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Int. J. Production Economics 89 (2004) 165–174

international journal of production economics
www.elsevier.com/locate/dsw

A functional model of supply chains and waste

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Received 30 April 2002; accepted 16 January 2003

Abstract

Waste management is a strategic supply chain issue. This paper explores the definition and classification of waste from different viewpoints. A generic functional model is presented for modelling the material and flow of waste from both a physical and cumulative cost perspective. The application of the model is illustrated through a case study. The research demonstrates that improved waste management practices can simultaneously reduce disposal cost as well as generating additional value through the creation of new supply chains that reuse or recycle materials.

Keywords: Waste management; Modelling; Supply chain

1. Introduction

Waste is a strategic issue in the supply chain for a variety of reasons. Firstly, companies are seeking to reduce cost by minimising all types of waste within their internal and external supply chains. Secondly, the amount of national and international legislation and regulation governing waste management is increasing. Thirdly, customers and consumers are becoming more concerned about the impact of products and services on the environment.

The European Union (EU) 10-year environmental programme aims to achieve a de-coupling of resource use from economic growth through improved waste management (OJ L 242, 2002). Great Britain produces approximately 9 tonnes of waste for each tonne of finished product (BIFFA, 1997; EA, 1999). The disposal of industrial waste to landfill, excluding transport, costs English and Welsh industry more than £650 million per annum (Heidrich, 2001). These costs are likely to increase with the implementation of new taxation, legislation and regulation.

Research has suggested that effective waste management may be constrained by barriers between the environmental and operations management functions (Heidrich, 2001; OECD, 1995). Effective waste management requires the coordination of business functions and manufacturing processes throughout internal and external supply chains.

The objectives of this paper are to:

1. Explore alternative definitions of the term 'waste';

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0925-5273/03/$ - see front matter
doi:10.1016/S0925-5273(03)00045-8

2. To describe a functional model that represents supply chains in terms of processes, their interconnections, material flows, waste streams and cumulative cost. The model may be used to improve communication, analysis and provide a tool for optimisation;
3. To report on the application of the model by a university research team at PlasticCo, a medium-sized company producing perishable plastic products.

2. Waste

Waste is defined and classified in several ways. In lean manufacturing, waste may be considered to be any activity which consumes resources or creates cost without producing any form of offsetting value stream (Porter, 1991; Porter and van der Linde, 1995). Ohno (1988), the founder of the Toyota Production System, described seven general types of waste:

1. Making too many items or making items too early causes the *waste of overproduction*. This situation leads to excessive lead-times and storage times with increased inventory;
2. Any time that materials or components are not having value added to them is described as the *waste of waiting*;
3. The movement of materials within the factory adds cost but not value. This is known as the *waste of transportation*;
4. The use of a large expensive machine instead of several small ones leads to pressure to run the machine as much as possible rather than only when needed. This is known as the *waste of inappropriate processing,* which may lead to poor layout, extra transportation and poor communication;
5. Inventory tends to increase lead-times, reduces flexibility and prevents the rapid identification of problems. This is described as the *waste of unnecessary inventory*;
6. The *waste of unnecessary motions* relates to ergonomics. If operators have to bend and stretch it may lead to quality and productivity problems;
7. The *cost of defects* includes internal failure (scrap, rework and delay) as well as external failure (repairs, warranty cost and lost custom).

Waste may arise from individual processes or relationships between processes. Wastes 4 and 6 result from individual processes. Wastes 1, 2, 3 and 5 above arise from relationships between processes. Waste 7, defects, emanate from either individual processes or relationships between processes.

Bicheno (2000) identifies 'new' wastes: the waste of untapped human potential; the waste of inappropriate systems that add cost without adding value; wasted energy and water; wasted materials; wasted customer time and the waste of defecting customers—it may cost many more times to acquire a customer than it does to retain one. The research team have found it helpful to describe non-physical waste as 'loss' to avoid confusion with physical waste.

Waste managers tend to consider waste mainly in its physical form, which may be classified according to its type, source, material type or characteristics. There are various international legal definitions of the term 'waste' including:

- The EU Framework Directive on Waste (OJ L 78, 1991, p. 3) defines waste as "any substance or object that the holder discards, or intends or is required to discard". For the purpose of regulation, the Directive defines 16 categories of waste, the last of which covers any materials, substances or products that are not contained in the other categories.
- The Basel Convention, which covers hazardous and industrial wastes, provides the following definition: "wastes are substances or objects which are *disposed* of, or are required to be *disposed* of by the provisions of national law" (UNEP, 1989, article 2). The convention was introduced by the EU in 1993 and by 1999 had been adopted by 130 countries worldwide.

