Simulation of an Airport Automated Baggage System

(The Denver Airport Baggage Fiasco; revisited)

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This model was developed as an example during an introductory course about modelling of event-driven discrete parallel systems with PACE [2].

1. Introduction

In Dr. Dobb's Journal # 261 of January 1997 John Swartz describes in his article 'Simulation of the Denver Airport Automated Baggage System' the Denver airport baggage fiasco [1]. He states that the simulated ABS (Automated Baggage System) would likely deadlock, since there are situations where not enough telecars are available to handle the airliner arrival.

In the following we extend his approach insofar as we do not stop the simulation if not enough telecars are available. We assume that the missing telecars are sent to the gates as soon as they are available and investigate the consequences with respect to the time delay for baggage pickup.

To simplify this investigation we use the advanced simulation tool PACE [2] which allows for a fast semigraphical development of simulation models. PACE has been used among others to simulate the ABS of a large European airport in its planning stage.

2. Assumptions

To reduce the size of our ABS description we have to simplify the problem in such a way that the essential characteristics of an ABS are still valid. It should be mentioned that the real Denver ABS could be modeled to any requested depth using the methods described here. For a more complete description more information about the Denver ABS and its characteristic parameters (like total number of telecars, times for the movement of telecars from the terminal to the different concourses and gates, distribution of the airport efficiency over the day, etc.) is needed.

We make similar assumptions as in [1]:

1. There are 4000 telecars.

2. To every arriving airplane 200 telecars are assigned to bring the arriving baggage to the terminal..

3. Another 200 telecars are needed to transport the departing baggage from the terminal to a gate.

4. The time between the arrival and the departure of an airplane is 30 minutes.

5. The time for loading a telecar together with its running-time between the terminal and a gate is 5 minutes in both directions.

With respect to the arrival we can predict approximately the following ideal time scale[1]:

Delay after arrival (min)	Activity
0	airliner at the gate
0	start 200 telecars for baggage pickup from the terminal
5	telecars for baggage pickup at the gate, start of loading the telecars; for every telecar 3 sec load time
10	passengers unloaded
15	start of the last loaded telecar to the terminal
20	passenger arrive at the baggage pickup area
20	last baggage piece arrives at the Baggage pickup area

Assuming an airport with 40 gates the time intervals between two airliner arrivals can be calculated using the following formula:

average-time-interval-between-two-arrivals = 30 / (40 * efficiency)

The efficiency of the airport is defined as the mean percentage of used gates.

The following table contains the mean time intervals between two consecutive landings for several airport efficiencies:

Efficiency of the airport	Average number of airliners arrivals per hour	Average time interval between two arrivals (minutes)
40 %	32	1.9
50 %	40	1.5
60 %	48	1,3
70 %	56	1.0
80 %	64	0.9
90 %	72	0.8

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[1] Ideal means that a passenger arrives at the baggage pickup area at the same time as his baggage.

3.   Modelling

We develop the model of our simplified airport top down in several steps using extended Petri nets and Smalltalk-80.

At first we have to model an airliner stop at the airport from his arrival to his departure. To this purpose we have to describe the gates and their use.


```
| numberOfGateAttributes  |
numberOfGateAttributes := 2.


"Define description of gates and initialize:"
Gates := Array new: (NumberOfGates+1).
1 to: NumberOfGates+1 do:
        [:i | Gates at: i put: (Array new: numberOfGateAttributes).
           (Gates at: i) at: 1 put: #free.
           (Gates at: i) at: 2 put: i.]
```

Fig. 1: Description and initialization of gates

The gate description is placed in the so called 'Model Code' to be executed at the start of a simulation run (Fig. 1).

Fig. 2 shows the main window of the model and the use of the gates.

If an airliner arrives the transition 'Arrival' allocates the next free gate and fires. The gate description is moved via a token to the place 'Gates'. In parallel the Baggage-Management is informed about the arrival. After 30 minutes the transition 'Departure' fires and deallocates the gate again.

In the upper left corner of Fig. 2 there is a place with inscription 'Exponential mean 1.9' which defines the arrival rates of airliners.

