A Multi Agent Based Model for Airport Service Planning

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Abstract: *Aviation industry is highly dynamic and demanding in nature that time and safety are the two most important factors while one of the major sources of delay is aircraft on ground because of it complexity, a lot of machinery like vehicles are involved and lots of communication are involved. As one of the aircraft ground services providers in Hong Kong International Airport, China Aircraft Services Limited (CASL) aims to increase competitiveness by better its service provided while minimizing cost is also needed. One of the ways is to optimize the number of maintenance vehicles allocated in order to minimize chance of delay and also operating costs. In the paper, an agent-based model is proposed for support decision making in vehicle allocation. The overview of the aircrafts ground services procedures is firstly mentioned with different optimization methods suggested by researchers. Then, the agent-based approach is introduced and in the latter part of report and a multi-agent system is built and proposed which is decision supportive for CASL in optimizing the maintenance vehicles' allocation. The application provides flexibility for inputting number of different kinds of vehicles, simulation duration and aircraft arrival rate in order to simulation different scenarios which occurs in HKIA.*
Keywords: *multi agent, airport service planning, vehicle allocation, optimization, simulation*

1. Introduction

In recent year, there is increasing number of air flights as well as passengers using air transport to travel to the foreign countries. In order to satisfy the increasing demand of using aircraft services, aircraft services provided by operators must be enhanced that the demand of usage of airport, like parking, maintenance, arrival and departure services, is increased. According to International Air Transport Association (IATA) (2004), worldwide the total air transport passenger was increased by 17.7% and freight tonne was also increased by 14.1% over the prior year in the first three quarters of 2004. Moreover, IATA (2004) expects total number of passengers using air transport will be increased to 2.2 billion, which is 0.6 billion more than the statistics in 2003. However, the size of the airports are limited and fixed which cannot be expended easily.

In order to satisfy the continuously increasing demand of usage, airport operators choose to increase the throughput of the airport by increasing number of departure and arrival rate of the runaway. In addition, a fact provided by Castrol et al. (2005) that all of the airport operators like to compare their business of their airports by expressing their throughput of passengers and cargos as well as the number of passengers processed and turnover of tons of air freight annually. The total annual income of the airport is directly proportional to these two factors, so they try any possible methods to increase the throughput of their airports. They aim to increase efficiency and effectiveness of handling aircrafts in the airport, just like reduction of ground operations time available for each aircraft in order to increase turnover of aircrafts can be served by the airport in a period of time. Mao et al. (2009) states that the ground services performed are planning, scheduling and control of all aircraft turnarounds at an airport.

However, this approach may increase the chance of delay in ground handling of the plane. According to Andersson et al. (2000), the increasing demand of air travel causes congestion and delays in the air traffic system become more and more common, especially in busy international airports. As one delay can cause chain effect like delay of arrival and the other planes cannot land to the airport on time that bad impression and dissatisfaction will be given to customer about both of the airport and airline company, airport operators want to prevent chance of any kind of delay occur during enhancing number of aircrafts they have served. Andersson et al. (2000) also states that delay uncertainty in the different parts and procedures in the airport makes airlines and air traffic service providers hard to manage passengers, fleets and crews correctly. In addition, increased congestion at busy airports results in significant financial and environmental inefficiencies. Each of the delay of the departure of aircraft leads costs to the airline company. It includes the aircraft delay costs, passenger delay costs and scheduled time cost. According to Janic (1997), the unit ground delay costs for European airlines were estimated as US$1330, US$2007 and US$3022 per hour for the medium, large and heavy sized aircrafts respectively. Similarly, for the unit delay cost of aircrafts in United States are US$430, US$1300 and US$2225 per hour for the small

sized, medium sized and large sized aircraft, stated by Richetta and Odoni (1993).
In this paper, the performance of ground service done by China Aircraft Services Limited (CASL) will be evaluated by developing a multi-agent system to simulate situations faced by CASL. The real data of the plane arrival and departure figures must be taken correctly in order different situations can be tested for evaluation accurately. Moreover, the results of the simulation can be the reference for the management of CASL to decide the vehicle planning in airport ground operations. This project focus on the aircraft ground handling issues. There are many activities involved in the operations and a lot of vehicles are used in performing the services, just like cabin cleaning and safety checking. In the project, overview of the ground handling processes will be reviewed for planning of the simulation. In the way of suggesting optimization of performing ground services, multi-agent approach will be applied for the simulation of the vehicle planning for ground services. The design of model must not be case-specified. It should be applicable for any possible combination of the vehicles allocation as well as number of aircrafts need to be served and their distribution. A lot of data are needed to be collection, like the arrival and departure of aircrafts and the resources available for CASL. The multi-agent simulation application in this project is designed by using JAVA programming language.