The EU definition of waste is absolute, whereas the Basel Convention definition, adopted by the United Nations, is subject to national law. The legal situation leaves a lot of room for interpretation. The resolution of cases by the European

Court of Justice has confirmed a broad definition of the term 'waste': "(s)omething can simultaneously be 'waste', a product, good, raw material or substance, irrespective of economic value, collection, processing, etc. This definition of waste is independent of qualitative or commercial value, possible market, geographical purposes or the destination of waste" (Bontoux and Leone, 1997, p. 10). It would seem that this definition makes no distinction between waste and non-waste. Additionally, there are many other national and international legal definitions. Nevertheless, the precise definition of physical waste is important as it forms the basis of legislative and regulatory controls that govern the handling, processing, transportation and disposal of waste. The OECD is therefore seeking to define a common terminology for waste (OECD, 1998).

The EU has also selected specific types of waste ('waste streams') which are receiving priority attention through legislative control (EC, 1999). These include: packaging, end-of-life vehicles, batteries, electrical and electronic and hazardous household waste. The production of waste is reported in terms of its source, such as municipal solid waste, industrial and commercial waste, wastewater, etc. (DETR, 2000). Waste can be classified according to the type of material e.g. glass, paper, aluminium, etc. It may also be considered in terms of its characteristics, including its effect on health; for example, hazardous/non-hazardous, or radioactive.

Waste may be considered in terms of processes. It may be caused by process variability or uncertainty. Furthermore, waste may be transformed into a useful commodity by the application of additional processes. The notion of waste is often relative. Material becomes waste when it loses its primary function, but it may have a secondary function. Waste in one context may be a raw material in another context; in this case the concept of waste may be relative to the owner or process (Bontoux and Leone, 1997). Operations managers are responsible for the processes and interconnections that produce 'waste', whereas environmental managers are responsible for ensuring appropriate waste management to ensure economy, safety and compliance with the law. Integration between these functions and responsibilities, for example, through the use of environmental management systems, may reduce waste production and disposal.

Several researchers have used functional modelling methods to model waste and waste management processes. Bullinger and von Steinaecker (1999) used Petri Nets (Peterson, 1975) to model material flow throughout a product's life cycle to capture environmental information. Sarkis (1995) used the Integrated Computer Aided Manufacturing Functional Modelling Method, known as $IDEF_0$ (Bravoco and Yadev, 1985), to model the product development lifecycle and its impact on the environment. These methods provide a process-based view that facilitates analysis and communication between organisational functions. Thierry et al. (1995) investigated the strategic issues in product recovery management. They presented a functional model of the supply chain for waste management, product recovery and reuse that showed the forward and return flows of material. The functional model described in the next section considers material flow, waste (physical and non-physical) and cumulative cost.

3. A functional model of waste management in supply chains

The manufacture of goods may be conceptualised as a supply chain in which raw materials are transformed into final product through a series of linked processes. Each process may add value, but may also create physical and non-physical waste. It is also possible that activities that link processes may also create waste.

Harland (1996) describes four main uses of the term supply chain:

- The internal supply chain that integrates business functions involved in the flow of materials and information through a business;
- The management of dyadic, or two party relationships between customers and suppliers;
- The management of a chain of businesses;
- The management of a network of interconnected businesses involved in the ultimate

provision of product and service packages required by end customers.

Fig. 1 shows a generic functional model that illustrates the flow of materials and the associated increase in cumulative cost per unit through the processes and interconnections in a supply chain. The figure uses thick dotted lines to represent companies (the external supply chain) and thin dotted lines to show different departments within the companies (the internal supply chain). Thus both internal and external supply chains can be represented. The model comprises two parts: a mass balance that includes physical material flow and waste destinations; and a cumulative cost curve, which includes costs associated with processing, physical and non-physical waste and disposal. The mass of raw material input is equal to the sum of the output masses, including physical waste. Individual companies may be responsible for one or more processes. Physical and non-physical waste may arise from individual processes; for example, a machine may produce some defective parts or an inspection activity may add cost but not value. Waste may also arise from the interconnection between processes, such as transport cost or damage caused during transit.

The model allows physical and non-physical waste to be represented for both processes and interconnections. The physical waste created can be reduced through improvements in the processes or their interconnections. This represents the first level of the waste hierarchy. The waste hierarchy includes various options for managing physical waste. The order of preference is: avoid, reuse, recycle, energy recovery and as a last resort the controlled final disposal e.g. incineration without energy recovery and landfill (OJ L 78, 1991). In the model, the destinations of waste that result in mass transfer are classified as reuse, recycle, energy recovery and safe disposal.

Each process and interconnection adds cost, which is illustrated by a cumulative cost curve. Cost may arise from material purchase, material processing, direct and indirect labour, transportation and disposal. Non-physical waste (as described in Section 2) results in additional cost. Physical disposal may entail additional cost, for example, landfill charges, or may generate additional revenue in the case of reuse or recycling.

The aims of the model are: (i) to provide a methodology that can represent, analyse and optimise material flow, waste utilisation and cumulative cost in a wide range of internal and external supply chains; (ii) to reduce barriers to effective waste management by facilitating communication within and between organisations.

This generic model provides a straightforward mechanism for analysing supply chains, waste and cost. Firstly, a mass balance can be performed to reconcile the various material flows including raw material, intermediate and final products. Secondly, the model, together with detailed costing information, enables the impact of changes to the processes, interconnections or waste streams to be evaluated. It is shown that the cumulative cost of material per unit mass increases through the supply chain.

