended period as there can be a high variability in job execution times as well as late communication from customers on container readiness. There is then a need to reschedule frequently. The principal objective of the haulier in operations scheduling is to meet the job deadlines but at the same time make good connections between the jobs so as to avoid trailer changes and reduce inter-job travelling (deadheading).

Application Description

Main Design Considerations

Since SunRay V aims to support the entire work flow of the haulier business, starting from order processing, to data transfer with the port authority, from capacity planning to dispatching of jobs to towheads, the system must:

- capture representations of entities manipulated by the planners during planning, such as containers and towheads;
- support an architecture that allows interactive planning; and
- model and automate the planning process.

System Components

The major components of the system are as in Figure 1.

There are three main stages in the work flow which are supported by the system. They are the preparatory and monitoring stage before and during deliveries, the planning and dispatching stage during operations and the management control and reporting stage after delivery completion. In order to co-ordinate and support these processes, the application consists of several modules which are discussed further.

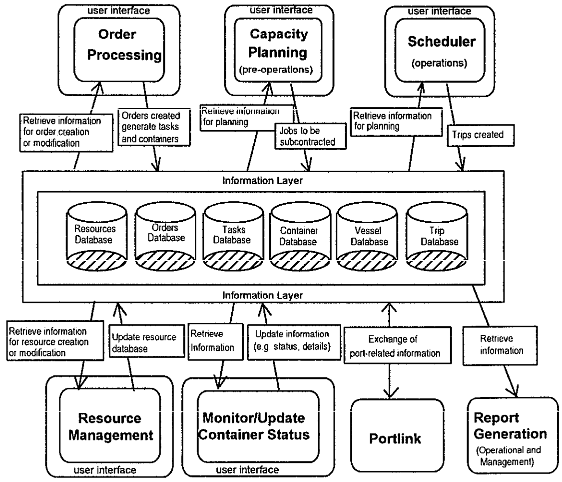

Figure 1. Architecture of the System

1. Preparatory and Monitoring Stage

Firstly, the order processing module has to ensure that customer orders are created, modified, monitored and deleted easily. From the order, the user can specify details such as delivery locations, requested timings and container information which is vital for the delivery. Excellent customer service is a top priority of a transportation company. Therefore, the haulier needs to provide accurate, real time information to its customer through the system. With the co-operation of the port, the portlink module allows port-related information to be exchanged between haulier and port by direct EDI link. This information exchange is automated and new information is propagated to the application so that human intervention is reduced to the minimum.

2. Planning and Dispatch Stage

There are two phases involved in the planning and dispatch stage. During pre-operations capacity planning, the system determines jobs to be subcontracted due to limited resources. There should be as few lower yield jobs subcontracted out as possible.

Although pre-operations planning can determine the bulk of jobs to be done, the situation during operations is too dynamic and therefore the planner cannot dispatch jobs to towheads based on a pre-planned schedule. Instead, (re-)planning is executed frequently based on a per-job schedule for each towhead, taking into consideration the dynamism of information flow and updates. Jobs planned for each towhead should meet the deadline imposed and at the same time ensure good connections between jobs. Job dispatch is guided and many search facilities and specialist functions are provided to make job selection and assignment flexible and efficient.

3. Management and Control Stage

To provide the management a view of the trucking operations, information on jobs, resources, customers and performance is presented on-line as well as by means of reports.

Representation for Operations

Object-oriented techniques are used to represent resources (towheads, trailers and drivers), entities (customers, locations, orders) and delivery orders (tasks, trips) as objects. The techniques help manage the attributes and operations of each object and their complex relationships. To further provide a layer of encapsulation to the application, objects are created at the information layer which binds these entities together logically. This allows natural association of attributes and constraints to be applied to these objects easily.

Representation for Delivery Process

Towheads and Trailer Parks

Towheads are limited resources that are used to deliver containers during operations. Towheads' availability are modelled so that only available towheads are scheduled jobs at any one time. There is a need to model the availability of trailers of each size and the throughput at each trailer park during planning. Therefore, each trailer park holds reservoir for each trailer size which can be withdrawn from or deposited.