2. Workflow of ground operations

In every airport, there are a lot of airplanes landing and depart everyday. The duration of the planes stay in the airport is short. However, a lot of procedures have to be done before departure, including loading and unloading of luggage, refilling of fuel and water, safety check, and so on. The turnaround time for a short-haul flight is defined as the total time of an aircraft to complete full offloading, loading and the other services needed, including catering and cabin cleaning procedures (International Air Transport Association, 1997). However, according to Wu & Caves (2000), for long-haul fights, the turnaround time should include the comprehensive technical and cabin services time, which are the mechanical checking, refilling, cabin cleaning and other related activities.
The basic requirements of the ground handling processes, according to Kazda and Caves (2000), can be separated into three parts, which the primary objective of the ground handling processes is to ensure the aircrafts' safety. Meanwhile, the process of ground services include a lot of sequenced specialized activities, stated Kazda and Caves (2000). In order to perform the procedures, both of the high skilled engineers and specific equipments are needed. Therefore, the planning of the ground operations is much harder because having constraint of the limited number of skilled workers and equipments.
The ground services operation is a critical task in airport as simplified in Fig 1 and the flow shown in Fig 2. There is a constraint that the aircrafts have to be takeoff again after arrived airport. The time available for the ground services operation is aimed to be minimized in order to increase the turnaround rate of the aircrafts, increase the time of aircrafts in services, increase the number of aircrafts can be served in the airport and increase the efficiency of operating aircrafts. Generally, according to Kazda and Caves (2000), the required time planned for the ground operations during a turnaround should not be over 10 to 15 minutes for the short flights. Since the aircraft reaches the apron, firstly, all of the passengers and luggage have to leave the aircraft before performing any ground services and inspection because of ensure passengers' safety. Then, the aircraft is fuelled and cleaned simultaneously. After several time of cleaning and fuelling processes, when the environment is suitable, the catering service can then be performed. After all of these activities have finished, while the checking and inspection of the aircraft is ended and proved that the aircraft is save for the next journey, the passengers of the next journey are allowed enter the plane. Finally, the plane leaves its apron position, heading for the runway.
In the detailed version, according to Kazda and Caves (2000), the services needed to be provided by the ground services operators to the plane which is at its end station in apron during ground operations are to provide refueling of the aircraft, providing electrical power to the aircraft system, telephone and data connection, air conditioning, clean water, compressed water for starting of engine, transporting of baggage from and into aircraft and also the safety check. They take the ground services of handling Boeing 747 at an airport with a time constraint which the entire ground operation, from arrival to departure, is 60 minutes only. In handling a Boeing 747 aircraft turnaround, there are usually 19 procedures need to be done before the departure, excluding the procedures in checking of the aircraft,

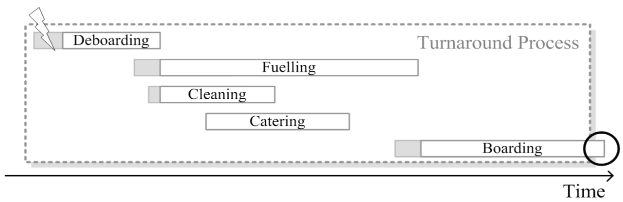

Fig. 1. Simplified version of the airport ground turnaround processes (Kuster and Jannach, 2006)

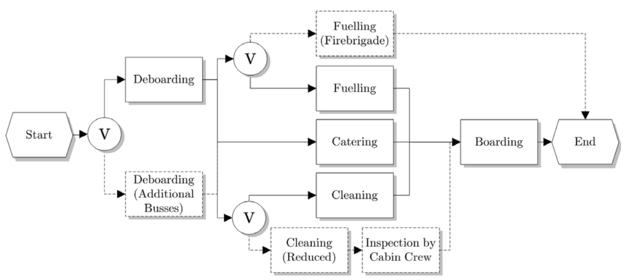

Fig. 2. Flowchart of ground operations processes (Simplified) (Kuster and Jannach, 2006)

which are shown in the figure below. Each of these procedures can be performed concurrently but some of these may need to follow a sequence. In the ground services processes, there are a lot vehicles needed to be used for performing these processes, including push back vehicle, baggage cart, catering services vehicle, cabin cleaning vehicle and lavatory service vehicle. In addition, electrical, water, conditioned air vehicles, fuel dispenser, shuttle bus and mobile passenger bridge cart are also needed if they have not built the ground at apron or the aircraft is parked at outer side in apron, while some of the tasks can be performed simultaneously. Decker (1996) also has a similar idea about the parallelism in the task structure of airport ground services.

