Scheduling of Marine Resources in the Port of Singapore Authority: A Total Approach

Goh Kwong Heng, Goh Kah Seng, Lye Chee Whye, Tan Puay Hwa, Tay Eng Kiang

Port of Singapore Authority
7B Keppel Road #08-07/12
Tanjong Pagar Complex, Singapore 0208
Republic of Singapore
Tel: 65-3211303
Fax: 65-2248454
email: emsd@technet.sg

Abstract

The Port of Singapore Authority (PSA) is one of the busiest and most efficient port in the world. With about 300 vessels calling at Singapore everyday, a fast and efficient allocation of marine resources to assist the vessels in navigating in the port waters is essential in maintaining its lead and competitive edge over other ports. Scheduling these marine resources, such as pilots and tugs, is a complex task requiring the consideration of numerous constraints and factors. The olden days of manual planning using pen and paper was erroneous, uncoordinated, and slow in coping with the rapid increase in the vessel traffic. This paper describes an expert system that uses heuristics to assist human planners in the scheduling of pilots and tugs to service the vessels in Singapore.

Introduction

This report describes the Pilot and Tug Scheduler (PATS), a fielded application running 24 hours at the Port Operation Centre (POC) of PSA which generates schedules for the two marine resource types, namely the pilots and tugs.

The scheduling tool includes an automated scheduler capable of generating a reasonably good set of schedules. It also comes with a comprehensive and user friendly graphical user interface (GUI) which represents the information in the form of a gantt chart. This gives the planner a graphical and more realistic view of the resource schedules as compared to the old system where information was printed on a text-based worksheet. The GUI allows planners to alter the schedules generated by the automated scheduler. The need for human intervention is attributed to the fact that the schedules generated by the automated scheduler are not always completely optimal, the human planner may wish to reassign some jobs if he has a better plan. Another reason for the need for human intervention is that, due to the dynamic nature of the operations, there are occasional cases of last minute amendment that require the immediate attention and reaction of the human planner. Availability of transport also poses another problem as sometimes there is not enough transport to support the generated plan.

Object oriented techniques were used to facilitate the implementation of an extensive graphical interface and the representation of the complex real world objects manipulated by the human planners during planning. These techniques help manage program complexities through high-level date abstraction and encapsulation while providing for a high degree of code reusability.

The language used for the development of the system is Objective C®, a powerful and flexible object-oriented language, which adds object-oriented features to C without losing or changing any C language capabilities. The GUI was developed using XView wrapped in Objective C classes for easy programming. The database management system used is SYBASE®, a relational database system which uses Structured Query Language (SQL).

Domain Description

The Port of Singapore, being a global port, is a focal point for more than 600 shipping lines which link more than 800 ports around the world. The island's strategic position and the port's efficiency has made the Port of Singapore one of the busiest and most efficient port in the world. There are an average of about 300 vessels arriving and departing from the port everyday. To strive for excellence and maintain its top ranking in the world, it is important for

PSA to provide a fast and efficient system of allocating marine resources to the vessels.

A vessel may require a few marine resources from the PSA during its stay in the port. These services use resources such as pilots and tugs which are indispensable in navigating a vessel to its destination. Before a vessel arrives at the port, the shipping agent will place an advance order for pilot and tugs through PORTNET, a fielded EDI system from which shipping lines can place marine orders directly. The service required time, location and destination of vessel, vessel characteristics and special remarks are some of the information captured for the scheduling of pilots and tugs.

Pilot

Pilots are ship handling experts who are very familiar with the port water. They are required to navigate vessels in the port. Pilots are classified by qualification. The qualification required will depend on the vessel type and size. A piloted job duration may range from 1 to 3 hours depending on the location and size of the vessel, the level of difficulty of the job, and the prevailing navigational conditions.