Tasks

Each transport movement or leg of a delivery order is represented as a task. Associated with it are attributes which affects its execution. They are :

- start and end locations, opening hours, lunch operations, waiting time and location's problem are some of the information pertaining to each location.
- time windows for the task to start and end as requested for the delivery
- required trailer size
- trailer status (container on or off trailer) at the start and end location
- readiness status for the delivery

Tasks may also have precedence constraints between them (e.g. when executing the different legs of an order within the same planning period)

Trips

A trip is a planned/actual transport movement which is composed of usually 1 task, but sometimes 2 tasks. The latter, not uncommon case, arises from two kinds of trip saving performed by hauliers to optimise their resource utilisation :

- double-mounting : carrying of two 20' containers (usually empty) on a 40' or 45' footer
- container-reuse : matching of the return of an empty container to the yard with the request of an empty container of the same size from the same yard thus eliminating one trip.

A trip consists of at most three components (sub-trips) which are the setup-trip, deadhead-trip and paid-trip.

- a setup-trip models the optional unpaid-trip between the end location of the towhead's previous paid-trip and the trailer park with trailer hitching/unhitching activities
- a deadhead-trip models the optional unpaid-trip between the end location of the towhead's previous paid-trip or the trailer park (if the setup-trip exists) and the start location of the paid-trip.
- the paid-trip captures the transport (travel time between start and end locations) and non-transport related (location entry wait time, container mounting/unmounting, trailer hitching/unhitching) execution times which make up the overall execution time.

These components are illustrated in Figure 2.

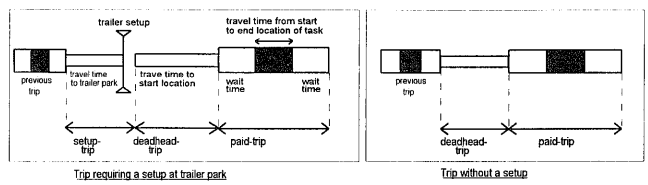

Figure 2. Graphical Representation of Trip

Relationship between Tasks, Trips and Trip-components

As an example, take the first leg of an export order :

Task : Truck an empty 20' container from a yard at location A (container on ground) to a customer's place at location B (container on trailer).

Trip : setup-trip (1 to 2) to pick up a 20' trailer at the trailer park deadhead-trip from (2 to 3) to pick up container at location A paid-trip (2 - 3) to truck container from location A to location B.

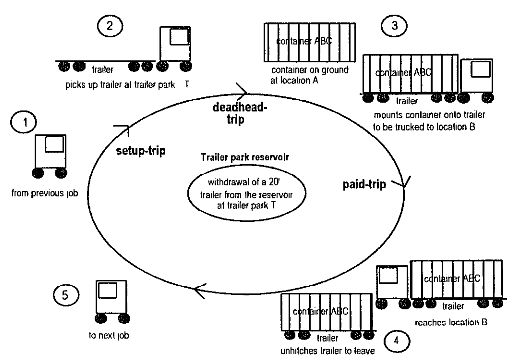

Figure 3. Relationship between Tasks, Trips and Trip-components

The Scheduler

The principal scheduling decision is the *connection* or the linking of an unassigned trip to the last of a towhead's already assigned trips in chronological sequence. The scheduling algorithm is thus to iteratively select possible and suitable connections until all trips are scheduled or no more connections can be made. The scheduling algorithm is implemented in a constraint programming tool (iLog Schedule/Solver) with customized constraints for propagation of resource utilization and connection feasibility information on connection.

An important measure in the evaluation of possible connections is the *connection-time* between two paid-trips, which is basically the execution time of the auxiliary trips of the successor paid-trip assuming the connection is made. The actual connection selection procedure takes into account a large number of considerations and preferences of the haulage industry but a simplified view is the selection amongst the following:

- for all towheads the connection with minimum connection time
- for the most urgent trip the connection with minimum connection-time which meets the deadline or minimizes the delay
- for the towhead with earliest assigned trip completion time the connection with minimum connection-time

Selecting connections on the basis of the first criterion produces schedules with excellent global (aggregate) connection-time (the main objective function). The others are required to ensure deadlines and load-balancing while maintaining good local connection times. Together they model the main criteria by which good human planners evaluate schedules. Note that the procedure is not an optimizing one. The justifications are:

