MULTI-AGENT SYSTEMS FOR EFFICIENT AIRPORT FREIGHT TERMINAL MODELLING AND SIMULATION

Dragoş Stoica[a,c], Abdelkrim Achaibou[c], Carlos A.N. Cosenza[b], Félix Mora-Camino[a,c]
[a] Ecole Nationale de l'Aviation Civile - Laboratoire Automatique
7, Avenue Eduard Belin, 31055, Toulouse, FRANCE Tel. +33-(0)562174692
[b] COPPE/UFRJ, Rio de Janeiro, Brésil
[c] LAAS du CNRS, 7, Avenue du Colonel Roche, 31077, Toulouse, France
dragos.stoica@enac.fr, achaibou@laas.fr, cosenza@pep.ufrj.br, felix.mora@enac.fr

Abstract

In this paper, after discussing the issue of modelling airport freight terminals, a macroscopic freight terminal simulator, the MACS (MAcroscopic Cargo Simulator) tool, is presented.

The OPAL (Optimisation Platform for Airports, including Land-side) [OPAL] research and development project identified the absence of an adequate tool for airport freight terminal modelling and simulation. So, within this project the tool MACS has been designed and implemented as a multi-agent simulation tool for airport freight terminal representation, analysis and simulation. The aim of this tool is to model, analyse and simulate at a macroscopic level the entire freight terminal activity of a given airport. A MACS version is presently integrated into the OPAL platform together with other tools in order to obtain a full simulation platform able to represent all the traffic activities of an airport (total airport simulation and analysis).

In MACS, the airport freight terminal is modelled as a multi-agent network, where freight agents act in a specific environment according to a set of pre-established rules. The results given by the tool provide support to the decision making process of the airport management authorities for an efficient freight activity organization and management. The MACS system can be applied to a large category of airport freight terminal configurations and may be applied to medium and large airports.

The MACS tool has been validated using the case of Toulouse-Blagnac airport where the study of different scenarios has been performed and is also reported in this communication.

Keywords: Cargo operations; Airport land-side efficient planning; Freight terminal modelling; Multi-agent systems
Topic Area: B3 Logistics, Freight and Fleet Management

1. Introduction

The OPAL project is a research and development project funded by DG TREN within the Fifth Framework Program of the European Commission on Competitive and Sustainable Growth, Key Action: Sustainable Mobility and Intermodality, which is called to provide answers to the total airport modeling and simulation problem. The project was started in May 2000 and had duration of 27 months. The scope of OPAL project is reflected on the following two major targets of the project: (i) the development of a concept for a computational, integrated and distributed platform in the form of a facility for integrated simulation with different airport performance models, for modelling/evaluating/ optimising airports at land-side and airside simultaneously, (ii) the provision of a proof of this concept at the following six selected European airports: Amsterdam Schiphol, Athens

International Airport, Barcelona El Prat, Madrid Barajas, Franfurt, and Toulouse-Blagnac airport.

The OPAL system consists of a set of models and tools addressing issues related to the airport capacity and delay, the environmental impacts and risk associated with the airport operations. Within OPAL the concept "total airport" is used to indicate the complete airport operation as a combination of land-side and airside airport operations. More specifically, the OPAL models and tools are integrated within four interrelated modules, namely: (i) Capacity and Delay Module, (ii) Safety Module, (iii) Environment module, and (iv) Cost-Benefit module. Capacity and Delay module contains models and tools that estimate several airport capacity measures like the throughput capacity, delay, and punctuality, for both airside and landside. In particular, MACS tool, dealing with freight issues, is addressing capacity and delay module. The figure 1 schematically illustrates the architecture of the OPAL model base.

