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DEVELOPMENT OF AN INTELLIGENT AGENT FOR AIRPORT GATE ASSIGNMENT

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ABSTRACT

The Aircraft-Gate Assignment Problem (AGAP) is a well-known Non-deterministic Polynomialtime (NP)-hard problem for optimization. During daily airport operations the arrival and departure times of flights may vary compared to their original schedules. This may require reassignment of gates to capture the dynamics of flights and gate status to enhance the level of services provided to passengers. For busy airports with high numbers of arrivals/departures, the assignment decisions must be made within a short time to capture all the changes. To satisfy this requirement, an intelligent agent for airport gate assignment (InGates) is being developed for this purpose for the management and assignment of gates at an airport for daily operations. The agent is aimed at performing the gate assignment for every flight, taking into consideration gate and flight dynamics, transfers, requirements of the airlines, aircraft types, airport operation rules, etc. A knowledge-based expert system forms the cores of the system and is connected to external databases for flight and passenger information. Real-time changes on airport gates and flights can be made through a graphical user interface, with the capabilities of performing real-time updating of the results and information. Data obtained at Singapore's Changi Airport is used to examine the performance of the system. Results obtained from the scenario analysis have shown that the system provides an enhanced way to assign gates at an airport. In the development of the next stage, InGates will be integrated with an optimization model to provide an integrated solution for planning and assignment of gates at an airport.

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INTRODUCTION

Airports around the world continue to face pressure to expand their capacities to handle increasing numbers of flights due to increases in air travel demand. The airspace will be more congested, and it will be increasingly difficult to site new airports or expand existing airports to cater to the growing demand for air travel. Therefore, efficient gate assignment is increasingly important because it would allow an airport to increase the capability of existing passenger terminal facilities and resources, as well as to cope dynamically and proactively with sudden changes which often take place in real-time operations. Through proper planning of gate assignment, level of service offered by airports can be enhanced.

Gate assignment is a complicated task involving the consideration of many factors. The assignment usually needs to be completed within a short time frame, and under such constraint an overall optimized utilization of airport gates is difficult to achieve. In technical terms, the gate assignment problem is combinatorial in nature, NP-hard, and cannot be optimized easily within a practical time frame. Past approaches have seen the use of simulation, mathematical programming, and artificial intelligence techniques. Results have not been satisfactory due to the uncertainties that could happen in real operations, where the necessary quick modifications to the gate assignment plan are needed.

Assigning aircraft to gates is an important task in airport operations. Although these activities may take only a small part of the direct cost of airline operations compared to flight operations, they might have a major impact on maintaining flight schedules or even the flight networks. Normally, based on the flight schedules, the airport has an established assignment that allocates aircraft to gates as well as specifies the apron time of aircraft at gates. Nevertheless, in daily operations, it is usually unavoidable for the airport scheduler to handle some unforeseen delays caused by various factors. Thus, there are usually needs to reassign the aircraft to gates for a specific period in future based on the real-time dynamics and special requirements from aircraft and airlines. This has to be accomplished in a short time period. On the other hand, in order to enhance the productivity and service level, the real-time assignment of gates is expected to be optimal in terms of minimizing passenger walking distance, baggage transferring distance, aircraft taxi distance, and the like. In this sense, the problem becomes a very difficult combinatorial optimization problem. As a result, an efficient Decision Support System (DSS) would be very helpful for daily operations. In this paper, the development of an intelligent agent for airport gate assignment by providing real-time decision support will be presented. With the limitations on real-time performance in mind, a hybrid framework is adopted to provide the needed efficiency and optimality of the solution at the same time. The core of the system is a knowledge-based intelligent agent incorporating a quadratic optimization model to achieve optimality of the solution.

The paper is structured in the following manner. The next section gives a review of literature on past studies and different approaches taken to solve the airport gate assignment problem. The methodology for the research is presented next, followed by the discussion on the structure of the intelligent agent. Knowledge represented in the intelligent agent will subsequently be discussed and then the validation of system performances will be presented. Finally, conclusions will be drawn based on the discussion in this paper.

