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Transportation delays in reverse logistics

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ABSTRACT

In this paper we extend and apply MRP theory towards reverse logistics including the considerations of transportation consequences. Our aim is to demonstrate the versatility obtained from using MRP theory when combining Input–Output Analysis and Laplace transforms. This enables an analysis of a supply chain including four sub-systems, namely manufacturing, distribution, consumption and reverse logistics, where the geographical distance between the activities play an important role. The main focus in this paper is on reverse logistics (recycling, remanufacturing). Especially we wish to model the evaluation of disposal and reverse activities far away from agglomerations, which often means an improved environment for nearby inhabitants. This is also illustrated in a numerical example. We use the Net Present Value as a measure of the economic performance.

Our ambition is to show that supply chain sub-systems may accurately be described using input and output matrices collected together in corresponding matrices for the system as a whole. Activity levels in each sub-system govern the speed of the respective processes, and these activity levels, in general, will be considered as decision variables.

We now analyse reverse logistics activities in which the flows of materials and goods are typically divergent (arborescent processes), similar to properties of the distribution sub-system, and recent results on the extensions of basic MRP theory introducing the concepts of *output delays* and the *generalised output matrix* are also introduced here, when modelling the reverse logistics sub-system.

1. Introduction to the reverse logistics, studied in integrated supply chain

Optimal decisions on (i) where to produce, (ii) how to distribute the product and (iii) at what time to order or deliver items in an integrated supply chain can be successfully discussed and evaluated in a transformed environment, where lead times and other time delays are easily considered. This approach, for instance, has earlier been applied to the site and capacity selection problem (Bogataj et al., 2011), treating where it is best to locate a facility and what capacity is needed. Lead times in the entire supply chain can be analysed in the Laplace transformed space in a compact form using MRP theory.

As in (Grubbström et al., 2007) in this paper we classify activities of the integrated supply chain into four distinct sub-systems:

– manufacturing,
– physical distribution,
– consumption and
– recycling or remanufacturing.

Various operating stages in the logistic chain (nodes of the chain) can be represented by simple models of material transformations. In each process cell values are added and/or costs incurred. At each processing stage there is a supply and a demand, and often both are stochastic by nature. However, in this paper we only consider deterministic processes.

Inventories provide insurance against the risk of shortage of goods in each cell of the logistic chain. They are limited by the capacity of each processing node of the chain and by the transportation capability of input and output flows, and thereby influence all kind of inventory costs.

The flows of items in supply chains influence transportation costs and costs of activities in logistic nodes of the global economy, and consequently the Net Present Value (NPV) of the cash flows generated by all activities performed in logistic networks. The cost of item flows between the two processes depends on their location and the transportation mode adopted. Important in this context is the location of reverse logistics activities and disposal units, with spillover of negative pollution externalities. Sometimes these effects are not included in the price of items, but

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they create high external costs to nearby agglomerations, and normally decrease by distance. Arguments for applying the Net Present Value as a superior criterion for capturing economic consequences of working capital decisions are found in, e.g., (Grubbström, 1980).

An integrated supply chain includes the purchasing of raw materials, manufacturing with assembly and/or extraction and the distribution of the produced goods to other production units, or to the final clients, where consumption defines the activity levels. A fourth sub-system, the main subject of our analysis here, is reverse logistics, which we model using the same formal properties as for the other sub-systems.

In a supply chain, key variables that have to be considered for each activity are its activity level and timing, the inventory level and lead times and other delays.

Managers of a supply chain have two main goals: (a) to keep the level of inventory in the supply chain as low as possible reducing inventory costs while balancing the these costs against ordering costs; (b) to move the products in their continually changing form or location from raw materials to finished goods, and to manage the physical distribution to the final consumer at different locations, or back into remanufacturing or recycling as fast as possible.

We consider the supreme objective to be to achieve the maximal Net Present Value (NPV) of all activities in the supply chain. By releasing wastes into the environment, supply chains may avoid costs of mitigation of pollution. If they do not have to bear them, market prices and the resulting NPV do not reflect these costs accurately, which would encourage a higher consumption level. By reallocating reverse activities and disposals to more distant locations, the cost of transportation increases and externalities decrease.