Tug

Tugs are powerful marine crafts that are required to assist the vessel in berthing and unberthing at the wharf. A ship may require up to a maximum of 6 tugs for a berthing or an unberthing operation. The duration of a tug job may range from 20 to 60 minutes. Tugs are classified by their horse-power and types. Bigger vessels will require the services of more powerful tugs, while some vessels require tugs with certain special capabilities, like a tractor tug, which can manoeuvre better than other tugs.

Scheduling Rules

Scheduling of pilots and tugs is not an easy task, requiring the experience and expertise of two resource planners working individually round the clock.

The main task of the human planners is to generate schedules for the two resource types based on numerous constraints such as:

- resources assigned must meet minimum requirements of vessels
- resources must not be worked overtime unless absolutely necessary
- jobs that depend on the tide of the day must be serviced on-time

At the same time, the schedule must comply as far as possible with planning guidelines such as:

- minimize the delay to the vessels
- maximize the utilization of the resources
- even out the workload of the resources
- minimize the travelling time and travelling distance of the resources

Performance Indicator

Providing high service level to the vessels is the main objective in scheduling the marine resources. Therefore, it is also essential that the planners ensure the optimal utilization of the resources. Service level is a measure of the percentage of number of vessels serviced within an acceptable delay threshold in the planning horizon. Resource utilization is a measure of the ratio of number of hours on the job to the shift duration. Hence, high service level or good resource utilization is a good indication of a well-planned resource schedule. Before the implementation of PATS, the human planners achieved about 90% in service level and about 60% in resource utilization (travelling between jobs and standing by at the resource base attributed to the other 40%).

Pilot and tug schedules are often affected by external events. These events can be cancellation of pilot or tug orders, change in service required time, and delays in vessel arrival or departure time. The planner must assess the impact to the schedules and make changes to the schedules if necessary.

Problem Description

Before the implementation of PATS, planning was very much localized. Planners scheduled the resources based on a worksheet which was printed out periodically showing the updated details of all the resource orders. Communication between the two resource planners were mainly verbal, and one planner did not know the other planner's schedule unless he requested for it. With the rapid increase in the number of vessels calling at the port, this manual planning system soon gave rise to the following problems:

- The rapid increase in the number of vessels had aggravated the workload of the planners. With this increase in workload, the planners were not able to produce schedules as good as before. They would be mentally overloaded with the distribution of resources and the progress of their jobs. It was expected that the load will soon be too heavy for human planners to allocate resources effectively and efficiently.
- The number of external amendments could be too voluminous at times for the human planners to cope with, thus affecting the quality of the schedules.
- Different planners, based on personal preferences and experience gained over the years, would produce

schedules differently from one another. As a result, there were no consistent set of rules and priorities for the scheduling of resources. In addition, the human planners might sometimes let their feelings for the resources hindered the generation of a good schedule.

- In the old system, the two resource planners work quite independently, each scheduling his own resources without the knowledge of the availability of the other resources. Supposing there is a vessel requiring the service of a pilot and a tug. There were cases whereby the pilot could be deployed for the job without knowing that the tug would only be available 30 minutes later. Thus 30 minutes of the pilot's time was wasted as he could not start his job without the assistance of the tug. This would lower the productivity of the pilot and might affect the service level, especially on a busy day. Another problem also arises when there are two vessels waiting to be serviced at one time, with only one pilot and one tug available at that time. Due to the lack of coordination, the pilot may be sent to service vessel A while the tug is sent to service vessel B. As a result, both vessels are not serviced at all.
- Planning based on worksheet meant that there was no real-time update of information. With the increase in number of amendments to the orders, the worksheets would become invalid quickly. The planners would then have to keep printing new worksheets to keep themselves updated with the latest requirements.
- The increase in load also resulted in excessive verbal communication, which was often prone to errors, between the two resource planners. It has also made the working place not so conducive to work in.

Solution

System Architecture

Figure 1 shows the new system architecture. The primary objective of this system is to provide a service level that is as good, if not better than the service level achieved by the human planner. At the same time the system ensures an optimal utilization of the resources.