REVIEW OF LITERATURE

Tosic (1992) gave a comprehensive review on modeling the Aircraft-Gate Assignment Problem (AGAP), which is normally formulated as a Quadratic Assignment Problem and is a type of well-known, difficult problem. Various researchers including Bihr (1990), Haghani & Chen (1998), and Mangoubi & Mathaisel (1985) have applied OR techniques to solve AGAP directly. These approaches have better assurance in terms of the optimality of the solutions, but substantial computation time is needed in obtaining the solutions due to the complexity and scale of the problem. In addition, these approaches also have weaknesses in handling uncertain information and multiple performance criteria. Xu and Bailey (2001) reported solving a test-case problem using the tabu search technique, which resulted in a significantly shorter time in getting the solution.

To overcome the shortcomings of OR-based approaches, knowledge-based expert systems were developed to solve the problem, such as Brazile & Swigger (1988), Gosling (1990) and Srihari & Muthukrishnan (1991). A knowledge-based approach is ideal for solving ill-defined problems through the use of heuristics reasoning. By using a knowledge-based system, the knowledge of experienced apron controllers in the airport, that is, the heuristics, can be captured in the form of production rules. A recognize-action cycle that uses information held in the rules will search for the right actions through either backward or forward chaining of the rules, thus allowing the consideration of multiple objectives and constraints in the gate assignment problem. Such a system can also be used to obtain an optimized gate assignment due to unforeseen events such as bad weather, mechanical failure, late arrivals and other unexpected events that would interrupt the original flight schedule. This type of approach can capture well the operation features, handle uncertain information, meet needs of real-time decision support, and more, but it has less assurance in terms of optimization.

In this paper, a hybrid approach, which combines both the knowledge-based expert system in the form of an intelligent agent, and an optimization model to obtain optimal gate assignment solutions is presented.

METHODOLOGY

Combining the intelligent agent and OR techniques, the development of an Intelligent Airport Gate Assignment System (called InGates) is discussed in this paper. A framework of InGates is designed based on the analysis of a real-time AGAP. Taking into account the complexity of the problem, the DSS consists of an intelligent agent module and an optimization module, as illustrated in Figure 1.

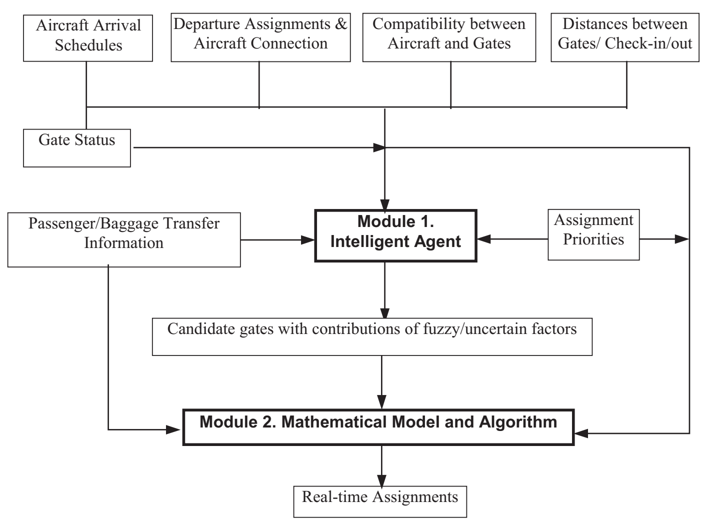

Figure 1. Flow chart of the system

The intelligent agent is developed to determine the candidate gates for every aircraft. These gates are selected through the consideration of criteria such as passenger and baggage transferring distance, operation rules as well as requirements from the airlines. The criteria are implemented in the form of production rules. This module aims to reduce the scale of the problem to make it easier to determine a final optimal assignment. With this approach, available gates will be assigned to aircrafts through consideration of factors such as the compatibility of the gates and aircraft, passenger walking distances, baggage handling distances, and conflicts between adjacent gates as well as aircraft passenger capacity. These are rules implemented in the expert system. The multi-objective function implemented in InGates is a combination of minimum delays to arriving aircraft, maximum use of contact gates with aerobridge facilities, minimum passenger walking distances and baggage handling distances, and minimum changes to a pre-established assignment.

