# Process-oriented Simulation of Air Cargo Flows within an Airport Network

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## Abstract

International air cargo is transported by worldwide networks. Arriving from feeder airports cargo is typically bundled at a continental hub airport and forwarded over large distances to yet another hub airport. From there it is distributed to the destination airports. This bundling and distribution through hubs becomes more and more important for air cargo transportation. Some of the hub-locations have almost reached their capacity limit already today. The challenge is to use the available resources most effectively, to reduce expenses und to allow further growth. Our recent research results show, that a comprehensive cargo flow control considering different strategies can support airport cargo networks to determine a more effective point of operation. The examination is conducted by modelling the relevant hub-elements using the process chain paradigm ProC/B.

## 1 Introduction

The prognosticated growth rate for air cargo is higher than for international goods traffic altogether. Beyond that current analyses of air traffic data show an increased shift of air cargo to a few, therefore more frequented airports. The bundling and distribution of air cargo through hubs will become more important for the traditionally labour divided, international air cargo. Net strategies of airlines and carriers will be aligned towards own hubs at these international hub airports. Within this concentration process it is to be expected that the partner airline and carrier must cooperate more closely and have to optimise the operation of their global transportation services regarding the time-shared offer, the quality and the costs. In particular the super ordinate view of the cargo flow between the hub locations is not adequately considered so far and potentials for optimisation are getting lost

## 2 Approach

The Fraunhofer Institute for Material flow and Logistics - IML and the University of Dortmund are researching within the framework of the Collaborative Research Center 559 "Modelling of Large Logistics Networks" to reveal these optimisation potentials in the air cargo transport chain. The focal point lies on the examination of effects that different scheduling strategies have on the utilisation of resources and on the expenses in the air cargo network overall. For this purpose a model of the courses of the shipments through the air cargo transport network has been developed and analysed.

# 3 ProC/B

ProC/B is a formalised version of the process chain paradigm that was developed to support the design of logistics networks. ProC/B provides the possibility of modelling and analysing a logistics system in a single toolset. The ProC/B paradigm is based on a hierarchical tree structure. Each tree node is built of a Functional Unit (FU) that may offer services to the level above and use services offered from below in the hierarchy. E.g. FUs could be used to model a whole company at the highest level, departments of a company at the sub levels and the tasks of one working group member at the lowest level. FUs of all hierarchy levels are built from the same set of elements and contain Process Chains modelling the sequences of activities in the respecting hierarchy level. Activities may use the services of lower levels to be performed. The hierarchy is closed at the lowest level (leaves level) by FUs that have a standardised behaviour and model basic time (Server-FU) or space (Counter-FU) consumption. At the highest level (root level) the hierarchy is started by sources that generate processes following the series of activities and modelling a cut to the real environment that is creating processes with the rate that would be found out when viewing the real system. All processes end when reaching a sink.

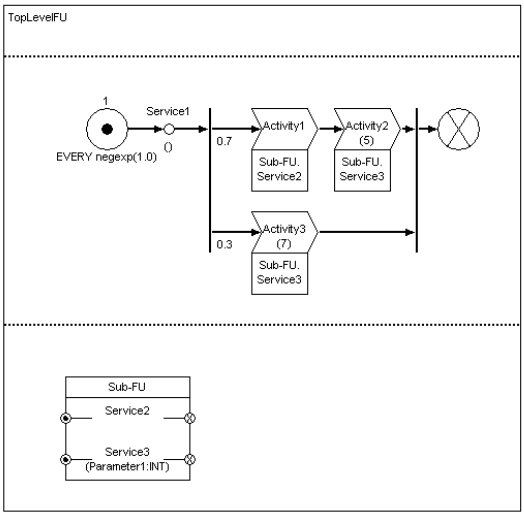


**Figure 1: Exemplary FU**

Fig. 1 shows an exemplary FU (`TopLevelFU`) including the exterior view of a sub-FU. The service `Service1` starts on the average every 1 time unit (with a negative exponential distribution) one process at a source. The service has two alternative series of activities modelled by means of a pair of connectors. The first alternative with two activities is chosen by the processes with a probability of 70% and makes use of the services `Service2` and `Service3` of FU `Sub-FU` while the second alternative (with a probability of 30%) only includes one activity using the service `Service3` with a different parameter than the first alternative. After performing these activities the process ends at the source.

Before conducting the analysis the models have to be supplemented with information about the analysis objectives. Those can consist of pre-defined measurements like populations, throughputs, turnaroundtimes or utilisations which can be selected for calculating for every FU resp. their services. Beside these also self-defined measurements (Rewards) are supported. In contrast to the pre-defined measurements the modeller is responsible for the updating of self-defined measurements which is done by placing Update-elements into the process chain, wherever the corresponding value changes. The pre-defined as well as the self-defined measurements are evaluated automatically through results like mean values, confidence levels and standard deviations.