It is interesting to refine the module 'BaggageManagement' in several steps. By this we can gain a deeper understanding of the rules which govern the baggage managment system. We can learn by this how inadmissible simplifications may falsify the simulation results.
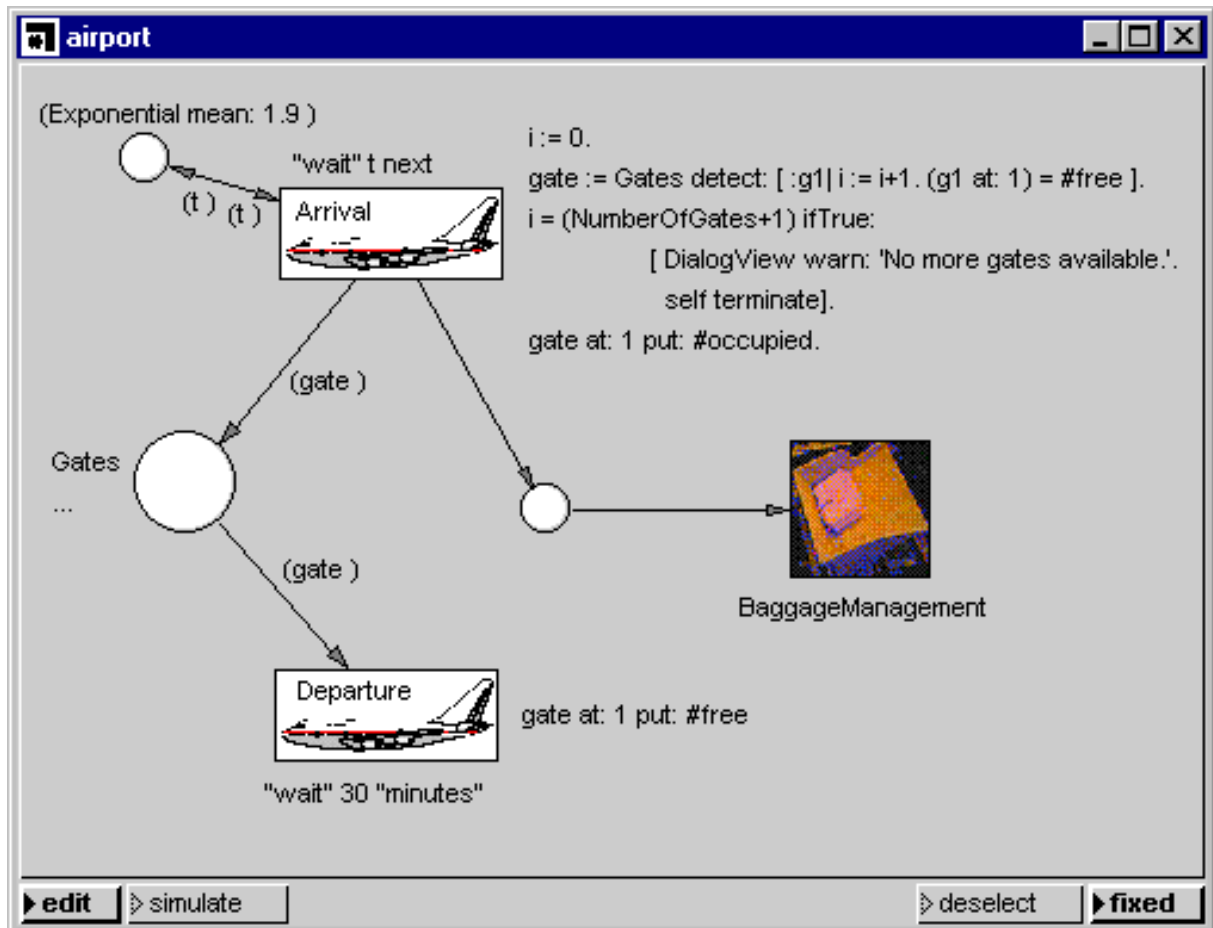
Fig. 2: The main module

3.1 BaggageManagement, step 1

We combine assumption 2 and 3 and assume that all 400 telecars which service an airliner can be allocated at gate time. A first refinement of the 'BaggageManagement' is shown in Fig. 3.

In this case we can reduce the amount of tokens (and computing time) and assign 400 telecars to each of 10 tokens contained at the start of a simulation run in the place 'telecar holding area'.

As soon as an airliner arrives at the gate the transition 'Next set of telecars' fires and a token (400 telecars) leaves the 'telecar holding area' to be placed in the place 'conveyor belt from'. After 5 minutes the token is placed in the 'Gates telecar holding area' and so on.

This is the complete description and we now can push the simulate button to enter the simulation mode. To get an easy overview we connect a histogram and a line diagram to the place 'telecar holding area' and start simulation. The result is shown in Fig. 4 and Fig. 5.
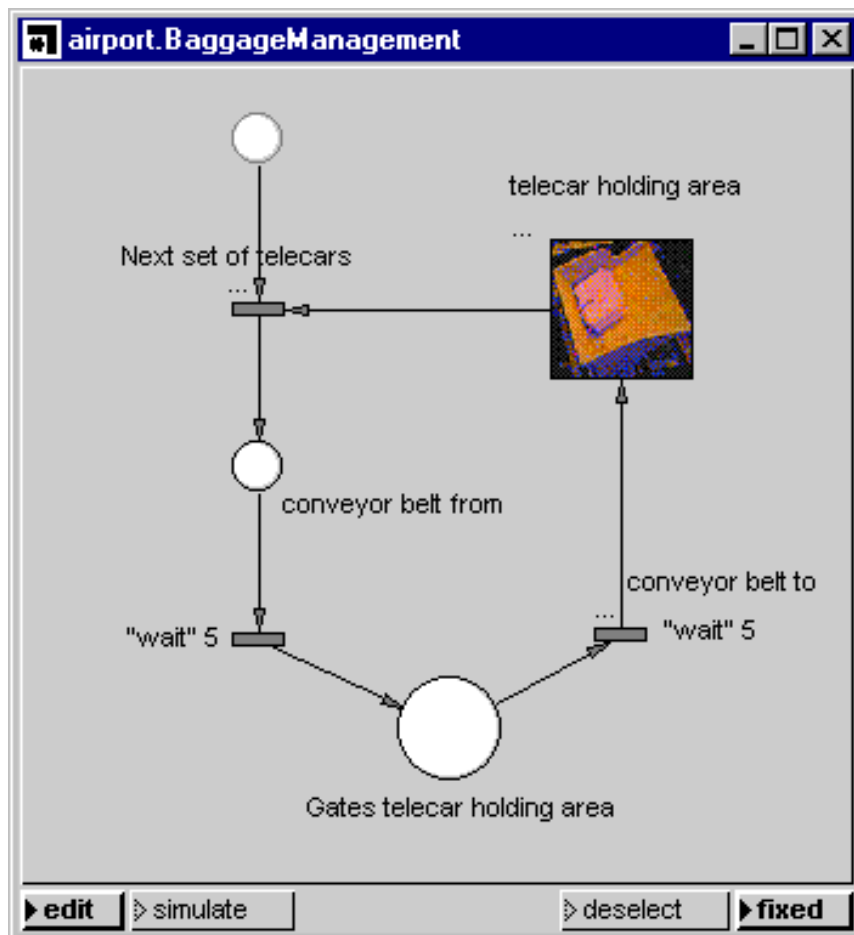
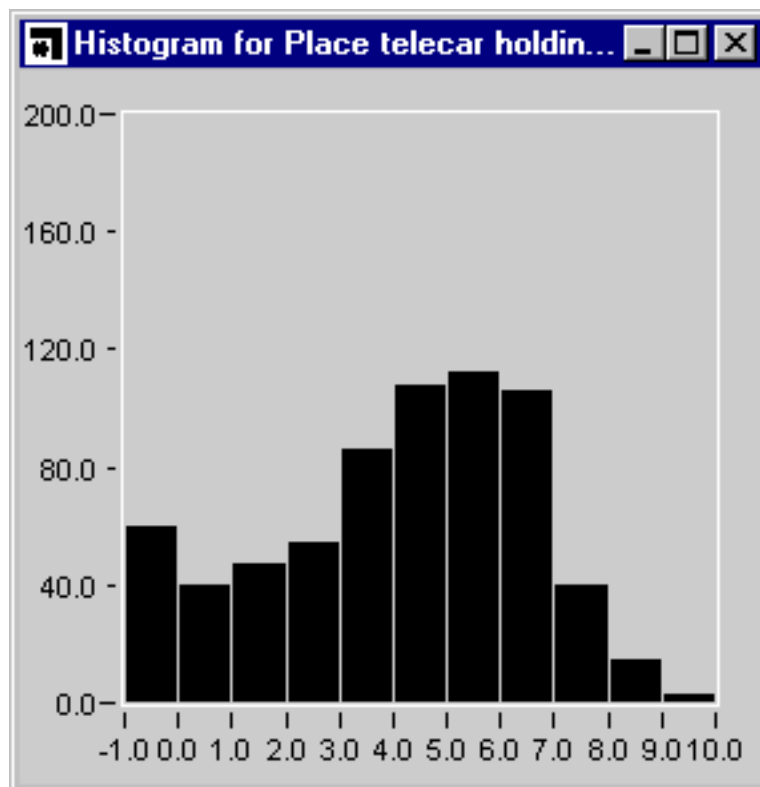**Fig. 3: A simple refinement of module 'BaggageManagement'**