The candidate gate list generated in the intelligent agent module will be passed to the optimization module to obtain an optimal assignment within the size limited by the intelligent module. This ensures that the solution will not be worse than any one concluded directly by the intelligent agent. In this paper, the emphasis will be placed on the intelligent agent module.

STRUCTURE AND DEVELOPMENT OF INTELLIGENT AGENT

An object-oriented approach is used to model the entities in the system. These include flights and gates. Each entity contains attributes that are mapped into the attributes of relevant objects, which inherit characteristics and values from their parents, that is, classes. The attributes are placeholders that contain values of specific characteristics associated with different objects. The class-object structure provides an easy way to add or delete objects in the structure as well as sharing of common characteristics and values.

Gate Class and Objects

Information such as gate number, gate group number, operation time, and aircraft type compatibility are the attributes used to describe the gate class of objects. To reflect the real-time changes in real operations, the system offers an interface, as shown in Figure 2, for users to set gate features whenever they need to. With this interface, users can set the operation time of the gate and limits for the gate to hold various types of aircraft if there is a need. Note that there are some aircraft types named as not assigned (NA), those are pre-set places for users to add new aircraft types.

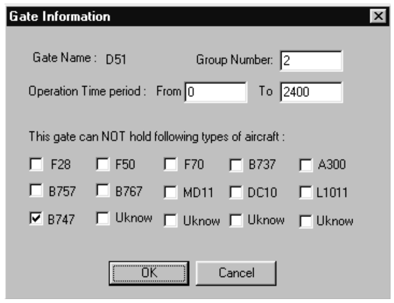

Figure 2. The stand information window

Flight Class and Objects

The flight class represents the information about all arriving or departing aircraft. For each flight, the information such as the flight number, arrival and departure times, terminal used, type of aircraft used, type of gate required, and any pre-assigned gate. In the flight information interface, as shown in Figure 3, users can set the flight features they need, such as arrival or departure time, arriving terminal, aircraft type, and expected gate type (remote or bridge), and current assignment for the flight (shown in the last line). This will allow the possibility of real-time modification of the flight information and allow the system to perform the optimal assignment based on the new information.

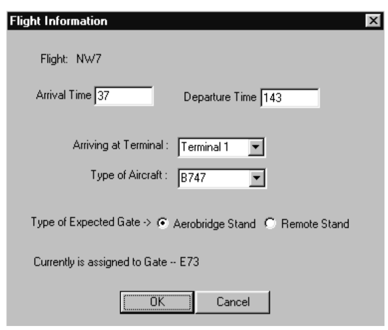

Figure 3. The flight information window

Based on the class-object structure shown in Figures 2 and 3, knowledge can be represented using production rules in the generic format of: A (and B) C.

The rule structure of production rules effectively captures essential cause-effect situations. These rules were developed based on the normal operation rules-of-thumb applied at the example airport used in this research. This information was obtained from interviews with apron managers and controllers, as well as documented domain knowledge from company records and operational manuals. For the rule given above, A and B represent conditions to be satisfied and C represents actions to be taken once the conditions are fulfilled.

Through the use of a graphical interface, the values and behaviors of objects can be modified at any time. Rules can be modified, inserted, or deleted during run time. The users can monitor the gate assignment progress and override recommended gates by InGates, if desired. The following are examples of how this can be done.