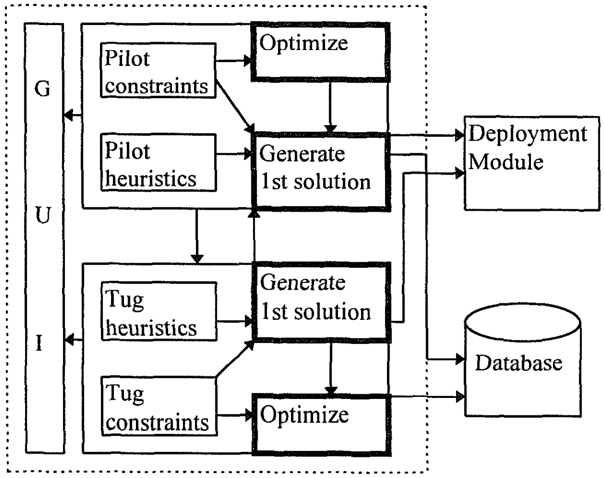


Figure 1. System Architecture of PATS

Pilot and tug planning are now integrated. The two automated schedulers will schedule the resources based on a set of constraints and heuristics, and also taking into consideration the schedules of the other resource type. Scheduling the two resource types is now done by one chief planner, thus minimizing the need for verbal communication.

Graphical User Interface

The user interface is designed to provide a graphical representation of the information to the planner. It is developed using an object-oriented library of graphics routines which sits on top of XView.

Information is presented on the screen in the form of a gantt chart, with orders for resources represented in the form of gantt bars. The length of each gantt bar denotes the duration of each job. Colours are used to represent different status of a job, i.e. whether the job is started, completed, and so on.

One of the main function of the GUI is to allow the alternation of the schedules generated by the automated scheduler. Other important functions provided include:

- activating the automated scheduler
- displaying statistics on the demand and supply of resources for the next 12 hours
- displaying statistics on performance of resources
- editing the duty roster of the resources
- sending job details to the resources through wireless network

Automated Scheduler

Scheduling of pilots and tugs is a complex combinatorial problem. A complete search using the "branch and bound" technique may not be feasible as the response time is critical. Another reason for the unfeasibility of using "branch and bound" technique is that it tries to generate a globally optimal solution (i.e. minimizing overall delays) which is sometimes undesirable for this system. For example, the technique may generate a solution whereby all jobs, except one having a delay of 40 minutes, are on time. Using the present scheduling method may produce a delay of 10 minutes on 5 vessels, resulting in a total of 50 minutes delay in the whole schedule. In this case, the second result is more desirable as PSA does not wish to delay any vessel for more than 30 minutes.

PATS handles the scheduling of pilots and tugs in a two tier process:

1. A first solution is generated using heuristic search.
2. The solution is then optimized through permutation.

During the first phase, vessel orders are first prioritized. For each order, PATS will select the best resource from a list of qualified resources to service the vessel. The first phase is completed when all vessels are assigned with the required resources. The selection criteria are based on heuristics that will help to achieve the primary objective of minimizing vessel delay and maximizing resource utilization. The set of heuristics for assigning pilots are as follows:

- select pilots who can meet the service required time of the job
- select pilots who have not done any job
- select pilots who are nearest to the job
- select pilots who requires the least travelling time
- select pilots who have ended their last job earliest
- select pilots with the least accumulated workload
- select pilots with the minimum qualification

The set of heuristics for assigning tugs are as follows:

- select tugs that are currently in the same region as the job
- select tugs that can meet the service required time of the job
- select tugs that require the least travelling time
- select tugs that are not currently performing a job
- select tugs with the minimum accumulated workload
- select tugs that are least qualified for the job
- select tugs that have ended their last job earliest

At each heuristics rule, some resources are eliminated if there are other resources that can better meet the requirement of that rule. This process continues until there is only one resource left or the last rule is fired. If the last rule is fired and there are more than one resource left, the first resource on the list will be picked.

Because of the strong heuristics used, the first solution generated is usually good.