- refinement procedures such as 2-opt can rarely better the produced schedules with respect to the primary objective function
- there are secondary objective criteria which contradict the primary objective which are best captured in the above framework
- the estimated execution times are subject to variability beyond what might additionally gained from rigorous optimization
- the response time of scheduling particularly in operations scheduling mode would be unacceptably degraded by rigorous optimization

The scheduling module is used in two modes. The first mode in capacity planning is to produce a predictive schedule within a given planning period for all paid-trips. In this mode every scheduling decision is prefaced by an additional optimistic capacity estimation of remaining towhead-time against required paid-trip time and an optimistic estimation of global trailer availability against trailer requirement. If there is insufficient remaining resources then the trips are ranked according to various criteria (mainly yield to the haulier) and the trips pruned accordingly. This step basically identifies the trips most appropriate for sub-contracting while eliminating needless consideration of trips which ultimately cannot be scheduled.

The second mode in operations scheduling is to produce an on-line schedule which assigns each towhead with one trip after the currently executing or completing trips. Here there is a trade-off between response time and the objective of low global connection time. In this case the scheduling module schedules for a certain period ahead and until all towheads have at least one trip. The excess scheduled trips are then ignored. The net result is that most of the consequences of a purely greedy assignment of only one trip per towhead are avoided by some, but not excessive, lookahead.

Scenario of Use

When the haulier receives orders from his customers, the orders are created using the Order Processing module which then generates a list of tasks according to required delivery instructions and latest vessel-voyage information. These tasks can then be planned and executed when they are of ready status. The status of the tasks can be monitored and updated via the Monitor/Update Container Status module. For tasks that depend on port information such as the discharge status of the container, the Portlink module updates the status automatically for these tasks.

When tasks are ready for execution, capacity planning is done by the Capacity Planning module to gauge the jobs to be sub-contracted to other hauliers due to limited resources and stringent deadlines imposed.

The scheduler module is also responsible for dynamic scheduling of tasks to towheads during operations. After a task is dispatched and executed, a trip is created to record the activity, and the status of the container and order pertaining to that task are then updated accordingly. For example, when an empty container is delivered to the customer for packing of goods, the status of the container is then updated to be at the client's premise and the execution of the next task of the order (from the client's premise to the port) depends on the readiness of the container after packing and the vessel's departure from port. The status update is updated via the Monitor/Update Container Status module.

The Portlink module is responsible for receiving latest port-related information from the port so that the default timings of the tasks can be generated based the updated vessel's information or entry times to the port automatically.

The system can also generate operational and management reports to help in decision making process. The reports can also generate drivers' performance analysis and incentive payments based on the captured operational information.

The Environment

The various modules of the system run as clients of a client-server relational database (Oracle) running on a TCP/IP network. In the first installation, the server is running SCO UNIX and the clients are running Microsoft Windows for Workgroup. Client modules maintain currency of information through special queries which allow efficient incremental retrieval of information. As the data is highly time sensitive, the clients are synchronised via a central time-server on the network.

The system uses object-oriented technology to encapsulate the domain. iLog Solver and Scheduler were tools employed to develop the scheduling component of the system. iLog Views was used to develop the User Interface. These tools were chosen as they are platform independent, allowing the software to be ported easily to other platforms like UNIX or OS/2. Rogue Wave DBTools.h++ was used to implement the database-object translation layer to ensure database independence. Borland C++ was the compiler used to develop the product.

Application Development and Deployment

Prior to the development of the system a prototype was developed within 3 months and presented to the haulier associations in Singapore. After an extensive (9 months) feasibility assessment, requirements gathering and product scoping effort, development of the system as a product for the haulier industry in Singapore commenced. Initial development involved 5 technical staff and took place over 12 months with a further 6 months of iterative refinement at the beta-customer site.

During the initial development process, knowledge acquisition was the main hurdle to cross due to problem complexity, lack of operational knowledge and the ad hoc work process of many of the hauliers. However, constructive interactions with the beta-customer helped to clarify the various processes so that knowledge can be better represented during system development. The knowledge acquired also enables the scheduler to model the human controller using constraint programming and heuristics to automate the planning process.

Problems Faced

During the deployment phase, the experienced planners were initially reluctant to use the system to assist them to plan jobs for their towheads. Their reluctance stemmed from a number of factors:

- lack of familiarity and proficiency with computers
- their perceived superior planning compared with the initial plans suggested by the system
- the fear of losing their sphere of influence in the company

Strong management support coupled with patient education and dedicated support of the users helped make the earlier part of the deployment easier. The situation then improved as the system planning quality improved and as the planners gradually realised the benefits of the planner and system working co-operatively together.