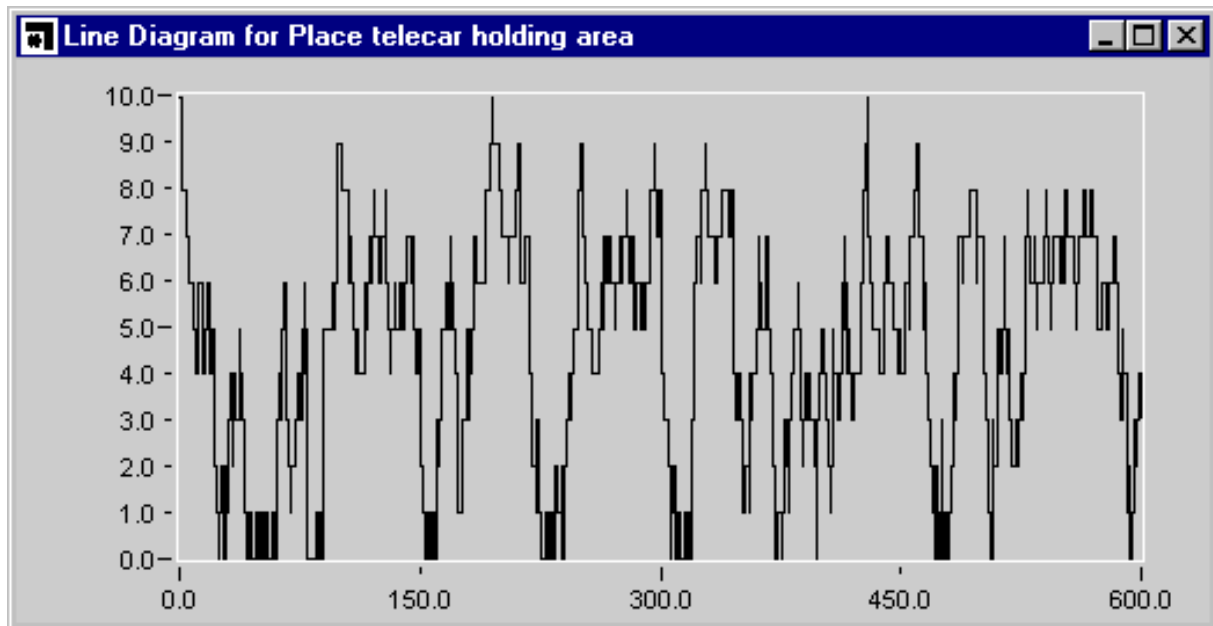**Fig. 4: Histogram (first refinement)**

Fig. 5: Line Diagram (first refinement)

The line diagram in Fig. 5 shows a strong oscillation between the maximum value 'all telecars allocated' and the minimum value 'no telecar available'. This is a direct consequence of our simplification by which we divided all telecars in only ten groups.

3.2 BaggageManagement, step 2

It is obvious that the curve in Fig. 5 would be damped and smoothed if telecars would be better distributed over the tracks. This would be the case if we would invent a better model for the transport of departing baggage from the terminal to the gates.

We assume a uniform distribution for the arrival times of the departing passengers at the terminal. From this we can calculate approximately the time interval between two telecars which bring baggage to the gates. The number of baggage pieces which have to be transported from the terminal to all gates is in 30 minutes approximately:

numberOfTelecarsForDepartingBaggage =

actualNumberOfOccupiedGates * 200.

From this we obtain the time distance between two telecars in minutes:

30 / numberOfTelecarsForDepartingBaggage.

The actual number of occupied gates is known during simulation.

The refined module of BaggageManagement is shown in Fig. 6. There are essentially three remarkable extensions compared with Fig. 3:

- Since we now look on single telecars we have to initialize the place 'telecar holding area' with 4000 token. To do this statically would be very cumbersome. Therefore we initialize this place dynamically at the start of a simulation run.

6

- Using the connector from the place 'telecar holding area' to the transition 'departing passengers' departing baggage will be transported to the gates in rates defined above.