KNOWLEDGE REPRESENTATION BY RULES

The rules are implemented to capture the knowledge retrieved from domain experts. Production rules with if-then structure were used. To cater to the easy customization of applications in different airports, the rules interface was developed to allow users to make changes to rules during run-time and to avoid the needs of modifying the program. For instance, the rule "*Prohibit parking aircraft with sizes larger than A300 side by side among Gates C41, C43, and C45*" may be specific to an airport. Since the relationships among gates C41, C43, and C45 may be different from airport to airport, or even if there is no gate with such a name, rules like this need to be revised or even deleted when applying the system to a new airport. Even for the same airport, sometimes there is a need to revise the rule when changes occur, such as changes in configuration or airline requirements for example. As shown in Figure 4, this can be achieved by using a module that provides the users with an interactive interface to revise, enable or disable and add or delete rules on the run-time level.

Some rules are aimed at setting limits for gates and flights, as in the rule, "*Do not park B737 and smaller aircraft at gates F75, F77, and F79*." This type of rule can be revised in a similar manner by setting gates and flight information as presented previously. Rules can be turned on or off, or simply deleted, from the knowledge base. The conditions of rules can be changed easily. As shown in Figure 4, the object attributes of aircraft and gates can be used in the left-hand side (the IF portion) of the rules. The action of rules can be abidance, preference, avoidance, or prohibition, to reflect the necessary requirements due to the real operations. In the example given in Figure 4, the rule indicates that if the aircraft type is B747, the gates C41, C43, C45, D51, D53, and D53 should be avoided in the allocation. While these represent specific gate names given at a particular airports, in this example, at Changi Airport similar rules can be adopted easily to the real situation at different airports.

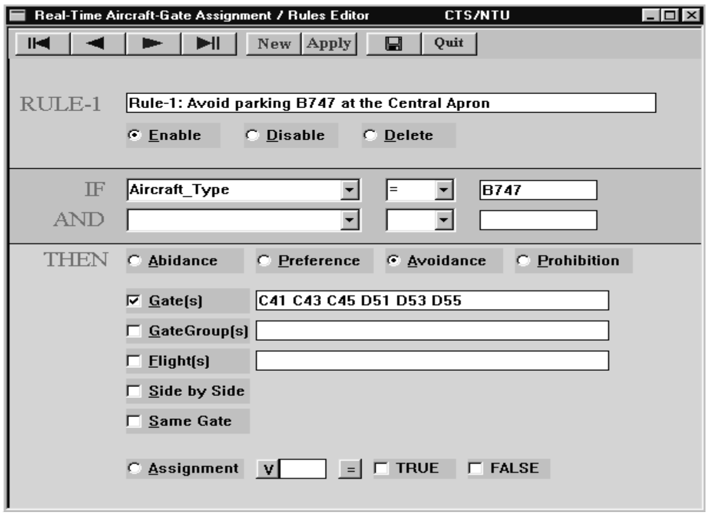

Figure 4. Interface of Rules Editor

Rules such as "*Wherever possible assign aircraft arriving between 0100/0500 at Gate Groups 1 and 2,*" as shown in Figure 5, are used for situations where preferences are to be satisfied as much as possible.