ProC/B has proven suitable for the described problem in particular due to its ability to consider and illustrate the utilisation of resources by Rewards. In addition values of technical variables result from ProC/B, which can directly be used in the downstream cost analysis, as demanded.

# 4 Model

The Fraunhofer IML and the University of Dortmund have developed a hands-on simulation model of a representative air cargo network, by means of ProC/B. The model is representing the flow of air cargo shipments between two corresponding hub airports (see fig. 2). The hierarchy is three-stage, see fig. 3. On the first level the first Hub B and second Hub C are located, beside the air transports. On the next level, the processes at each hub are positioned, while on the third level the cargo handling processes are represented in more detail. The levels are linked by FUs.

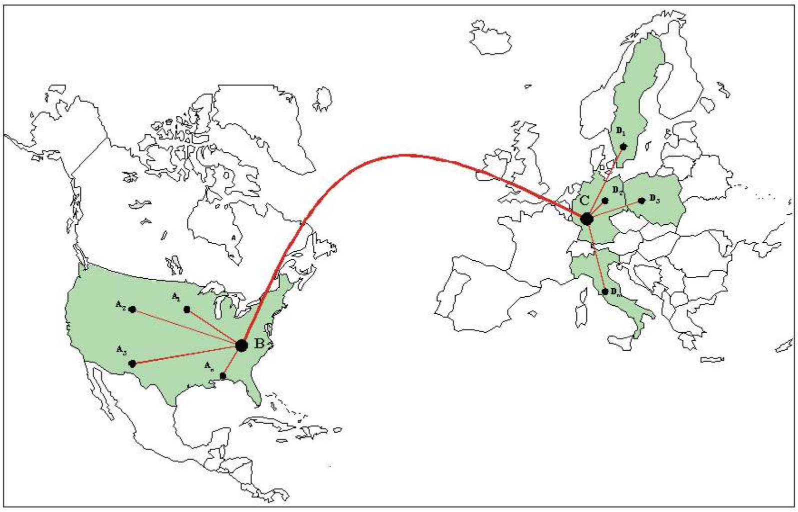
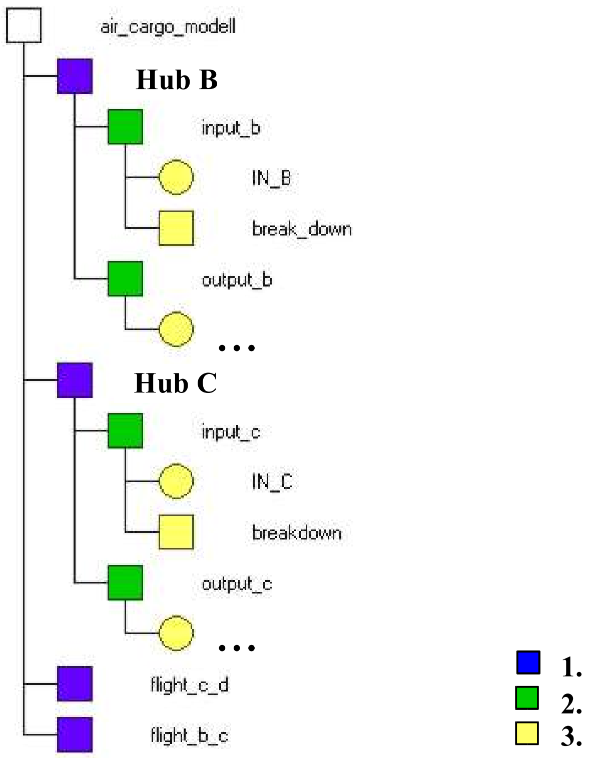


**Figure 2**

The material flow overall within the considered system can be controlled by using different strategies. For analysing and optimising the air cargo flow within the air transport network, the material flow is simulated and the effects of different strategies are being compared. The treated strategy parameters are personnel strategies, collecting and distributing strategies, build-up strategies at the hubs, and break-down strategies at the hubs.

**Figure 3: Overview modelled air cargo network**



While the time and costs needed to run through the processes of the air and ground transport are fixed, the same for handling processes can be varying. Therefore the processes on the third level are the ones used in the listed strategies. Above mentioned strategies can be varied by varying predetermined parameters. By doing so, the interdependencies between the nodes can be analysed, comparing the effect of each variation. Combining strategies can lead to a higher effect instead of looking at each strategy alone and adding the effects later . Therefore the combined effects of the strategies have been considered as well.