The second phase tries to optimize the solution through permutation of the first solution. The first solution is a sequence of jobs (job list) to be performed by each resource. The permutation begins by swapping two jobs taken from two different job lists which have about the same service required time. The fitness for swapping the jobs are evaluated based on the delay (cost) incurred. If the overall cost after swapping is lower than that of the previous one, then the new schedule is accepted. The permutation process continues until it performs a pre-defined maximum number of permutations or the overall delay of the schedule is zero. Essentially, the second phase attempts to reach an optimal solution by changing the vessel priority sequence which may result in better job connection.

Object Design

Since object oriented techniques are adopted, all information are represented in objects. Some of the major objects represented in PATS include:

- objects representing the vessels
- objects representing the vessel orders, which have pointers to the pilot and tug service objects required by the orders
- objects representing the pilots and tugs
- objects representing the pilot and tug services
- object representing the job list of each resource
- object used to generate a schedule

The relationship between the objects is shown in figure 2 and 3.

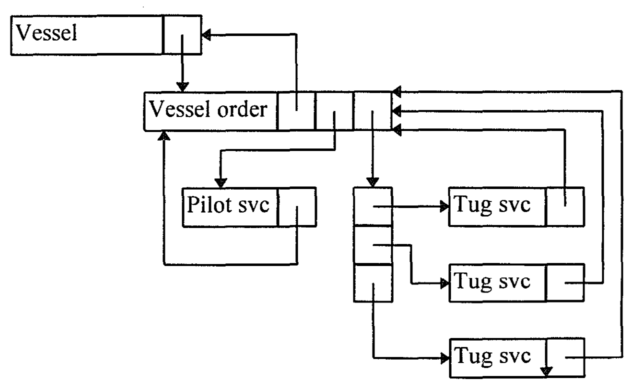


Figure 2. Relationship between vessel, vessel order, and the service objects

Each vessel object has a pointer to a vessel order object, which in turn points to the required pilot service object and a collection of tug service objects. Each service also has a pointer to reference back to the related vessel order object.

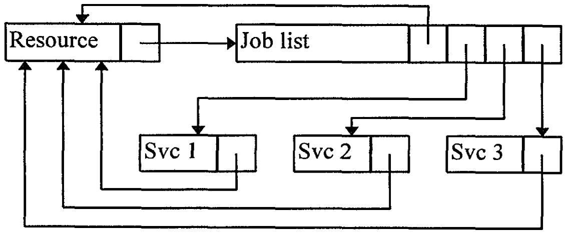


Figure 3. Relationship between resources and their jobs

There is an abstract class called Resource from which the classes Pilot and Tug sub-classed. All constraints of the system are built into these resource classes. Given a job, each resource object is able to determine, based on the set of constraints, if it is qualified to do the job. There is also a Service class from which the classes PilotService and TugService sub-classed. Each Pilot and Tug object has a pointer to its own job list (implemented using the JobList class) which stores a list of services that are assigned to the resource. Each service also points back to the resource object it is assigned to.

There is also a Scheduler class which contains all the logic and rules for generating resource schedules. The heuristic are represented in functions that are local to this class. Thus, the addition of a new heuristics requires only the addition of a new function implementing the required set of behaviours. Thus, impact on the existing codes is minimal This framework allows quick exploration of the use of different heuristics.

Database Design

The chosen database for the system is SYBASE, an SQL-based Relational Database Management System (RDBMS). The database adopts a client-server approach as the database server resides in a VAX-cluster, and PATS runs on a Sun workstation

The database server belongs to another separate PSA system called the Port Traffic Management System (PTMS), which centralizes all planning and operational information of the marine operation. The system is responsible for communicating with the existing mainframe system, which houses applications that are relevant for order processing and billing. Orders accepted will be passed to PATS via PTMS. Information on completed jobs is also sent back to the mainframe system through PTMS for billing. Figure 4 shows the relationship between these three systems.