- Finally we have to unload single baggage pieces from the 'Baggage Container' and allocate a telecar for each baggage piece.
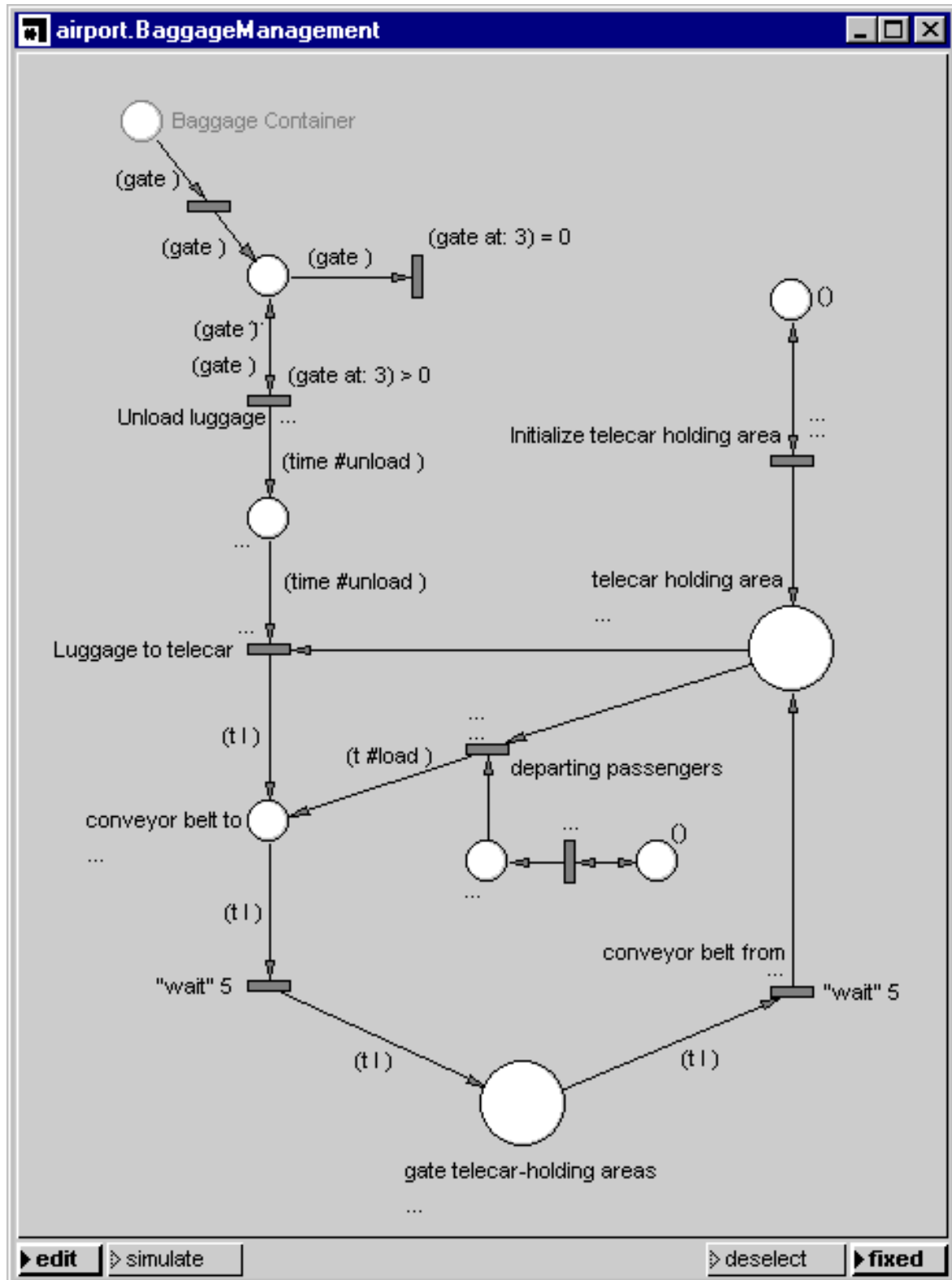

Fig. 6: Module 'BaggageManagement' (second refinement)

The first four line diagrams for the efficiencies 40%, 50%, 60% and 70% are shown in Fig.7 to Fig.10. We see a disastrous deterioration of the baggage system with increasing efficiency of the airport.

To execute simulations using different parameters and to develop a feeling for the behavior of the baggage management system it is convenient to put all relevant windows together and open message windows for the most important parameters. A control panel to execute our model is shown in Fig. 11.
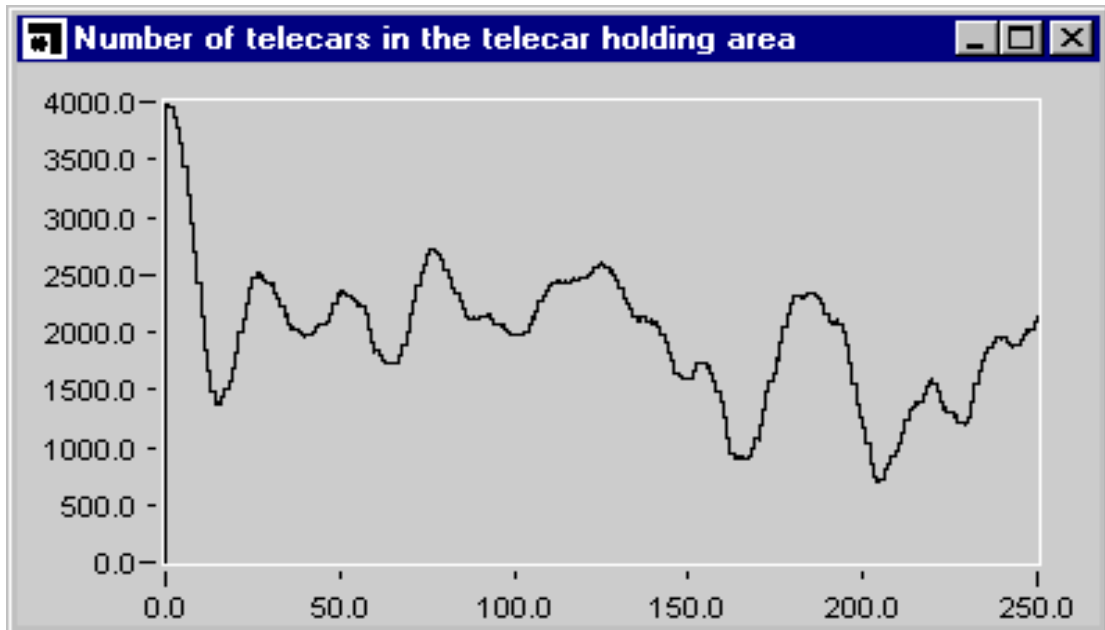