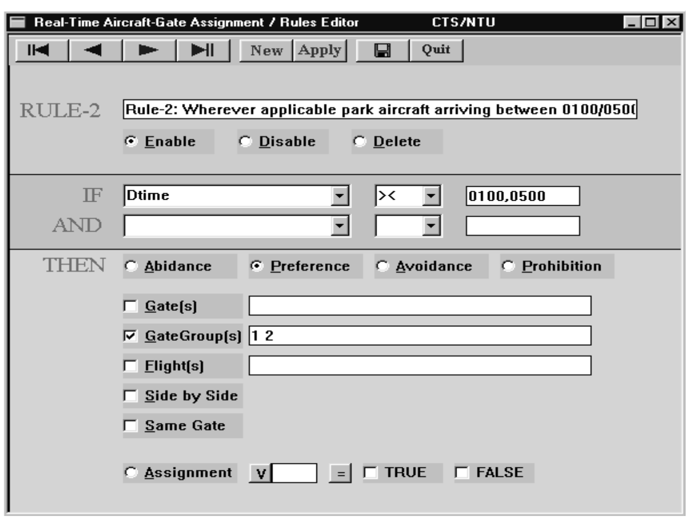

Figure 5. Edition results of Rule-2

To ensure the safety and operational separation of aircraft, the following type of rule is applicable. "*For aircraft with sizes larger than A300 and time interval of departure/arrival within 10 minutes, prohibit parking them side by side among Gates C41, C43 and C45*." This situation can be captured easily by utilizing the side-by-side restriction rule for gates C41, C43, and C45, as shown in Figure 6.

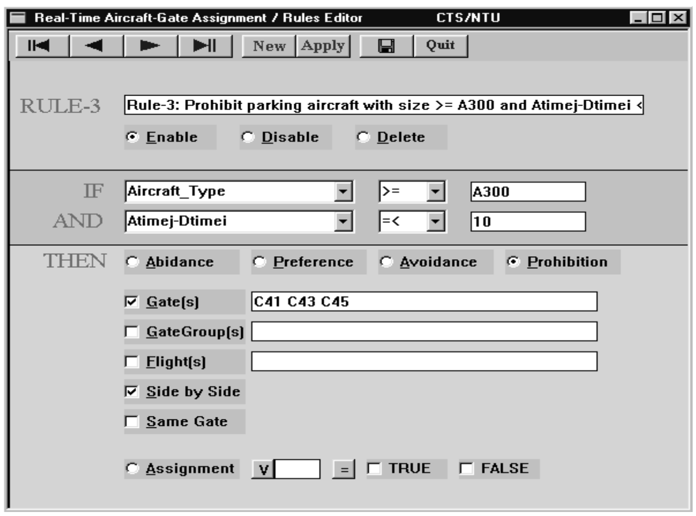

Figure 6. Edition results of Rule-3

In some situations, the system variables are defined as V1, V2, and so on, and are included in the rules. These variables can be used effectively to help control the logical relationship between rules. For example, as shown in Figure 7, users need only to key in the serial numbers of the ghost variables. This will allow the system to reinforce the pre-determined gate assignment by users, for example, for VIP arrivals at the airport.

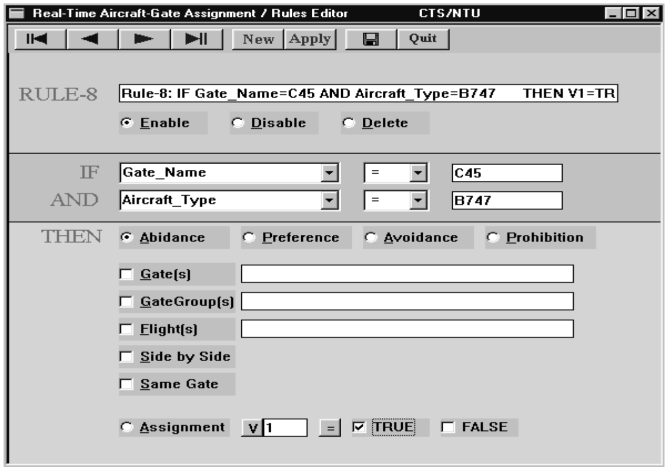

Figure 7. Assignment of system variable

VALIDATION OF SYSTEM PERFORMANCE

Thorough testing of model logic has been performed using a data set collected in a typical day of operations at Singapore's Changi Airport, with two terminals and almost 100 gates. The data set consists of more than 200 flights in a 24-hour period. The test performed on the data set has allowed the debugging and fine-tuning of the system. A comparison of the results from InGates and those obtained from manual assignment has shown that InGates is able to assign the gates in a manner similar to that of the human experts. The results illustrate that the objectives and the constraints stated above were satisfied. The computing time taken is just a few seconds on a mid-range PC.