3. Problem description

This project is focus on the optimization of vehicles planning for ground services for CASL. Therefore, it is needed to filter out the unrelated activities about the use of vehicles and focus on optimizing the activities involving the services vehicles and performed by CASL in HKIA, which are cleaning of the aircraft, services of potable water and tractor pulling services. In this project, the cleaning vehicles, water services vehicles and tractors will be focused in the optimization model. There are total ***N*** flights need to be served and **n** is the specific flights, $n \in N$, with estimated arrival, ETA_n, and estimated departure time, ETD_n, at specific time horizon ***t***, which will stay in different gates in the airport. The number of flights needs to be served by CASL is the same as HKIA's arrival and departure statistics.

There are three types of vehicles, cleaning vehicles x, $x \in X$, with the where x is the number of cleaning vehicles, water vehicles Y, $y \in Y$, where y is the number of water vehicles and tractors Z, $Z \in z$, where z is the number of tractors in services in apron of HKIA. T_{xn} is the service time of the cleaning vehicle x for flight n, T_{yn} is the service time of the water vehicle y for flight n and T_{zn} is the service time of tractor z for flight n. This model also minimize the flow time between each services of the maintenance vehicles, which is calculated as the starting time of the first operation to completion time of the last operation. It can also be described as idle time between each operation.

The main objective of the model is to minimize the total number of different kinds of airport maintenance vehicles in apron where the any late, including late in their services or late of aircraft departures, should be prevented. In the following statements, the mathematical objective functions are described.

Minimize total number of aircraft maintenance vehicles =

$$\text{Min} \quad \sum X_j + \sum Y_k + \sum Z_h \qquad (1)$$

Where $\sum X_j = x_1 + x_2 + \ldots + x_j$

$$\sum Y_k = y_1 + y_2 + \ldots + y_k$$

$$\sum Z_h = z_1 + z_2 + \ldots + z_h$$

Constraint:

$$Max\{\sum_{n=1}^{N}[C_n - (ETA_n + 15), 0]\} + Max\{\sum_{n=1}^{N}[W_n - (ETD_n - 20), 0]\}$$
$$+ Max\sum_{n=1}^{N}\{[T_n - (ETD_n - 12), 0]\} + Max\sum_{n=1}^{N}\{[T_n - ETD_n, 0]\}$$

where X_j is the total number of cleaning vehicles allocated, and the value of ETA_n +15 and ETD_n – 12 is the predefined value used by the company.

Y_k is the total number of water vehicles allocated

Z_h is the total number of tractors allocated

x_1 to x_j are the serial numbers of the cleaning vehicles assigned

y_1 to y_k are the serial numbers of the water vehicles assigned

z_1 to z_h are the serial numbers of the tractors assigned

N is total number of aircrafts served by CASL

C_n is the start service time of cleaning services for aircraft n

W_n is the service end time of water supplying services for aircraft n

T_n is the start service time of tractor service for aircraft n

ETA_n is the Estimated Time of Arrival of aircraft n

ETD_n is the Estimated Time of Departure of aircraft n

4. Methodology

This paper proposes agent-based approach to deal with the problem. The procedures of building the multi-agent model is shown as in Fig 3.

4.1. Multi-Agent Model

According to the flowchart, the environment of the model will be firstly built, including a platform for agents to communicate and interact in order to have a more realistic simulation of the model. After defining the environment of