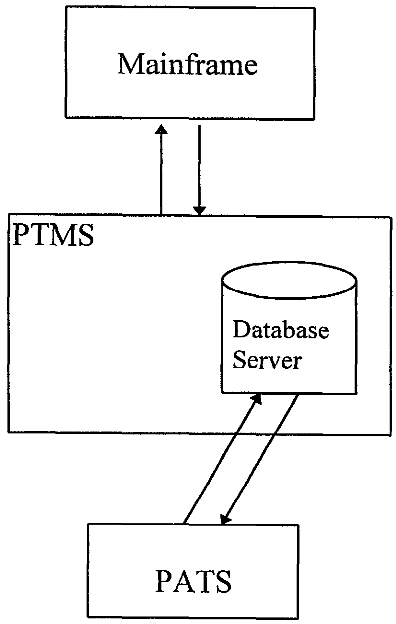


Figure 4. Relationship between PATS, PTMS and the existing mainframe system.

The data are organized and stored in an object-oriented manner. The tables in the database correspond closely to the objects in the application. For examples, data stored in tables like Vessel_Order, Pilot_Detail, Tug_Detail, Pilot_Service, Tug_Service corresponds to some of the objects in the application. The application will convert these information into objects.

Order and resource information is stored in the database and not in the applications. For instance, a new entry will be added to the Pilot_Detail table if PSA recruits a new pilot. This pilot will be available to the system for planning upon the retrieval of this information. Similarly, new orders accepted by the mainframe system will be translated into pilot and tug services. Upon retrieval, these services will be made known to the planner and appropriate actions will be taken to satisfy these requests.

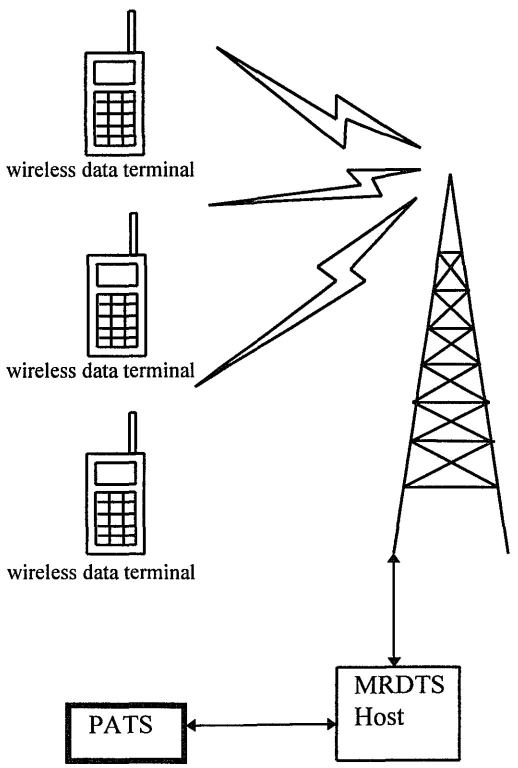
The database also stores information such as the estimated travelling time and estimated job duration that are relevant to effective planning. Preliminary results has shown that accurate estimates of these data drastically improve the accuracy and quality of the plans. This segregation of data from the application will allow the continual refinement of such data by the pilotage and tug experts without modifying the application.

Integration with Other Technology

To generate accurate and executable deployment schedules, the scheduler requires real-time feedback from the resources on their job status and any estimated delays and end time of their jobs. This is achieved by integrating the PATS with our Mobile Radio Data Terminal System (MRDTS) which facilitates data transmission between the resources and the scheduler through radio waves.

Every pilot and tug is issued with a hand held personal data terminal from which they receive job information and give feedback on job status and execution times.

Once the schedule generated by PATS is accepted by the planner, the jobs are sent to the respective resources through the MRDTS. The job information is then displayed on the resources' hand held terminals. Likewise, the resources update the scheduler on their job status by keying the information into their hand held terminals.