Raw materials or components are delivered and stored in raw material warehouses at the production centres. From there, raw materials and components are withdrawn as much as they are needed from the production centres. There raw materials and components are transformed into subassemblies, subassemblies are transformed in semi-finished goods, and so on till the final production centre, where finished products are manufactured. From there finished goods are put into final product storage. From storage centres finished goods are delivered to distribution centres, or to their own warehouses, or directly to retail outlets, often at several different locations. There goods are available to the final consumer.

The fourth sub-system, which can be considered in a similar way as the first (manufacturing) and second (business logistics), is the reverse logistics sub-system. Here the main question is when to include activities of the reverse logistics in a supply chain and how the increased percentage of recycling items in production affects the NPV of the total integrated chain. This is particularly difficult to evaluate when lead times are varying and when backlogs appear.

The compact analysis in the frequency domain, in which lead time perturbations may be studied, might also provide advice aiding in direct evaluations of the European Union (EU) directives on environmental protection by recycling and remanufacturing activities.

This research has a close tie with supply chain control in material requirements planning (MRP) studies. Basically, it consists of a set of logically related procedures, decision rules and records designed to translate a Master Production Schedule into time-phased net requirements (Orlicky, 1975). To fulfil the planned coverage of these requirements, a schedule needs to be implemented for each activity and its inventory.

A modern approach combining Input–Output Analysis and Laplace transforms was introduced by Grubbström and his Linköping School, for overviews see (Grubbström and Bogataj, 1998) and (Grubbström and Tang, 2000).

This approach gives us good theoretical and practical results also for the extension of the analysis to distribution (Bogataj M. and Bogataj, 2003) and especially to the reverse logistics part of a supply network first studied in (Grubbström et al., 2007), treating transportation costs and transportation delays in a less detailed way. The algebraic structures for various timing relationships were developed more thoroughly in (Bogataj and Grubbström, in press).

The concept of all four sub-systems of an integrated logistic chain can be illustrated as in Fig. 1.

From one stage to another, physical characteristics of the items and their location change step by step. In the process of globalisation, the physical distances between the pairs of production cells or between production and distribution cells increase. The restrictions in local legislation drive out disposal and reverse logistics activities from some countries to those, where environmental costs are lower, increasing transportation costs and lead times between the activities. Where to locate an activity influences transportation costs and lead

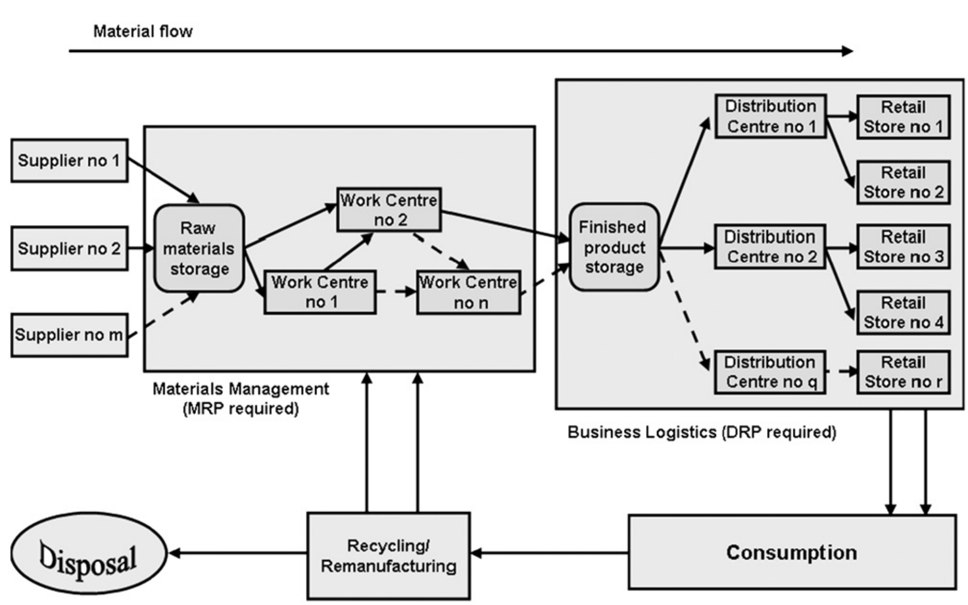

Fig. 1. Concept of all four parts of an integrated logistics chain system.