Although the system evaluation process enables the users to feedback requirements and enhancements, some of the feedback presented a problem as some were not technically or economically feasible. Thus change control management was required to evaluate the usability and expediency of the suggested enhancements. This management of change ensured that the system can be developed and deployed successfully.

Lessons Learned

With the implementation of a scheduling system, process flow in the company must change to accommodate to the new way of working. Spheres of influence of certain key individuals might be reduced. Users who are not computer proficient might feel uncomfortable with learning a new system. All these factors tend to fuel strong user resistance during the knowledge acquisition and system deployment phase. Therefore, it is crucial that strong support from top management must be assured before the system is to be implemented.

Change control management of enhancements to the system during the development phase of the system should be implemented early. Since thorough knowledge acquisition is not possible for complex scheduling systems, there will be new requirements, constraints and enhancements discovered during the course of the development and deployment. Implementing a control over these changes will ensure that the system will successfully deployed.

Application Use and Benefits

The system has been deployed successfully at CWT Distribution Ltd, one of the larger haulage companies in Singapore (deployments are in progress for two others). CWT has a vehicle fleet of about 30 towheads and 220 trailers and handles about 500 jobs per day. Although the system has been in operation for only one year, significant benefits have been realised. Through the use of the system, the management is now able to manage the trucking operations in a more controlled and systematic manner. Pertinent information related to orders, resources, customers and performance are available on-line as well as in the form of reports. This information enables the management to keep abreast of all important aspects of the operations and be in control.

A key aspect of a haulier is to provide quality services to its customers through timely delivery of orders and the provision of timely and accurate information to them. With the help of the system, the company is able to achieve this goal as each job is tracked from the time the order is created to the time the job is completed. In addition, the system ensures that jobs are scheduled to meet customers' requirements, deadlines imposed by the port and other parties, and at the same time, optimises resource usage and improve efficiency.

Most hauliers in the industry rely heavily on the planners to perform planning and dispatching. This over reliance becomes a problem when the experienced planner resigns or retires. In such scenarios, the haulier will incur loss of grade of service and operational efficiency while another planner is trained (on the job). With the system, a new planner can deliver a minimum level of service and efficiency. On the other hand, the experienced planner is relieved of tedious yet complex tasks as the workload gets heavier, allowing attention to be concentrated on higher and longer term planning activities.

Benefits

After the system has been deployed at CWT Distribution Ltd, the company has seen an improvement in their monthly throughput. This is achieved mainly through controlled sub-contracting criteria applied during capacity planning stage and the efficient use of resources during operations.

Previously, the users need to dial-up to the port's interactive database system to enquire about vessel information, container details and other port-related information. The system helps streamline the information exchange between the haulier and the port through an EDI link enabling automatic and timely exchange of port-related information and automatic update of the orders.

Prior to the system, order information was recorded on paper and this proved to be tedious and error-prone when information needs to be modified or retrieved. However, by entering this information into the system, on-line information such as job status, port schedules and container details can be provided to the users efficiently.

The information is also used in the generation of management reports for analysis and management decision making (such as resource acquisition). As a result, the company has increased the productivity level of its employees through computerisation.

Payoff to Date

According to a statement by Mrs Lynda Goh, Financial Controller of CWT Distribution Ltd, since the deployment of the system in early 1996, the company has achieved tangible benefits from the use of the system.

> "With SunRay V, we had achieved substantial improvement in revenue yield for our fleet of prime movers. For 1996, we had experienced a 10% to 15% improvement in average revenue per prime mover. This was achieved by intelligent job allocation and scheduling made possible by SunRay V.
>
> Operating capacity of operation control team has been enhanced by one third, with the system driven operation management through SunRay V."

(According to the CWT Distribution Ltd Annual Report 1995, the revenue for the transportation division of the company was S$17.79 million in 1995.)

With the system, the company is also able to accept more trucking orders without having to increase its present staff strength. The system has helped reorganize the business work flow by introducing more systematic and controlled procedures. This has helped the container trucking department receive the ISO 9000 certification in 1997.

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