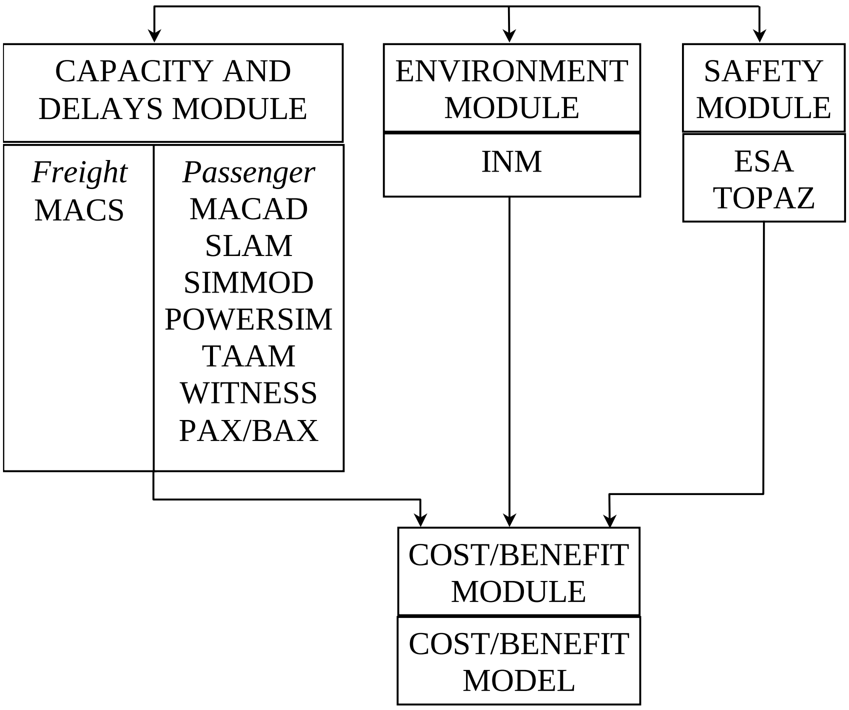

Figure 1. OPAL architecture

1.1. Description of MACS tool

The need for MACS was pointed out from the beginning of the OPAL project. The absence of a tool that models and simulates the processes at the airport freight terminal imposed creation of MACS. The tool had to analyze the capacity and delays issues connected to the freight activity at the airport.

The area covered by the tool is from the roads near the airport up to the taxiways. The modeled entities are: cargo trucks, freight agents, and cargo aircraft. The operational areas are: trucks parking, agents processing/stocking zones and aircraft parking stands.

MACS was designed as a management decision aid tool for the airport administration authorities. MACS has to answer particularly to the following scenarios: (i) new freight area, (ii) new noise regulation, (iii) new regular flights, and (iv) new freight agent implant. The design was conceived as a general modeling tool and from the beginning two aspects were established: the compatibility with other existing tools and the capacity of representing a large category of airports. The system is designed as a pipeline processing system, see figure 2 that exchanges texts files.

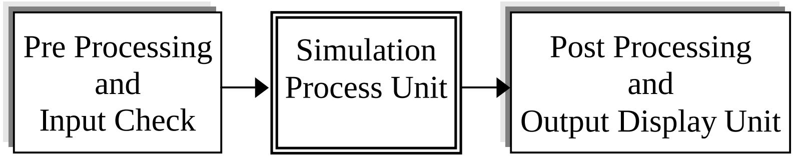

Figure 2. MACS system architecture

The choice of using text files for information exchange was imposed by compatibility aspects. Thus the input data may be produced by the user from various data sources (text files, spreadsheets, and formatted data) or obtained via the OPAL platform. This implies the possibility to have a remote execution mode and a stand-alone execution mode.

The core of the system is the Simulation Processing Unit. It is designed as a multi-agent system framework for simulating the freight agent activity at the airport freight terminal. The choice of multi-agent system was in favor of the possibility to represent various configurations of freight agents and the power to model a large category of airports. Other solutions that were analyzed as possible modeling candidates: queue network system, a global system based on dynamic programming, and flow graph system. The multi-agent system was capable to answer to most of the requirements; the only tradeoff was made for small airports. The multi-agent solution will not perform well for small airports and may not be used in the decision making process for this category of airports. This inconvenient is overcome by the small level of freight traffic at small airports, thus a much more complicated process. The size of the problem is significantly smaller and may be solved by a human expert.

For medium and large airports the combinatorial nature of the problem and the time dynamics of the activity imposed a tool that will be able to give a reliable answer in a reasonable time and to show various possible behavioral patterns of the freight agents. This imposed the multi-agent system as final solution over the others. The solutions obtained by the system represent optimal or near optimal solutions. The possibility to derive a dominant behavioral pattern from initial data was more important than a numerical precise response.

1.2. MACS the application

MACS was designed by a team of OPAL project. The team was composed by the Toulouse airport freight terminal manager, Communication & Systèmes - Paris (C&S) and the Laboratory of Automatics from Ecole Nationale de l'Aviation Civile (ENAC). The team coordinator was C&S. The tool was developed in two stages. A first version was implemented for testing and calibration, then the second and final version was produced.