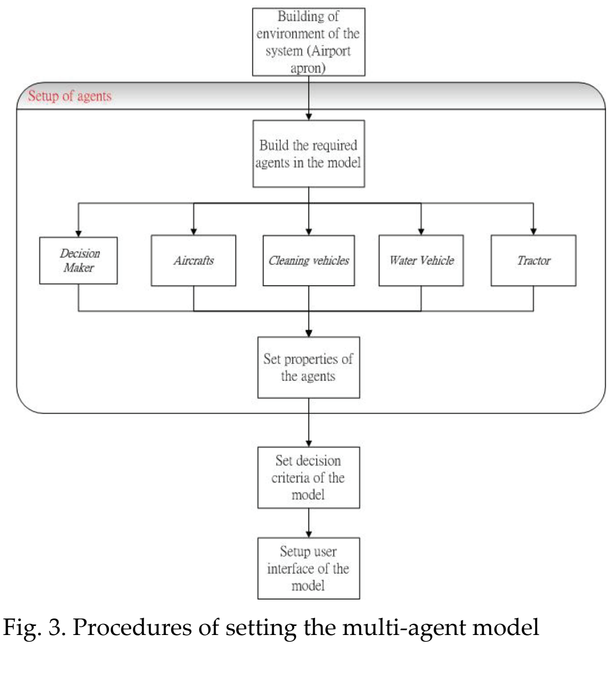

Fig. 3. Procedures of setting the multi-agent model

the simulation model, it is also important to set different agents. In this model, there are five types of agents need to be set in the model, including the decision maker, aircrafts, cleaning vehicles, water vehicles and lastly, the tractors. These agents have their different roles in the model. The decision maker decides the allocation of the cleaning and water vehicles as well as the tractors in order to serve the different aircrafts and ensure that all of the procedures has been made before aircraft departs. Aircrafts are the agents who park in HKIA which need to be served by different services before departure. Cleaning vehicles are used to perform cleaning and toilet services to the aircrafts, while water vehicles are used to provide water needed by the aircrafts to operate and lastly, the tractors are used to pull back the aircrafts from apron to runway before takeoff. Afterwards, the agents' properties and also the decision making parameters are then need to be set to ensure that the model can meet the designated objective. These properties and the decision making parameters will be discussed in the latter part of the methodology, while in this model, the role of decision making is centralized by the agent - decision maker.

4.2. Model Assumptions

The followings are the assumption of the multi-agent model:

1. There is no breakdown of any types of the maintenance vehicles;
2. There are no accidents, weather and other external factors which affect the operation and traffic of the airport;
3. Pre-emption of the services is not allowed, which the operations of services cannot be interrupted since it starts;
4. All of the vehicles needs all of the factor, including operators, tools and materials, in order to perform their services;
5. The due times are fixed;
6. All of the process times and transportation times are determinable and known in advance;
7. Each maintenance vehicle can serve one of the aircrafts at any point of time;
8. Each of the services must be successfully performed, since the service starts, the service must be finished successfully and no reprocess is needed.
9. Each of the services must be performed by one maintenance vehicle only;
10. There are no cancellation of flights;
11. There is no restriction of the routing of the vehicles;
12. All of the vehicles are identical with their same type which performance of doing the service is the same;
13. All of the aircrafts are identical physically, i.e. services requirement is the same;
14. All of the aircraft requires performing all of the three services, including cleaning, water and tractor services before aircrafts' departure;
15. The arrival pattern of aircrafts is solely based on the aircraft arrival rate. There is no variance of arrival pattern during one trial.

In the simulation environment of the model, it provides a framework for building different agents and a platform for agents to communicate. According to Chau et al. (2009), the multi-agent environment is regarded as a place that an organization's structure, rules, and plans are integrated. Moreover, all of the steps and decisions will be performed in the simulation environment. Last but not the least, the result of the simulation is depended by the setting of the environment.

5. Agent

There are five agents need to be set in the model in order to simulate the situations. There are the decision maker, aircrafts, cleaning vehicles, water vehicles and tractors. Each of them has different properties and these will be discussed in the following paragraphs.

5.1. Aircrafts Agent

Aircrafts are the agents representing the aircrafts which are using CASL's services in HKIA. The number of the aircrafts exists in the simulation environment and their arrival time will be generated in the simulation according to the input "Aircraft arrival rate" in the user interface. Each of the aircrafts has its own flight number, which is generated by the system during simulation. The design of the flight number is the similar to the actual flight number, which includes two alphabets and then four numeral characters, like CX1234. The JAVA coding of assigning the plane code is as following:

```
public Plane() {
        Random thisRandom = new Random();
        char planeNoArray[] = new char[6];
        planeNoArray[0] = Alphabet[thisRandom.nextInt(26)];
        planeNoArray[1] = Alphabet[thisRandom.nextInt(26)];
        planeNoArray[2] = Number[thisRandom.nextInt(9)];
        planeNoArray[3] = Number[thisRandom.nextInt(9)];
        planeNoArray[4] = Number[thisRandom.nextInt(9)];
        planeNoArray[5] = Number[thisRandom.nextInt(9)];
        planeNo = new String(planeNoArray);
        record = new PlaneRecord();
        record.setPlaneNo(planeNo);     }
```

Each of the aircraft has its own ground time, which their average ground time is around 1.5 hours with the range from 1 hour to 2 hours. The ground time will be generated randomly according to Normal distribution, which the mean is 1.5 hours and the standard deviation is 0.25 hours. Since the arrival of aircraft, ground time will start counting and the departure time of the aircraft will be set. The aircraft firstly takes 5 minutes to move from runway to apron. The time of moving is standardized because it is not an important factor at ground service vehicle planning while the variance in average moving time small with mean of around 5 minutes. Afterwards, it is needed to perform the cleaning service performed by cleaning vehicle, the water supply services performed by water vehicle and pull back service performed by tractor, while there are several time constraints about the service time of each of those services. Any time which the service does not meet these constraints will be regarded as different kind of "late".