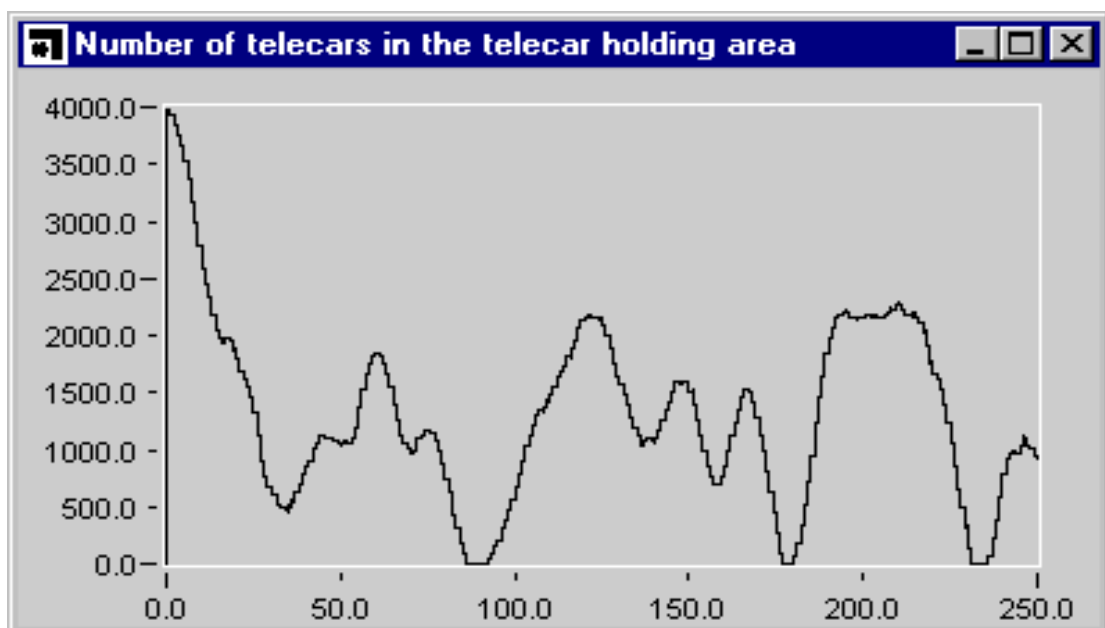**Fig. 7: Telecar holding area for efficiency 40% of the airport**

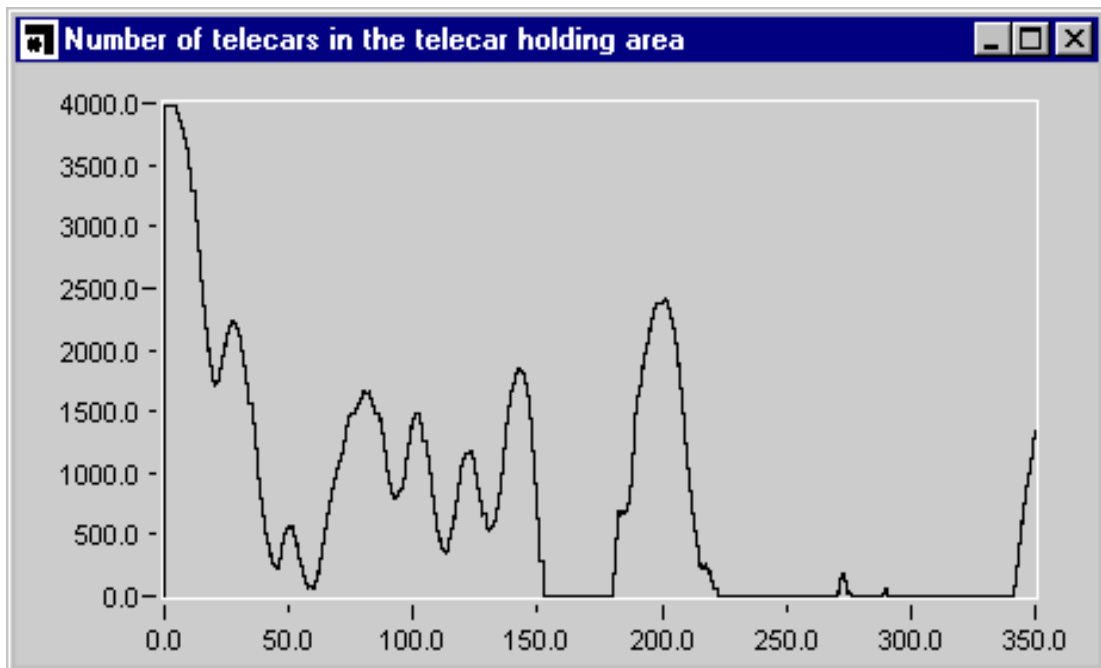**Fig. 8: Telecar holding area for efficiency 50% of the airport**