All along the development process the expert knowledge of the airport authority was incorporated into the MACS system. The possible types of freight agents and the general rules that apply to air freight process were implemented into the simulator unit. For testing and calibration the Toulouse airport data were used. Nevertheless, the tool was conceived for medium and large airports. Only the specific rules have to be adjusted, all agent behavior is parameterized so it can be easily adapted.

The development environment was Microsoft Visual C++ 5.0 under Windows operating system. The application does not produce any graphical display in stand alone mode. The results may be visualized and analyzed via OPAL platform or any other data analyzer software. A stand alone version was produced for testing purposes. This version is user friendly and has some of the statistics may be displayed. The main result analysis tool remains external.

1.3. System architecture

The main concept behind MACS is that a closed society of agents will evolve towards a quasi-stable state. The final configuration will give a stationary state of the multi-agent society that will represent the optimal solution or equilibrium solution. The future decisions will be based on this projection of agents evolution.

The freight traffic is grouped in three main flows: import (comes by air and leaves by land), export (comes by land and leaves by air), and transit (comes by land and leaves by land or comes by air and leaves by air).

The freight area is divided into three zones: truck parking zones, freight operators zone and aircraft parking zone. To the extremities of these zones two buffer zones are attached: access roads connected to the truck parking zones and the ramps/taxiways connected to the aircraft parking zones.

The freight operators are represented by three generic type of agents: express agents for express freight operators, forwarder agents for forwarding freight operators, and ground handling agents for ground handling operators. Each agent operates in a specified zone and with corresponding trucks and aircraft. For trucks fleet there are two types of operated trucks: normal trucks and truck flights. Express agents and forwarding agents use the normal trucks. The truck flights are used by ground holding agents and they replace cargo aircraft in some cases. There are considered two types of operated aircraft: all cargo aircraft and mixed (PAX/cargo) aircraft. The freight agents may use both types of the aircraft for cargo transport activity.

The considered airport freight terminal representation, figure 3, was considered as the basis of the MACS system.

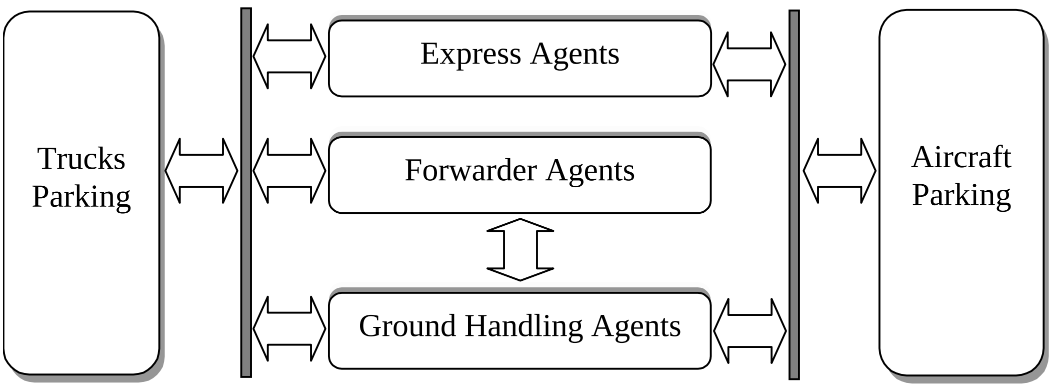

Figure 3. Airport freight terminal representation

System architecture is centered on the agents. Each type of agent has specific operating rules. Each agent is characterized by:

- the average processing time
- maximal fluid cargo flow
- operational surface
- transfer capacities (land-side, air-side and inter-agent)
- access time (land-side, air-side)
- truck types
- parking zones (trucks parking and aircraft parking)

Each agent has its truck fleet. Only express agents have their own aircraft fleet (only cargo aircraft), the ground handling agents may use the mixed aircraft fleet. The forwarder agents do not operate an aircraft fleet. At airport freight terminal several agents of the same type may operate in the same time.

The express agent (EXP), figure 4, models a generic express freight operator. It has its own truck and aircraft fleet and operates directly with it without any intermediary. In general it has a small freight processing time and high coordination between timetables (truck and aircraft timetables). For small and some medium airports there is no transit for express freight.

