



## **Chapter VIII**

# **Linking Economic Optimisation and Simulation Models to Environmental Material Flow Networks for Ecoefficiency**

Bernd Page, University of Hamburg, Germany

Volker Wohlgemuth, University of Hamburg, Germany

## **Abstract**

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*This chapter outlines Material Flow Networks as a special modelling approach in the context of ecobalancing, that is, for modelling the environmental impacts of economic activities. This approach focuses on understanding the underlying material and energy transformations and the environmental impact of the resulting material and energy flows. The software tool Umberto® was the first product in the market for material flow analysis based on Material Flow Networks. This approach models the material and energy flows in production and distribution systems by means of Petri-Net notation with transitions (i.e., the material and energy*

*transformation processes), places (i.e., inventories for material) and connecting arrows (i.e., energy and material flows). Using the Microsoft COM-technology, optimisation and discrete simulation models of economic processes can be embedded into ecologically oriented Material Flow Networks as complex external transitions. Three application examples (a transport optimisation model, a production and an inventory simulation model) are presented to demonstrate this useful approach of combining different modelling techniques in ecomanagement and its potential for ecoefficiency in resource and energy use.*

## **Introduction: Material Flow Networks – Concepts and Software Support**

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Material Flow Networks describe the flow of materials and energy within a defined economic system. The representation and evaluation of these material flows and their impact on our environment caused by human economic activities has become one of the most important tasks of the so-called environmental management (Rautenstrauch, 1999). Material flow networks have their origins in several disciplines. The most important sources are the Petri-Net theory from computer science as well as double-entry bookkeeping and cost accounting from business administration. The Petri-Net approach is used to describe the structure of a material flow network. Material flow networks consist of three elements: transitions, places and arrows. Mathematically speaking, the structure of a Petri-Net is a 3-tupel  $N = (T, S, F)$ ,  $F \subseteq (S \times T \cup T \times S)$ , with  $T$  being a set of transitions,  $S$  a set of places and  $F$  a set of arrows between transitions and places (Baumgarten, 1996). Thus, there are no direct connections between places or transitions.

In material flow networks the transitions, represented in diagrams by squares, stand for the location of material and energy transformations. Transitions play a vital role in material flow networks, because material and energy transformations are the source of material and energy flows. Another defining characteristic of material flow networks is their concept of place. Places separate different transitions. This allows a distinct analysis of every transition. Beyond that places can describe inventories for materials. Circles are used in diagrams to represent places. Arrows show the paths of material and energy flows between transitions and places. The diagram in Figure 1 illustrates a material flow network with several transitions and places connected by arrows.

The 3-tupel  $N = (T, S, F)$  only describes the static structure of a Petri-Net. Another part specifies its dynamic behaviour. This part is necessary to model the

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