Criteria for Success

Three main criteria are used to gauge the success of PATS, they are namely the service level, the resource utilization and the percentage of schedules generated that are executable in the actual operation. The service level achieved should be at least 90%, the resource utilization should achieve at least 60%, and at least 80% of the generated schedules should be executable.

So far, the results have been very encouraging, PATS has achieved an average of about 95% on service level, 60% on resource utilization, and 85% on executable schedules. The planners are satisfied with the system. Their workload have since been relieved as they will now need only to make changes to about 15% of the generated schedules.

Implementation

The system is implemented on a graphical workstation (Sun Sparc). The introduction of PATS represents a major change in the established working style and habits of the planners. Moreover, the planners were familiar only with the traditional text-based applications, it was thus important that the new system and technology be introduced to them gradually to achieve a smooth implementation. Full management support, which was given since the initial stage of the project, was also a very important factor contributing to the success of the system.

The development of the system began in May 1992. The system was implemented in two phases. The first phase was implemented in June 1993 to introduce the GUI for manual planning. It took some time before the planners could get used to the graphical representation of information. The GUI had since improved the effectiveness of manual planning of the marine resources. The automated scheduler was delivered to the users in the second phase in December 1994.

Three months of trial runs were conducted from July 1994 for user acceptance prior to the implementation. Several problems, which were overlooked in the development stage, were uncovered in the trial runs. One of the problems discovered was that some of the rules were not refined enough. To formalize rules into program codes was not a straight forward task. There were some details that were missed out during the design stage. All these rules were re-looked into and rectified immediately. Another important point discovered during the trial run was that all information had to be complete and accurate for the auto scheduler to generate accurate schedules. Before the implementation of the scheduler, some of the planners did not update some minor information, like the estimated end time of a job, into the system as they could remember them. This had resulted in the auto scheduler generating inaccurate schedules. The planner understood the problem and agreed that the all information has to be fed into the system.

Payoff

Implementation of PATS has brought about numerous benefits to PSA, both tangible and intangible. The user department is very glad with the results.

By integrating the scheduling process at vessel level, i.e. coordinating the schedules of both resource types, both pilot and tugs will be sent to the vessel at a coordinated time. Unproductive time spent waiting for other resources is thus reduced to the minimum. This will also result in increasing the service level especially on a busy day.

Integrating the scheduling process also eliminate the need for verbal communication which was present between the two resource planners, making the work place more conducive to work in.

From about slightly over 200 moves per day when the project first started 3 years ago, to the present 300 moves per day, the increase in workload would be too drastic for the planners if they are still depending on only worksheets to do their planning. PSA would then have to sectorize the port into two in order to manage the marine resources effectively. Based on a study, an addition of five pilots would be required per day which means about ten more pilots have to be recruited. In addition, two more planners would also have to be employed for planning, one for each resource type. With the use of the system, only one chief planner is required to take charge of the two resource types. This configuration will be sufficient even if the present traffic volume is increased two-fold. Thus a saving of 3 planners and 10 pilots is achieved. The salary of a planner per year is about US$47,000, and that of a pilot is about US$43,000. This will imply a saving amounted to about US$571,000 per year. Thus, in less than a year, the cost of the project (about US$500,000) has already been covered.

With the automated scheduler, the planning time required has been greatly reduced. Besides, the human planner need not deal with the external amendments anymore as the amendments, except for those last minute ones, will all be incorporated by the automated scheduler. This enables PSA to cope with the rapid growth in the number of vessels arriving at the port.

The planner will be able to perform some additional tasks since he is now off loaded from performing manual planning and reacting to changes to the vessel orders, which are both tedious and time consuming.

A side-benefit of the development effort has been the formalizing of the planning rules used by the human planner. Formalizing the rules has several advantages. It allows the easy study of the rules for the purpose of refining them. With the set of rules well tested and formalized, training time required new planners will be greatly reduced. In the past, where most rules were unwritten, it took weeks of guidance before a new planner could be competence enough to produce quality schedules. New planners will now need only to go through the set of rules and learn to operate PATS. Within a week they should be good enough to take on the job on their own. Schedules generated by a formalized set of rules will also eliminate the element of bias, which was often present in manually produced schedules.