The results of gate assignment can be displayed in either an airport map, as shown in Figure 8, or a Gantt chart, as shown in Figure 9. With the use of a Gantt chart, one can easily view the scheduled use and assignment of gates for different flights. The pictorial display of such assignment results is represented by an airport map, which provides the gate and flight information, as well as the availability of gates and assignment results, at any time of the day through the clicking of appropriate buttons on the menu.

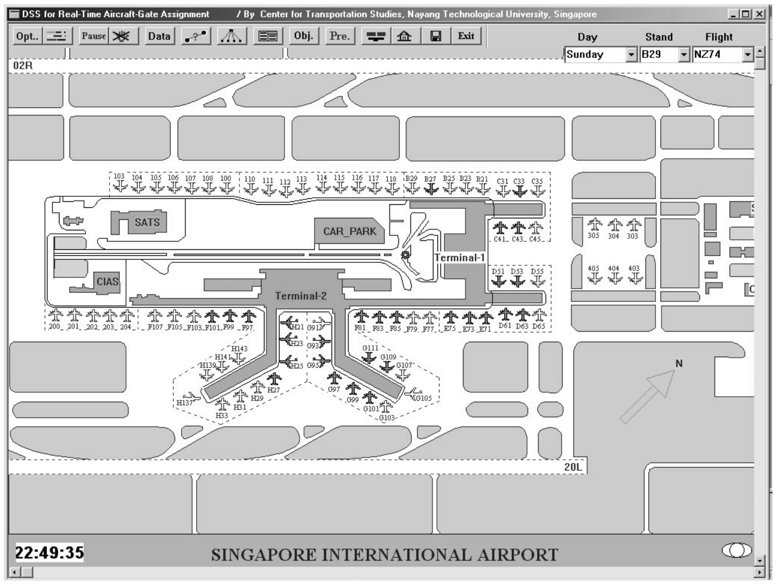

Figure 8. The airport base map showing the gates (aircrafts of flights allocated to gates are shown in red)

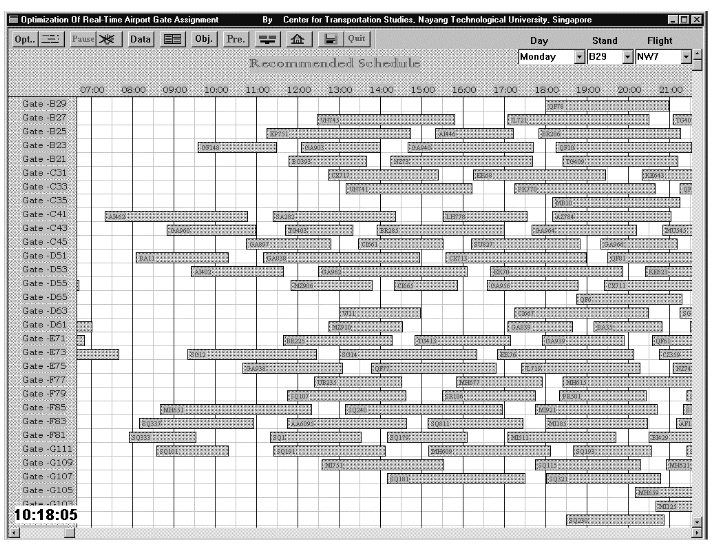

Figure 9. The Gantt chart showing the allocation results

CONCLUSIONS

In this paper, an intelligent agent for airport gate assignment (InGates) was presented. The structure and special features of the system were discussed, as well as applications to perform gate allocations to a set of data obtained from Singapore's Changi Airport. The results show that InGates is able to allocate gates to aircrafts of flights in a reasonably large and busy airport within a short time. Together with systems and tools designed to allow for real-time adjustments to data and settings used by InGates, it has the capability to function as a real-time decision support system for airport gate assignment. The results obtained from the intelligent system module of InGates will be used as input to facilitate the search for an optimum solution for the airport gate assignment program as the next step of the development.

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