Lastly, the aircraft must be departed on or before the estimated departure time. If all of the services have been performed before the estimated departure time, the aircraft will depart according to its estimated departure time. Besides, if the aircraft cannot depart at estimated departure time, the "late in aircraft departure" will be counted. In the following, the codes in determining late departure of aircrafts is illusrated:

```
public boolean isDelayed(int currInterval) {
        return (currInterval > departureInterval);
```

5.2. Cleaning vehicle Agent

Agent "cleaning vehicles" are representing the cleaning and toilet vehicles owned by CASL. Although there are limited number of this kind of vehicles available in reality, in the model, this concern is neglected which the number of cleaning vehicles available for allocation in apron of HKIA depends to the input of number of cleaning vehicles available in the simulation of the user interface. After receiving the signal of arrival of aircraft at apron, firstly, one of the cleaning vehicles uses 5 minutes to move to the apron which that aircraft is located. The reason of using fixed time is similar to that of agent "Aircraft". Afterwards, the cleaning and toilet services will be performed. The mean service time of the cleaning service is 15 minutes with standard deviation of 2 minutes, in order to illustrate the real operation of the cleaning services with different services time. As it is mentioned in the previous sub-chapter, there is a constraint of arrival of cleaning vehicles, which the cleaning vehicles are required to be arrived the apron and start services after 15 minutes of the aircrafts' arrival. This can ensure the cleaning and toilet service has to be performed as soon as possible in order to prevent delaying the processes afterward and cause the aircraft could not takeoff according to its Estimated Departure Time (ETD).

```
public boolean isCleaningVehicleArrivalLate() {
        return (cleaningStartTime - arrivalTime > 900);}
```

5.3. Water Vehicles Agent

Water vehicles are the agents representing the water vehicles used in CASL. Because of the same reason of agent cleaning vehicle, in the model, the number of cleaning vehicles available for allocation is unlimited and depends on number of cleaning vehicles available input in the user interface. It is important for the water vehicle to supply the clean water to the aircraft in order to serve different services in the aircraft. Although the request of supplying water may not exist in each aircrafts, in this model, in order to simplify the situation, it is assumed that all of the aircrafts require water providing services which is performed by water vehicles. Since starting of the cleaning and toilet service, one of the water vehicles is selected to serve the specific aircraft which also takes 5 minutes to move from parking area or other positions at apron to the aircraft's position. Then, the water providing service starts and its mean service time is 20 minutes while the process time has 3 minutes variance, which the reason of this setting is similar to setting of agent cleaning vehicle. Likewise, there are several requirements about the time of services performed exist in the model, which the services vehicle has to be arrived before 40 minutes of the aircraft's arrival time, while the cleaning services has to be finished before 20 minutes before the Estimated Time of Departure (ETD) of the plane to ensure the service can be performed before gate close and prevent late of departure of the aircraft. The codes of determining the late in arrival (1) and late in services (2) are as followings:

```
(1) public boolean isWaterVehicleArrivalLate(int
waterVehicleArrivalInterval) {
        if (departureInterval - startWaterInterval <
START_WATER_INTERVAL_LIMIT)
                return true;
                else        return false;

(2) public boolean isFinishWaterLate(int finishedWaterInterval) {
        if (departureInterval - finishedWaterInterval <
FINISH_WATER_INTERVAL_LIMIT)
                        return true;
                else        return false;
```

5.4. Tractors Agent

Afterwards, there are agents named as tractors in the model representing number of tractors available in HKIA operated by CASL. Similar to the other agents mentioned above, the number of tractors available in the model is unlimited and it is depended by the input in the user interface. Before the departure of the airport, it is essential that the aircraft has to be pulled back to the runway by the tractor. In the multi-agent model, after the previous services, including the cleaning and toilet services and also the water supply services, the tractors are notified and one of the tractor moves towards the apron position where the aircraft is located. Then, the pullback service starts and the service last for 10 minutes. Afterwards, the aircraft will takes off and depart HKIA. For this agent, it is required to arrival the aircraft's location before 12 minutes of the Estimated Time of Departure (ETD) in order to prevent the late in departure of the aircraft. If the tractor could not arrival the specific location at required time constraint, it is regarded as "late in arrival of tractor". The codes in determining whether

```
public boolean isTimeToSignalTractor(int currInterval) {
        if (departureInterval - currInterval <= 1200)
                return true;
        else        return false;}
```

5.5 Decision Maker Agent

Last but not the least, there is an agent set in the model which representing the coordinator role named Decision Maker. The main role of the decision maker is to make decision of which vehicle should be used to serve the specific aircraft. Different from the other agents, the decision maker has a wider knowledge about the environment that all of the other agents, including the different types of vehicles and the aircraft, which only have knowledge about their own environment only. The decision maker has an important role in the communication between the agents. The other agents have communication and provide information to the decision maker. Moreover, decision maker is also responsible for making decision of assigning the suitable vehicle agents to serve different aircrafts according to its information obtained by the other agents.