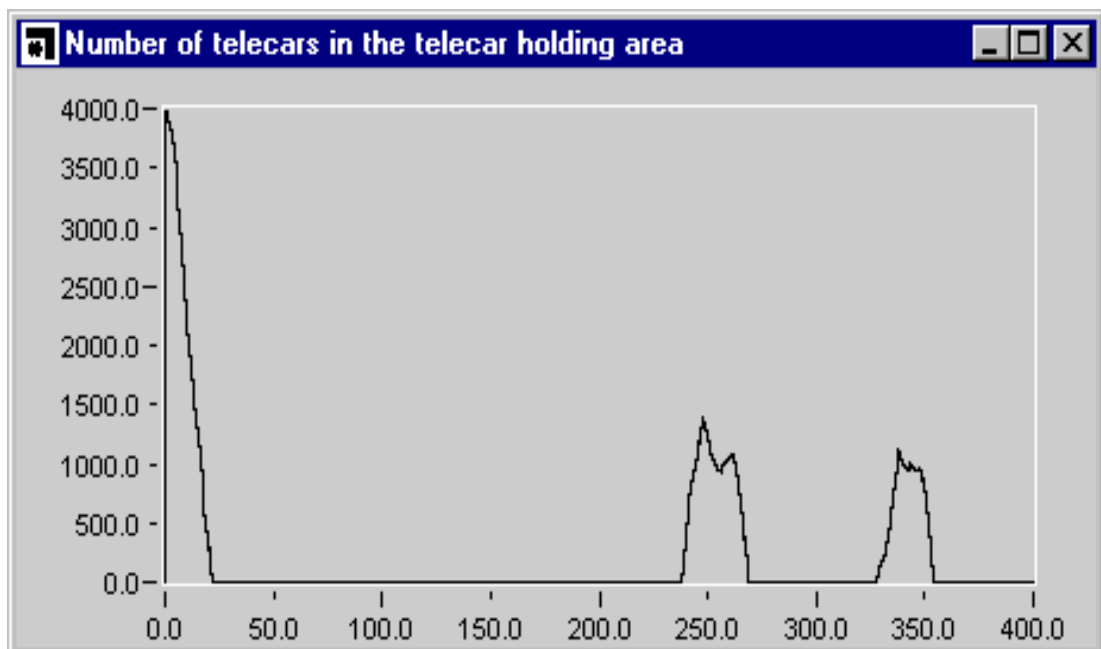**Fig. 9: Telecar holding area for efficiency 60% of the airport**

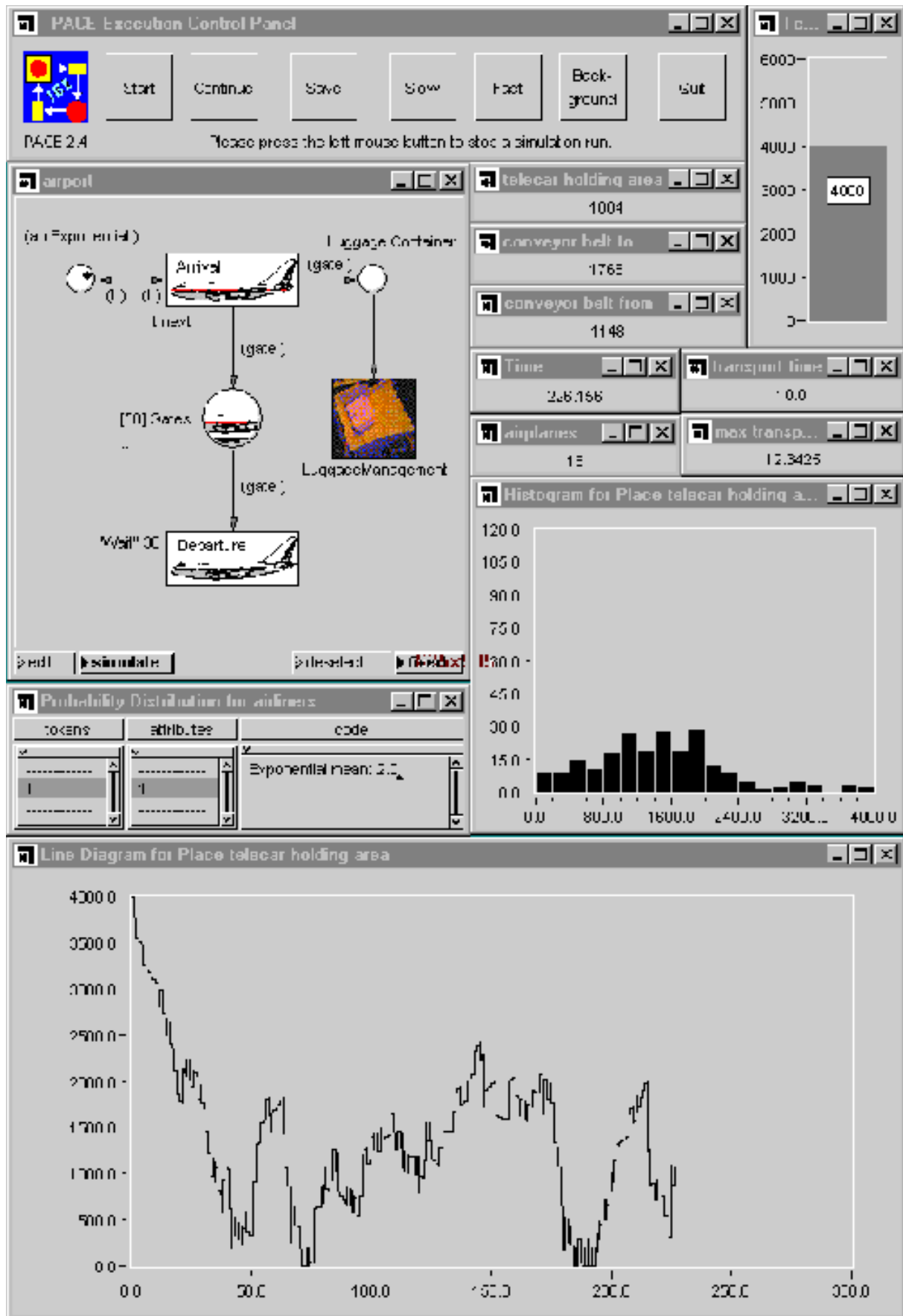**Fig. 10: Telecar holding area for efficiency 70% of the airport**

Fig. 11: User interface for the investigation of the ABS

3.2 BaggageManagement, step 3
Consequences for the passengers

Looking on the simulation results we could ask:

> Why does the baggage management system of an airport like
> the one we have modeled here is working at all?