By integrating PATS with the MRDTS, the quality of the schedules generated has improved. MRDTS will now provide real-time feedback of job information to PATS. PATS will make use of this new information to generate more accurate schedules. Another added benefit of integrating with MRDTS is that the amount of verbal communication between the planner and resources have reduced drastically. Before the integration, planners had to deploy and send job information to the resource through VHF channels, and resources will also report back upon completing their jobs through the same mean. All these massive verbal communication will now be replaced by the more efficient and accurate silent data transmission.

The schedules generated by the scheduler will be useful to other systems in PSA. When marine resource contention occurs during peak hours, some vessels will suffer delay in pilotage or tug services. These information will be sent to another PSA system called the Berth Monitoring System for the adjustment of berth schedules.

While the system can produce schedules almost as good as a human being, the system at this stage would still has to be manned. Firstly, the schedules produced is not always optimal and there is a need to react to the last minute amendments. Another reason is that the planner will sometime need to respond to some special requests from the resources. The plan will then need to be manually overridden. There are also cases where a tug may breakdown in the middle of a job. The human planner will have to remove the tug from the list of available resources and assign another tug to take over the job.

To summarize, the payoffs of the system is significant in preparing the port to face the challenges ahead of it. It cuts down on manpower, reduces planning time, and also reduces training time for new planners. It better optimizes the resource utilization, and most important of all, is able to cope with the rapid and ever increasing vessel traffic in the port. The limitation of the system is that it still has to be manned by a human planner.

Costs

The project has a budget of about US$500,000. The project team consists of six staff, including one experienced resource planner. So far, 15 man-year of effort has been spent on the developing and implementing the system.

System Maintenance

During the three months of trial runs, feedback from every planner was gathered. All the feedback was incorporated and the rules were refined. Thus, the set of rules that the system has to date is quite complete. However, the rules are still expected to change over time due to more rules being uncovered and possible change in operational requirements.

Currently, the performance of the scheduler is closely monitored. Monthly meeting with the users are scheduled to obtain user feedback on any system or knowledge base related problems. Any need for refinement of rules will be done by the development team.

To date, three such meetings were held with the users. One problem they reported was that some planners were initially not comfortable with using the automated scheduler. The reason being, though the schedules generated provide high service level, it does not plan jobs the way some of them do. This is inevitable as no two planners plan alike. The set of rules the system has was gathered from different planners in the development stage and integrated to produce the best through many rounds of discussion. These resistance has since dampened when they became more familiar with the system rules.

Other points brought up were some minor refinements to the existing rules. The points were discussed and the rules were refined accordingly.

This monitoring process will continue for a year.

Future Enhancements

After the system stabilizes, the team will look into further enhancing the system. Among other areas, the team will be looking into integrating the system with a transportation system and exploring other AI techniques like fuzzy logic.

Currently, the schedules generated for pilots do not take pilots' transportation, i.e. launches and cars, into consideration. This has sometimes resulted in the generated pilot schedules not being able to be executed according to the scheduled time because of shortage of transportation. The planner will have to do a manual override in this situation. Integrating with an existing transportation system will be able to solve this problem. The system take the availability of the transportation into consideration when generating schedules for pilots. In this case, the schedules generated will even be more accurate.

At present, the rules in the system are very rigid. When a resource does not satisfy a certain heuristics, it is immediately not considered for the job. The development team will be looking into implementing fuzzy logic into the heuristics. This will undoubtedly improve the quality of the schedule.

Conclusion

Over the past few years, the number of vessels arriving in Singapore has been on the rise. On average, about 7500 pilotage orders and 6900 tug orders are serviced per month. The challenge to the system now is to be able to schedule the resources without causing a significant drop in service level to the shipping lines despite the increase.

From a technical viewpoint, the marine resource scheduling system shows an innovative use of expert system and object oriented techniques in a complex real world problem.

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