5.6. Summary of agents

In order to summarize the properties of different agents, the two figures are used as shown in Table 1 and Table 2. Other from these agents, an agent Decision Maker is set for the communication with other agents and also making decision of assigning the suitable vehicle agents to serve different aircrafts according to its information obtained by the other agents.

5.7. Communications between agents in the model

In agent-based approach, communications take a very important role in the simulation. It provides the important information exchanges between agents just like the communication that human are performing. The communications between agents provide more information about their own perceived environment. Communication takes place between all of the agents in the environment, where all of the communication are achieved by sending messages through both of the broadcasting and one-to-one communication. In the multi-agent model built in the paper, it also has a number of communications between the different agents in order to operate and share information, which the summary of the communications between different agents are shown in Fig. 4.

Agent	**Aircraft**		
Arrival Pattern	Derived by input "Arrival Rate"	**Moving from runway to apron**	~5 Mins
Ground Time	Mean: 1.5 Hours S.D.: 0.25 Hours	**Late in departure**	Actual departure time > ETD
Services performed before departure		Cleaning and toilet, water supply and tractor	

Table 1. Summary of properties of agent (Aircraft) in the multi-agent model.

Agent	**Cleaning Vehicle**	**Water Vehicle**	**Tractor**
Transportation time to apron	*~5 Mins*	*~5 Mins*	***~5 Mins***
Service Duration	*~15 Mins*	*~20 Mins*	***~15 Mins***
Late Condition	*15 Mins ETA (Arrival)*	*20 Mins ETD (Service)*	***12 Mins ETD (Arrival)***
Concurrent performance?	***Can be performed Concurrently***		***No***

Table 2. Summary of properties of agents (vehicles) in the multi-agent model.

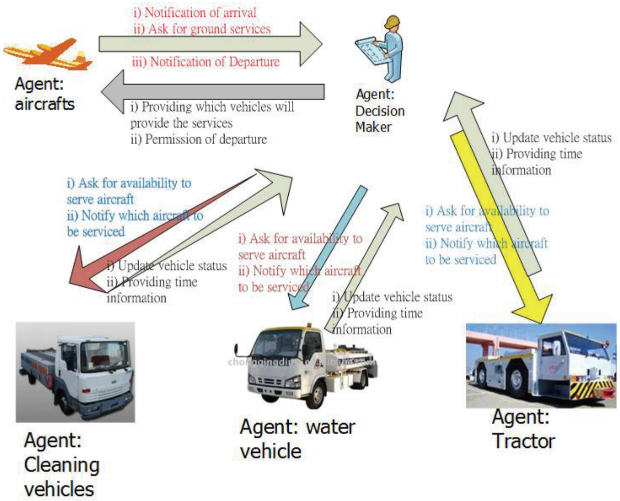

Fig. 4. Communication flow between agents.

Agent decision maker is the key agent in communication because it is the intermediate of the communication that all of the communications are involved between the decision maker and the other agents concerned. The communications between agent aircraft and agent decision maker include the aircraft notifies the decision maker about its arrival and departure. Moreover, the aircraft will also make request of ground services to decision maker after its arrival and also urge for the quicker services. For the decision maker, it will provide the aircraft the information about which vehicles will be used to serve the aircraft. Moreover, permission is also needed to be given from the decision maker before aircraft's departure because decision maker will check whether all of the three services are performed before departure.

The communications between the agent decision maker and the agents representing the 3 different kinds of maintenance vehicles are similar, which the vehicles update their status to decision maker for record, including idle and in services. Besides, while the each of the services provided by maintenance vehicles is finished, the vehicles have to update their status to decision maker as well as provide the time about services, including service start time, end time and also the service duration to decision maker to record and determine whether the late in service or arrival occur. For the decision maker, it is needed to ask for the availability of the specific type of vehicles after it was asked for the ground services by agent aircraft. When an idle vehicle is found, the decision maker also needs to notify that vehicle which aircraft should be served by the vehicle, deal with the vehicles to for ensuring they will perform the service properly and also provide the other useful information about the aircraft in order to better and fasten the services provided by the vehicle agents.