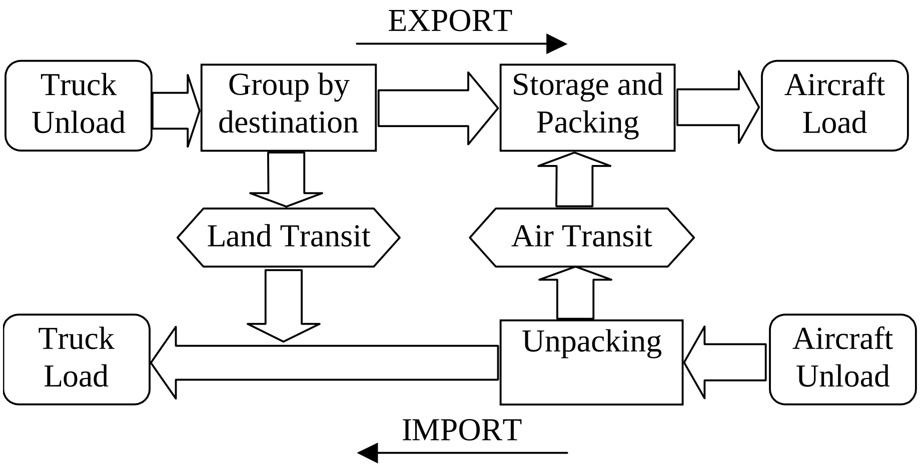

Figure 4. Express agent architecture

The forwarder agent (FWA), figure 5, models a generic forwarder freight operator. It operates its own truck fleet but does not operate with aircraft. Its main task is to be the interface between the customers and the ground handling agents. A forwarder agent may collaborate with several ground handling agents. Its activity is not synchronized with the aircraft timetables so it will mainly store the freight before it will be forwarded to an agent that operates with aircraft. Some forwarder agents act as a truck freight transporter since some of the cargo, supposed to go by air, will go by truck. The ratio of freight that goes again by truck is relatively small (less than 5% for a medium size airport). The main parameter for a forwarder agent is the operational surface. In conjunction with the average processing time and fluid cargo flow gives the general behavior of the agent.

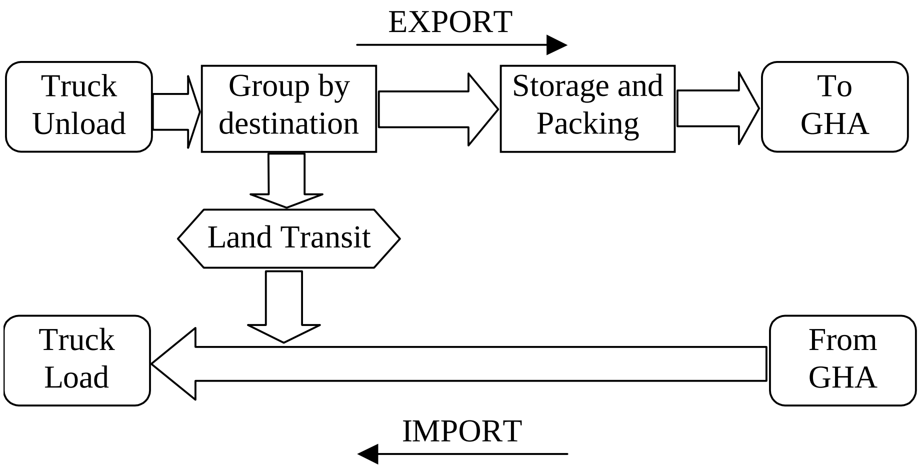

Figure 5. Forwarder agent architecture

The ground handling agent (GHA), figure 6, models a generic ground handling freight operator. It operates its own truck and aircraft fleets. The trucks are called “truck flights” because they replace the aircraft flights and they are not used as normal trucks in the airfreight transportation process. The freight is dispatched by one or more FWA that work with the GHA. The activity of a GHA is highly correlated to the aircraft timetables. The average processing time gives the dominant behavior of this type of agent.