The costs for the cargo handling processes are mainly subdivided into cost for the warehouse, ground and personnel. The costs and the required warehouse ground space are influenced by the applied storage techniques and the stock. The simulation provides the gradient of the stock (see fig. 4) and those again provide the foundation for the downstream analyses of warehouse and ground charges. Additionally the stock depends on the system load and the available capacities for the cargo build-up (BU) and break-down (BD). The capacity again is determined by the used ground space, the deployed personnel as well as by the applied techniques for the BU and BD. ProC/B allows to determine in the downstream calculation the required ground space through the output of the self defined Rewards.

Amongst said features, the model comprises a systematic data generation module, the integration of several flight plans and the bundling of shipments headed for the same destination in ULDs (Unit Load Devices). The model has been validated by simulation runs based on load distributions derived from real shipment data. Within the chosen representative air cargo network the material flow of single shipments is controlled by specific parameters and as described, stocks are being monitored.

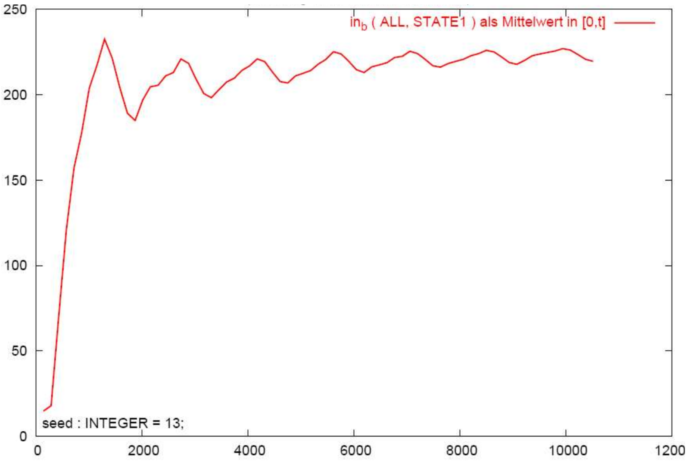


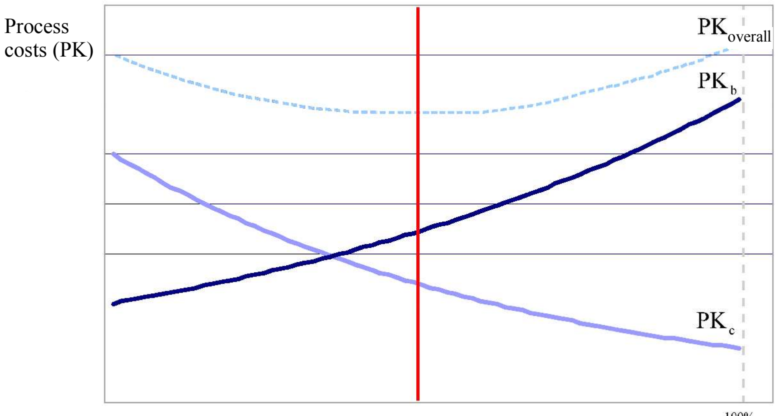
**Figure 4: Exemplary stock gradient**

# 5 Results

As the central result it could be shown, that interdependencies between hub airports regarding their overall performance exist and that optimisation potentials within the existing air cargo network can be pointed out by the model. Out of all strategy parameters the collecting and distributing strategy by bundling shipments to destination specific transfer units has proven to be an effective one for reducing costs of the whole network. The result is an overall cost gradient of the considered subnet in dependence on the bundling quota. This cost gradient again depends on the different processing costs of each station which the cargo shipments pass on their way through the air cargo transport network.

If the sum of the costs at the first hub is plotted against the costs at the second, in dependence on the bundling quota, two reciprocal cost curves unfold, see fig. 5. The bundling quota relates to the bundling and its potential on the more economical hub. As an overall cost consideration, the sum of both cost curves result in said over-all costs curve for the considered system. If the resources on the more economical hub are increasingly used, the total costs in the considered air cargo transport network can be reduced up to a certain bundling rate $\gamma_{opt}$. If this bundling rate is surpassed, the costs overall will start to rise again, see fig. 5.

The strategies controlling the shipment flow within the air cargo transport network, have proven thereby to be an important approach for an optimisation overall. As an additional result the ability to check the dimensioning of warehouses with the model can be seen.



Bundling quota
(γ)

Based on the identified effects and correlations of organising and steering processes within and through the air cargo transport network, the identified rules shall be examined for their general validity. Furthermore it is an aim to abstract this knowledge, to make it generally applicable in a decision support system. For this purpose additional system loads will be generated.

A comprehensive cargo flow control will lead to conflicts between the parties involved, since some of the participants will have initially higher costs. Those have to be compensated for the parties concerned. This might be accomplished by collaborating, adopting a cost benefit sharing model. The research and evaluation of such compensation measures have yet to be done.

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