6. Numerical Example

Data are collected for the aircrafts' arrival patterns and the arrival intervals in weekdays, weekends and public holidays, while the number of aircrafts need to use HKIA is maximized at the different public holidays. This high demand of services tests the handling power of HKIA and its services providers, including CASL. Moreover, at different time horizon within a day of operation, the numbers of aircrafts' arrival are different. The aircrafts' arrival is at peak from 10am to 12noon and from 10 to 11pm, while there is no aircraft arrival from 2 to 5am and just a few numbers of aircraft arrivals and departures at early mornings and also at midnights. This variance of aircraft arrival pattern within a day in HKIA makes it is more challenging for an efficient planning and scheduling of the maintenance vehicles in order to prevent any occurrence of aircraft delay. Therefore, in each of the cases, before simulating different cases, it is needed to consider the variance of aircraft arrival within time when entering the simulation durations, just like neglecting the time period which there are no flight arrivals in HKIA in simulations.

Moreover, according to the passenger data collected in HKIA website mentioned in methodology, part, it is possible to calculate the percentage of the aircraft arrival which is served by CASL. This figure is useful for analysis of different cases, especially for the cases which the actual number of aircrafts served by CASL is unavailable. By using flight arrival data of seven different days of HKIA, including public holidays and weekday, the average percentage of aircrafts served by CASL are summarized as in Table 3.

The initial inputs of the number of the vehicles are:

- Number of Cleaning Vehicles: 5
- Number of Water Vehicles: 5
- Number of Tractors: 5

Table 4 summarized the flight arrival and flight served by CASL in different hours. There are 3 services peaks for CASL, which are from 1000 – 1159, 1600 – 1759 and 2200 – 2259, which the number of services become the maximum at 10am that 21 aircrafts arrived in HKIA within the hour need ground services provided by CASL at 24th March, while the number of arrivals at that time in other normal days is similar as in Table 5.

Date	15/2	6/3	22/3	24/3	26/3	27/3	28/3	Total
No. of aircraft arrivals	376	331	332	326	335	329	327	2356
No. of aircraft served by CASL	176	149	159	147	162	149	157	1099
% of aircrafts Served by CASL	46.8%	45.0%	47.9%	45.1%	48.4%	45.3%	48.0%	46.6%

Table 3. Average % of aircraft Served by CASL in HKIA (HKIA,2010).

Time	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**
No. of flight arrivals	3	6	16	4	9	29	27	18	27	23
No. of flight served by CASL	0	1	0	0	5	21	17	6	9	8
Time	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**00**
No. of flight arrivals	19	17	24	18	15	19	18	23	7	4
No. of flight served by CASL	7	15	10	11	5	6	7	10	7	2

Table 4. Hourly number of flights and flight served by CASL at 24th March (HKIA, 2010).

Date	22/3/2010 (Mon)	23/3/2010 (Tues)	24/3/2010 (Wed)	25/3/2010 (Thurs)	26/3/2010 (Fri)	27/3/2010 (Sat)	28/3/2010 (Sun)
No. of arrivals	36	41	38	34	38	36	36

Table 5. Number of arrivals in other normal days.

The simulation trial, 4 hours will be used as simulation duration and the first 2 hours is used as pre-run for a more accurate simulation. For the aircraft arrival rate, it is calculated by division of 120 minutes by the number of aircrafts arrived in that 2 hours interval, which is 3.16. Fig. 5 shows the simulation results.

It is observed that a number of late are occurred in that 4 hours simulation, which the suggested allocation of the maintenance vehicles is unable to serve the aircrafts at the peak hours of aircraft arrivals in HKIA. A specialized allocation is needed to set to serve the peak hours in order solve the current problem. Therefore, further trials are needed in order to allocate suitable number of maintenance vehicles to serve all of the aircrafts on limited time in peak hours. By continue changing the combinations of maintenance vehicles allocated in different trials, it is found that near a double number of maintenance vehicles should be allocated in order to serve the high aircraft arrival rate in peak hours. Both of the optimized allocation of vehicles and the number of late in different combination of vehicles for the peak hour case in normal days are shown in Fig 6 and 7.