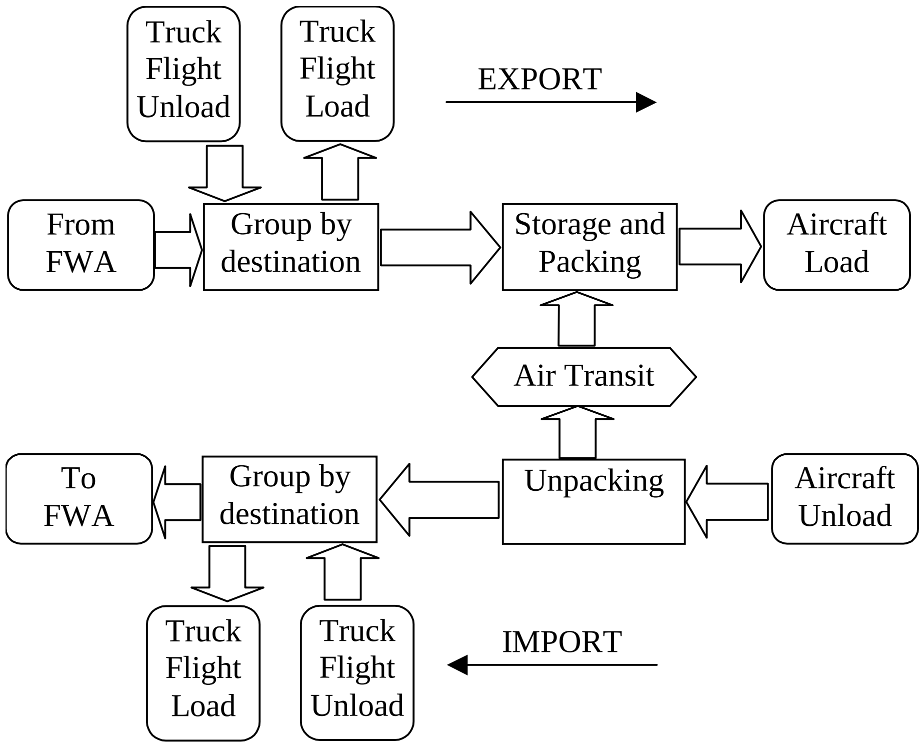

Figure 6. Ground handling agent architecture

An airport freight terminal may be modeled as a collection of several interconnected or independent agents working in parallel. The advantage of such a representation is that the analysis of the system performance can be done at global and component level, zoom analysis. Multiple bottleneck detection is possible and the system may continue to function even one of the components is saturated of blocked.

The agents interact in two ways:

- via direct connection (FWA-GHA connection)
- via resource competition (truck parking sharing and/or aircraft stands sharing)

1.4. Agent modeling

All agents are modeled by finite state automata. Some triggering events are external, like truck/aircraft arrival. These events may be deterministic (given by time schedules) or probabilistic (given by frequency distribution of arrival process).

The system is event driven; one of the alternatives for MACS modeling was as a discrete event system based on timed Petri networks. Events will trigger state transitions for each agent’s internal automata. Since the agents do not need an internal state synchronization, the finite automata are robust enough for agent behavior modeling.

An external clock is used for events ordering and time stamps. The clock period is given by the greatest common divisor of all agents’ processing times, thus a fast time simulation is possible. The simulation time period has to be long enough in order to make the whole system reach equilibrium. In our case, medium sized airport, a whole week is sufficient to capture this behavior.

The express agent reduced model is presented in fig 7. For this model the packing/unpacking capacity depends on average processing time, maximal fluid cargo flow and operational capacity.

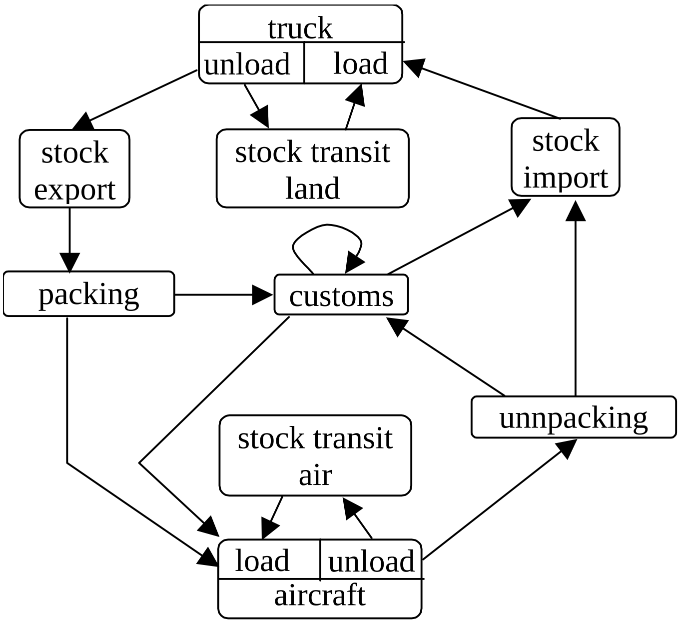

Figure 7. Express agent internal reduced model

The agent's capacity curve is presented in fig 8. One may not that it is desirable not to saturate the agent's processing pipeline. In fact it is considered that above 90% of the capacity utilization the agent becomes saturated, so an occupancy rate around 80%-85% is desirable. The inferior limit is at 50% of capacity utilization. Below this limit the agent is considered to have a poor management of its available resources.