The answer is: even if there are times with temporarily no telecars in the 'telecar holding area' this may be, at least for medium efficiencies of the airport, of weak influence on the waiting times for baggage pickup.

We therefore change our question and ask now: How much is the delay until the baggage is in the baggage pickup area made longer if not enough telecars are available at the arrival time of an airliner?

To answer this question we give every baggage during unloading the attribute 'unload' and a time stamp (see transition 'Unload Luggage' in Fig. 6). If the telecar with the baggage is processed by the transition 'conveyor belt from' we build the difference of the actual time (contained in the global variable CurrentTime) and this time stamp to get the baggage transport time.

Delay times for arriving baggage start in our investigation with efficiency 50%. For several efficiencies of the modeled airport we obtain the following line diagrams:
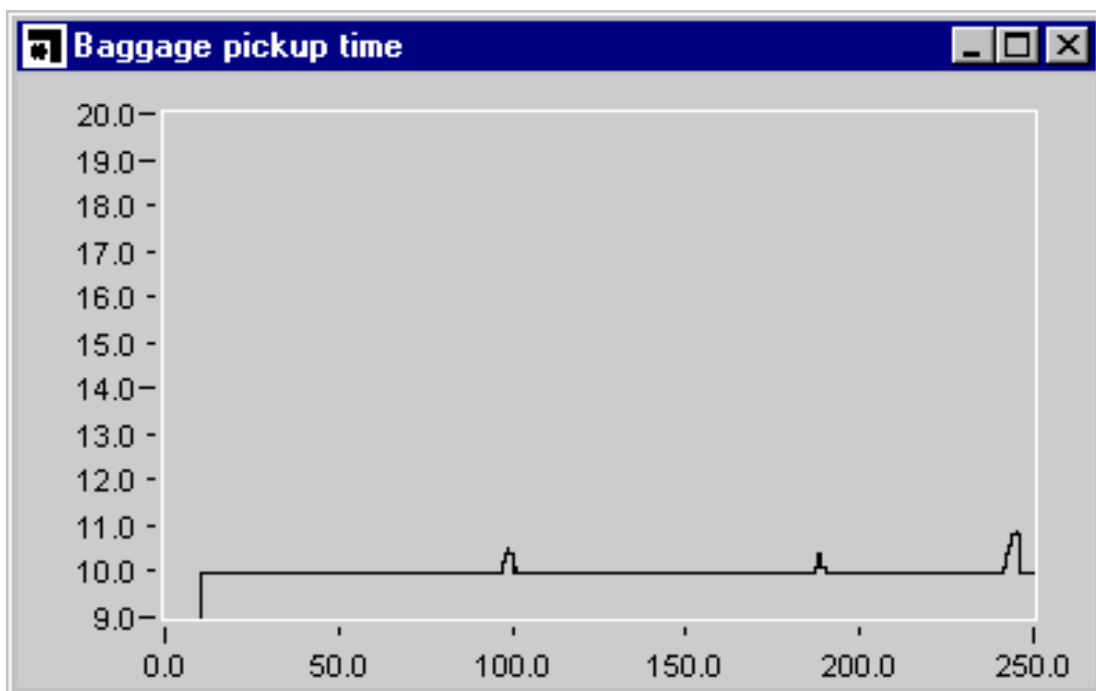

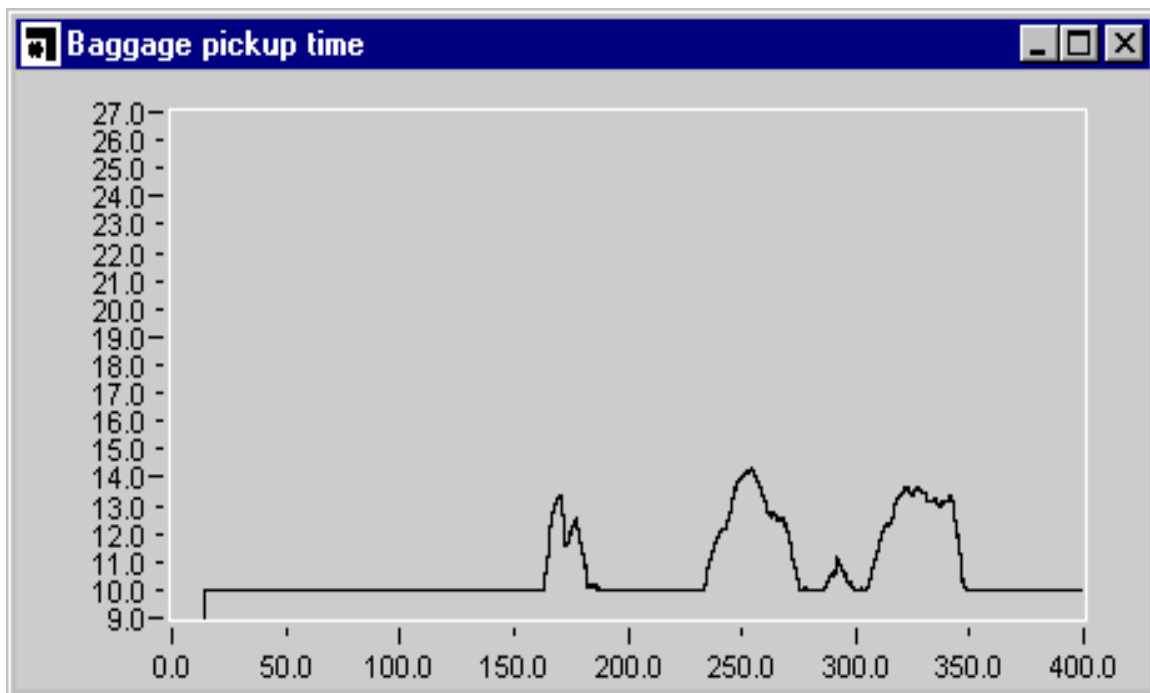**Fig. 12: Delay of bagagge for efficiency 50%**