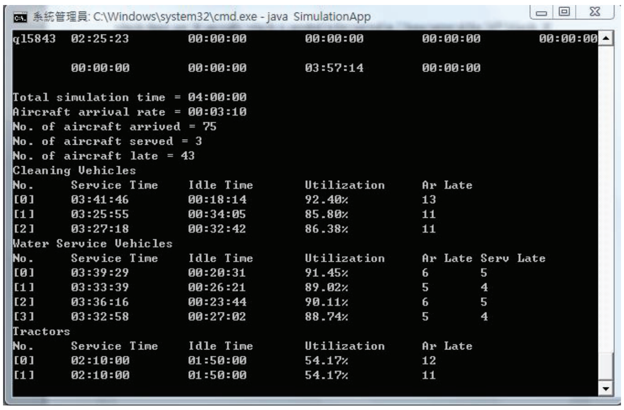

Fig. 5. Simulation result of using allocation suggested in first model for second model.

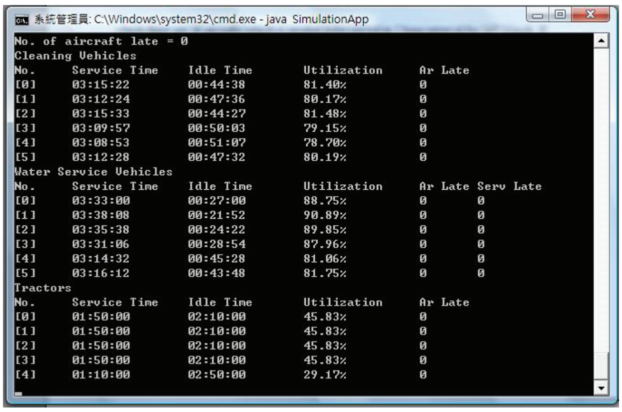

Fig. 6. Optimized allocation of vehicles for model 1 of Case 1.

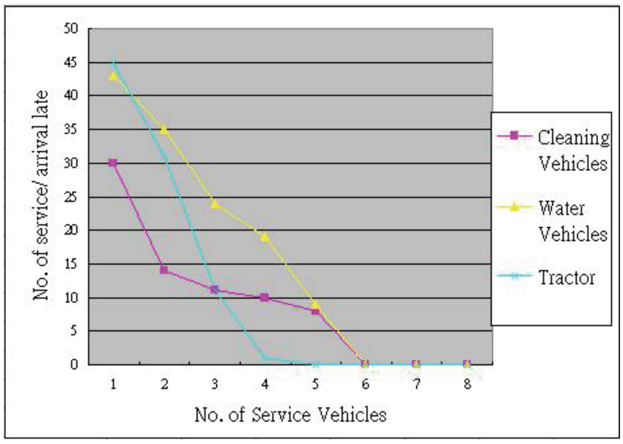

Fig. 7. Graph of number of late occurrence in different combination of service vehicles for model 1 Case 2.

According to the above figure, the optimized allocation of cleaning vehicles is 6, where the allocation of water vehicle is 6 and 5 for tractors. For both of the cleaning and water vehicles, their utilization is very high, which almost and over 80% of utilization is reached. It means that the allocation of these vehicles is very good that can prevent late occurrence while keeping a high utilization. For the tractors, although their utilizations is not high, just about 45%, all of them are essential for prevent late occurrence that late will occur if reducing the number of tractors. Besides, the utilization of tractors is not high because they provide the last service to aircrafts before takeoff which the services time of tractor is short, just 15 minutes. Moreover, the aircrafts have to be pulled back to runway by tractor after closing passenger gate before departure. It makes the time requirement for the tractors harder. Therefore, the allocation of the tractors shown above is already the optimized allocation even their utilization is not high.

7. Conclusion

Aviation is one of the most important industries in the world. It brings the fast, safe and reliable transportation to human being by using aircrafts. In recent years, there is a trend that the demand of using air service is increasing. Moreover, there is an increasing concern about the safety and also the service level of providing the aircraft services, which prevent late occurrence while increasing number of flight services and provide better services in both of the airport and aircraft services. In order to meet the increasing demand, the ground service efficiency must be increased in order to reduce the ground time in airport that to increase number of aircrafts can be served at an airport in any day. Therefore, it is more challenging for airport ground services providers to have a better planning of their ground services in order to serve the increasing number of aircrafts arrival where preventing any late occurrence, which chain effect will be caused in airport and also penalty will be cost to the service providers concerned. One of the ground services providers in HKIA is CASL, which is company being analyzed in this project. In this paper, it is aimed to improve the ground service by optimizing the scheduling of the ground services maintenance vehicles that to minimize the total number of maintenance vehicles while preventing any of late occurrence. A multi-agent simulation model has been built in order to simulate the environment of the apron in HKIA in order to find out the optimal allocation of maintenance vehicles in different situations. All of the agents are designed according to its figure and also the agents' communications has also being built. Besides, a lot of literatures and books are read and their ideas are adopted if useful.

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