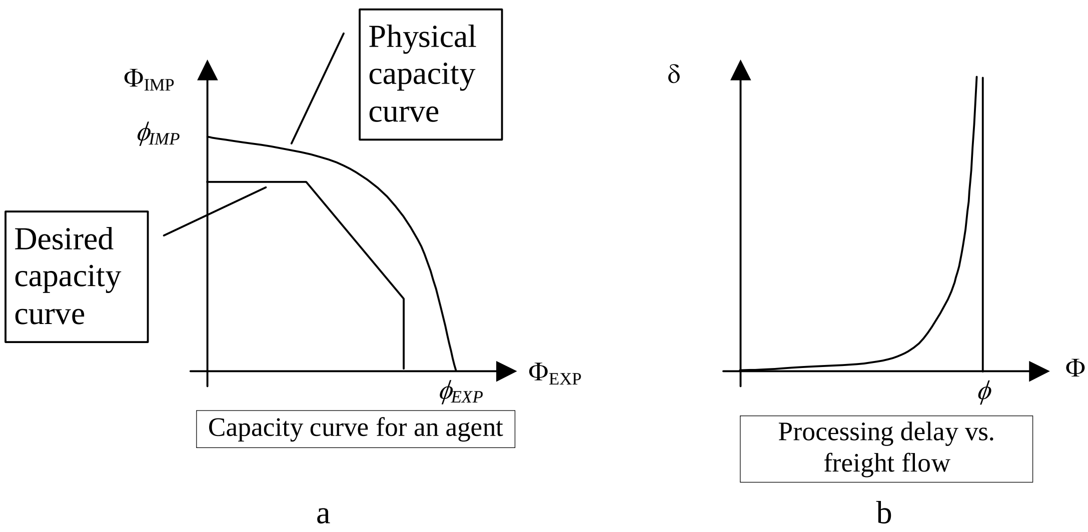

Figure 8. a) Capacity profile for an agent (physical vs. desired capacity), b) Processing delay as function of freight flow

Where: Φ_{EXP} is the export freight flow, Φ_{IMP} is the import freight flow, ϕ_{EXP} is the physical limit of export freight flow, ϕ_{IMP} is the physical limit of import freight flow, $\Phi=\Phi_{EXP}+\Phi_{IMP}$ is the total freight flow, $\phi=\phi_{EXP}+\phi_{IMP}$ is the physical limit of total freight flow, and δ is the freight processing delay. As the system acts as like a buffer between land-side and air-side the stochastic behavior of the system is more obvious. For this extreme operational mode the agent acts like a queuing system. This particularity is used to compute the actual limits of each agent. In our study we will try to avoid saturation thus queuing theory is not fully applicable.

For the other type of agents, similar modeling tools were used.

2. Results

From the beginning MACS tool was intended to answer to four major types of scenarios:

1. New freight area – the aim of this long-term scenario is to help organize the conception of a brand new freight area upon available airport spaces. The conception must be studied both on land-side (organization of warehouses and roads) and air-side (number of aircraft stands and links to the tarmac)
2. New noise regulations – the aim of this long-term scenario is to define whether TLS airport can cope with the changing in noise regulations (January 2002), which will lead to forbid the movements of specific types of aircraft during the night (both passenger and cargo flights).
3. New scheduled flights – the aim of this short term scenario is to check whether a new flight program, destined to last for at least one complete IATA season, can be accepted by the platform. If no, what would be the changes needed?
4. New implant – the aim of this long term scenario is to help define whether a global area can accept or not the buildings dedicated to a new activity at the airport (ex. UPS building, or Médecins sans frontières building).

For new freight area scenario the following setup was used:

- 2 aircraft parking zones: B1 and B2
- 4 trucks parking zones: Mail, Remote Stands, Express and Terminal Ramp
- 5 freight agents: Express group 4000m², DHL 600m², La Poste 2500m², Forwarder - Ground handling agents 2500m².
- freight demand of 30000 t/year for express agents, 50000 t/year for FWA-GHA agents, 9000 t/year for La Poste. This freight is transported only by aircraft. Truck flights freight demand is: 16000 y/year for FWA-GHA agents and 14000 t/year for La Poste.