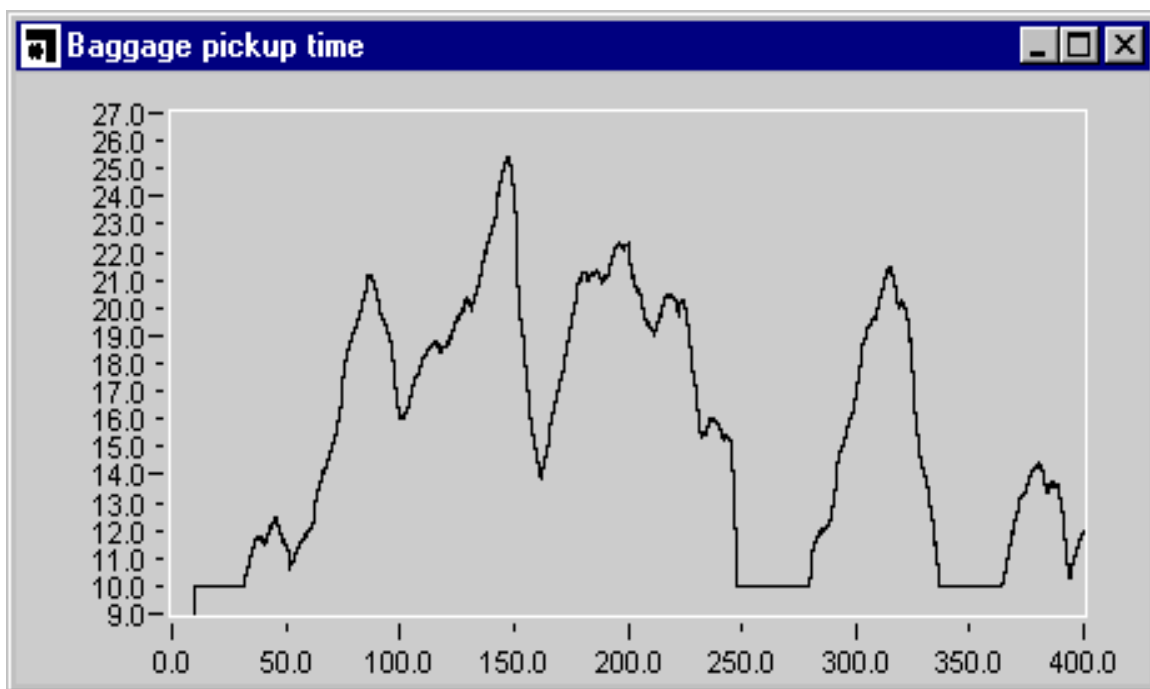**Fig. 13: Delay of bagagge for efficiency 60%**

Fig. 14: Delay of bagagge for efficiency 70%

In our model every time larger than 10 min is waiting time of the passengers in the baggage pickup area. Up to an efficiency of approximately 60% to 65% of the modeled airport we would accept these waiting times. From about 70% efficiency on we expect frequently unacceptable waiting times up to 16 min and even much more for higher efficiencies. We would call the ABS of an airport with these characteristics not designed to the today's state of the art. To reach acceptable waiting times for high efficiencies a lot of extra activities would have to be carried out behind the scenes.

4. Conclusions

Our example shows drastically that the performance of an ABS depends upon characteristic parameters of the considered airport very sensitively. To design such a complex system without pre-verification by an extensive simulation would be a sin against all modern engineering principles.

To upgrade the behavior of the modeled ABS we have two possibilities:

- Extend the hardware of the ABS (e.g. increase the number of telecars and possibly the track system, extend the track system for the use of higher velocities of telecars, etc.) and/or

- use of better strategies for the telecar allocation.

Extending the hardware is usually much more expensive than looking for better strategies. Invent better strategies first and if this is not sufficient propose hardware extensions.

5. Examples for further training

To train your abilities in using the PACE simulator you can make numerous extensions of the presented model. To execute the model you need a fast machine (Pentium 133 or better) and Windows NT or UNIX (Don't use Windows 3.x or Windows 95 for this application). Possible extensions are:

1. If the model is to be used for higher efficiencies the actual number of arriving airliners may be larger than the number of gates. Implement an airliner queue.

2. Change the strategy for baggage pickup as follows:

   > If an airliner arrives 100 telecars for baggage pickup are sent to the gate. If the number of baggage pieces is known (after unloading of the airplane) send the number of missing telecars to the gate. Be aware that the loading of the first 100 telecars can be done while the rest of the telecars is under way. What probability distribution can be used to model the distribution of the number of baggage pieces?

3. Increase the number of telecars to reach acceptable waiting times for waiting passengers in the baggage pickup area also for high efficiencies (90% and more).

4. Use the description of the Denver airport in [1] as a base for a realistic graphical model of the airport. Design a Petri net which shows the terminal, the concourses, the gates and the tracks for the telecars between the terminal and the gates. Iconify the net elements and try to get your airport working.

References

[1]   John Swartz: Simulating the Denver airport automated baggage system,
Dr. Dobb's Journal, Vol. 22, Issue 1, January 1997, pp. 56-62

[2]   PACE, Version 2.4, 1997
IBE, Postfach 1142, D-85623 Glonn, Germany