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 job readiness. There is then a need to reschedule frequently. The principal objectives of the haulier in operations scheduling is to meet the job deadlines but at the same time make good connections between the jobs which minimize trailer changes and inter-job travelling times (deadheading).

Some of the more detailed considerations of container trucking operations will be revealed in the discussion of the SunRay V scheduling module.

SunRay V

SunRay V is a Windows-based product which supports container trucking companies (hauliers) in the management and control of their operations. SunRay V is already installed and operating at its first customer site, CWT Distribution Ltd, one of the largest transport service providers in Singapore with 30 towheads, 220 trailers and about 500 jobs a day. Further installations in Singapore are expected shortly.

SunRay V provides the haulier with comprehensive support in customer order processing, electronic data interchange (EDI) with the port, capacity planning and sub-contracting management, job scheduling and dispatch and order tracking and update. The extensive information captured from operations enables accurate billing of customers and computation of driver incentive payments as well as timely analysis by management.

An important part of the capacity planning and operations scheduling functions is the scheduling module. This module uses constraint programming technology based on Ilog Schedule and Ilog Solver to schedule container trucks efficiently taking into account the numerous haulage constraints, considerations and preferences. Designed as an intelligent assistant, it is able to relieve the human controller of many tedious yet complex tasks during planning as well as during operations, leaving him to concentrate on more critical decisions that require human judgement.

SUNRAY V SCHEDULING

The following sections overview the modelling and problem solving approach in the SunRay V scheduling module.

Towheads & Trailer Parks

The towheads are typical *unary* resources (in the sense of an Ilog Schedule unary resource). However, for the trailers what must be modelled is the availability of trailers of each size at each of the trailer parks. Each trailer park then holds a *reservoir* resource for each trailer size which can be withdrawn from or deposited to. In Ilog Schedule 1.1 this has to be modelled as a linked pair of *provide-require* resources. Complementing the set of trailer reservoir resources for each trailer size is a parking reservoir resource for the trailer park. Withdrawing from the trailer reservoir automatically deposits to the parking reservoir and vice versa.

Trips & Tasks

A task is a *requested* transport movement derived directly from the customer order. Associated with it are attributes which affect how and when the task will be carried out. Principally these are:

- start and end locations
- time windows for the task start and end
- required trailer size
- trailer status (container on or off trailer) at task start and end

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

A paid-trip on the other hand is a *planned/actual* transport movement which is composed of usually 1, but sometimes 2 tasks. The latter, not uncommon case, arises from two kinds of trip saving performed by hauliers to optimize their resource utilization:

- double-mounting - carrying two 20' containers on a 40' trailer
- container-reuse - the matching of the return of an empty container to a yard with the request for an empty container of the same size from the same yard thus eliminating one trip

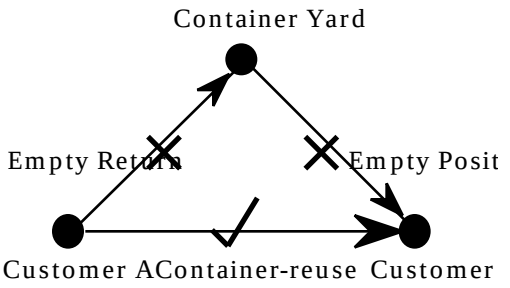

Figure 2. Container-reuse

The refore, a critical step performed by SunRay V before actual scheduling is to identify the best pairings of tasks to minimize the number of trips.

A paid-trip has similar attributes to a task, derived / constrained from the attributes of the component tasks. In addition, three *variables* (in the sense of an Ilog Solver constrained variable) model the assignment of a trip to a towhead resource:

- a towhead variable
- predecessor and successor trip variables representing the sequence in which the trip is executed by the assigned towhead

The paid-trip also captures the transport and non-transport related execution times which affect the overall execution time. These are composed of:

- average travel time between start and end locations
- average location entry wait times (the start entry wait time is variable as an entry may not be required if the towhead was previously already at the start location)
- average location container mounting / dismounting times
- average trailer hitching / unhitching times

When the paid-trip may be scheduled also depends on opening times of the locations which varies by the day of the week.

Associated with each paid-trip are two auxiliary trips:

- a *setup-trip* - modelling the optional *unpaid-trip* between the end location of the towhead's unknown predecessor paid-trip and an unknown trailer-park together with trailer hitching / unhitching activities
- a *deadhead-trip* - modelling the optional unpaid-trip between the end location of the towhead's unknown predecessor paid-trip *or* an unknown trailer-park and the start of the paid-trip

During scheduling one or both of these may be eliminated depending on the start location / trailer configuration of the paid-trip and end location / trailer configuration of the predecessor paid-trip.

Both tasks and trips are *activities* (interval activities in the sense of Ilog Schedule). On assignment to a towhead, both the paid-trip and auxiliary trips (if non-null) *require* the towhead resource. In addition, if the setup-trip is non-null trailers may be withdrawn and / or deposited at the trailer park at the setup-trip end time (as soon as the trailer lengths involved are known).

Connections & Scheduling

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 suitable connections until all trips are scheduled or no more connections can be made.

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

- the estimated execution times are subject to variability beyond what might be gained from optimization
- the response time of scheduling particularly in operations scheduling mode would be unacceptably degraded by optimization

Scheduling Modes

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 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.

CONCLUSION

SunRay V has been deployed and provided the following benefits:

- systematic management & control of operations
- increased fleet handling capacity and yield
- improved timeliness of execution of orders
- better use of planning and operations staff
- availability of information for more effective management

In particular, the scheduling module has enabled a rigorous approach to capacity planning and subcontracting which was not possible before the deployment of the system. Improvements in yield have already been realized and management is now confident that the level and job-mix of sub-contracting is appropriate.

In operations, the scheduling module has demonstrated increased emphasis on meeting of deadlines with effective connections which has translated into more timely deliveries.

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ACKNOWLEDGEMENTS

The author would like to thank the following who have made the development of SunRay V possible:

Management and staff of CWT Distribution Ltd for their support and valuable input, especially: Ms. Lynda Goh, Mr. Tang Ah Kok, Mr. Lee Soon Heng, Ms Jesslyn Heng, Mr P. Sankaran, Mr. Lim Kian Ann and Mr. Christopher Yeo.

SunRay V team members for their ingenuity and boundless energy in realizing the product: Chew Keng Wah, Ian Chia, Koh Mei Leng, Ina Ng, Vijaykumar Shah, Chris Yeung (Clarity Systems) and Chew Hong Gian and Goh Lih Wee (Information Technology Institute).

Ilog Singapore for their technical support and input on the use of the Ilog Schedule/Solver product, especially Mr. Vincent Gosselin.