For this scenario the operational surface for FWA-GHA agents group will be increased to 3500 m² and for the Express will be decreased to 3000m². We will test if this configuration is sufficient for a fluid treatment of the freight demand.

The following output files are produced at the end of execution: p_opsrep.txt, p_<operator_name>.txt, p_<operator_name>_proc.txt. These files contain the detailed operations information for each agent. The results are in tabular text format and can be further processed and analyzed with Microsoft® Excel™.

Data interpretation is made on the basis of saturation or under usage of a freight agent operational surface during one freight cycle (7 days).

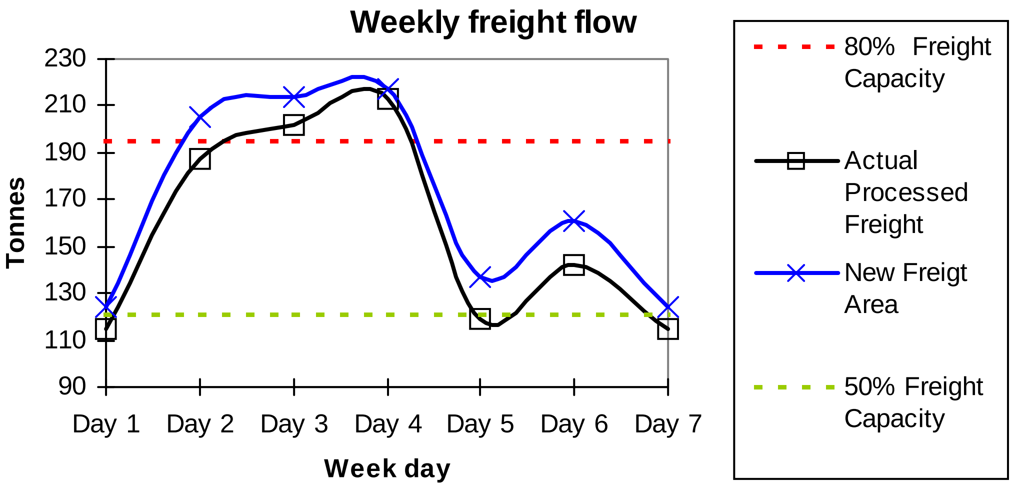

Figure 9. Weekly freight flow (actual vs. new freight area scenario)

The interpretation of this graph is: if the actual processed freight represents more than 80% of the freight processing capacity for several days. This implies stock overloading and overnight stocking, hence insufficient processing facilities for the corresponding agent. If the actual processed freight is bellow 50% for several days this implies a non-efficient utilization of the facilities, hence this agent may work with smaller operational surfaces. This analysis can be detailed for each freight agent at day level and hour level. The possibility of tracing the beginning of over stocking moment enables the bottleneck detection and appropriate management decisions may be taken.

For this particular configuration we have already an even distribution with important peaks of the freight flow over one week. So the existing problem will be amplified. One solution is to reorganize the freight activity according to the available capacity (e.g. move the traffic from day4 to day5).

3. Concluding remarks

In this communication the OPAL platform was presented. Within the OPAL project MACS tool was designed and implemented. This tool was built in response to the need of airport freight activity management authorities. The project team was multidisciplinary and that was one of the strong points, the complementarities helped the continuous development of the tool.

The tool was primarily intended to respond to four types of scenarios: new freight area, new noise regulations, new scheduled flights, and new implant. From technical point of view the new created tool had to be fully compatible with the OPAL platform. This is giving all the advantages of the OPAL platform. At this point the tool does not have its own graphical user interface. A stand alone version, more user friendly, is planned.

The concepts behind the tool are based on the multi-agent system theory. Nevertheless, some other architectures or modeling tools may be used. We have analyzed the queuing systems, discrete event systems and some linear programming mathematical tools as a possible candidate for the system modeling. The choice for multi-agent systems was made on the basis of the possibility to use the MACS tool for a large category of airport freight terminal representation, namely medium and large airports. Also the possibility to model the behavior of each agent was a good argument for our choice.

The tool was validated and calibrated for Toulouse-Blagnac airport, it was also tested for the other airports involved in the OPAL project.

Acknowledgement

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