Waste managers may concentrate on waste streams that are subject to legislative or regulatory controls. Operations managers are likely to focus on minimising those waste streams that represent the greatest cost. As a consequence, it is possible that large amounts of physical waste may be tolerated by operations managers during the early stages of production, if the cost associated with these waste streams is relatively low. In such situations, overall profitability may be insensitive to changes in disposal cost (e.g. landfill charges). Opportunities for releasing value from waste streams may be neglected. It may be possible to add internal or external processes to the supply chain to either recover raw materials, or to produce a secondary product, which gives rise to additional value streams. Furthermore, effective segregation of waste streams may help to maximise potential value and minimise disposal cost.

4. The application of the functional model at PlasticCo

PlasticCo is a medium sized company, based in England, which supplies perishable plastic products to both home and export markets. Fig. 2 shows the functional model of the

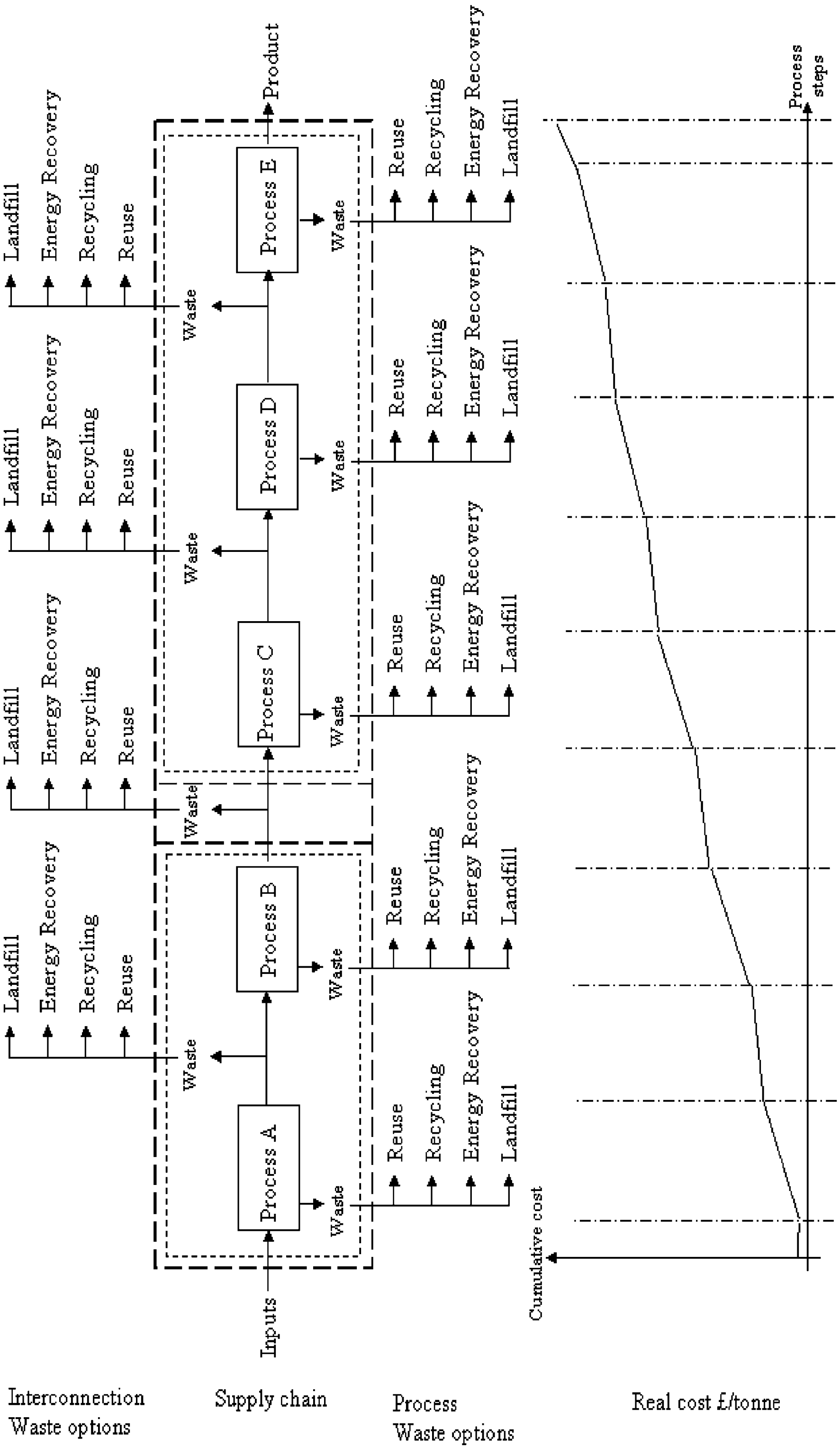

Fig. 1. A generic model of supply chains, waste and cumulative cost.

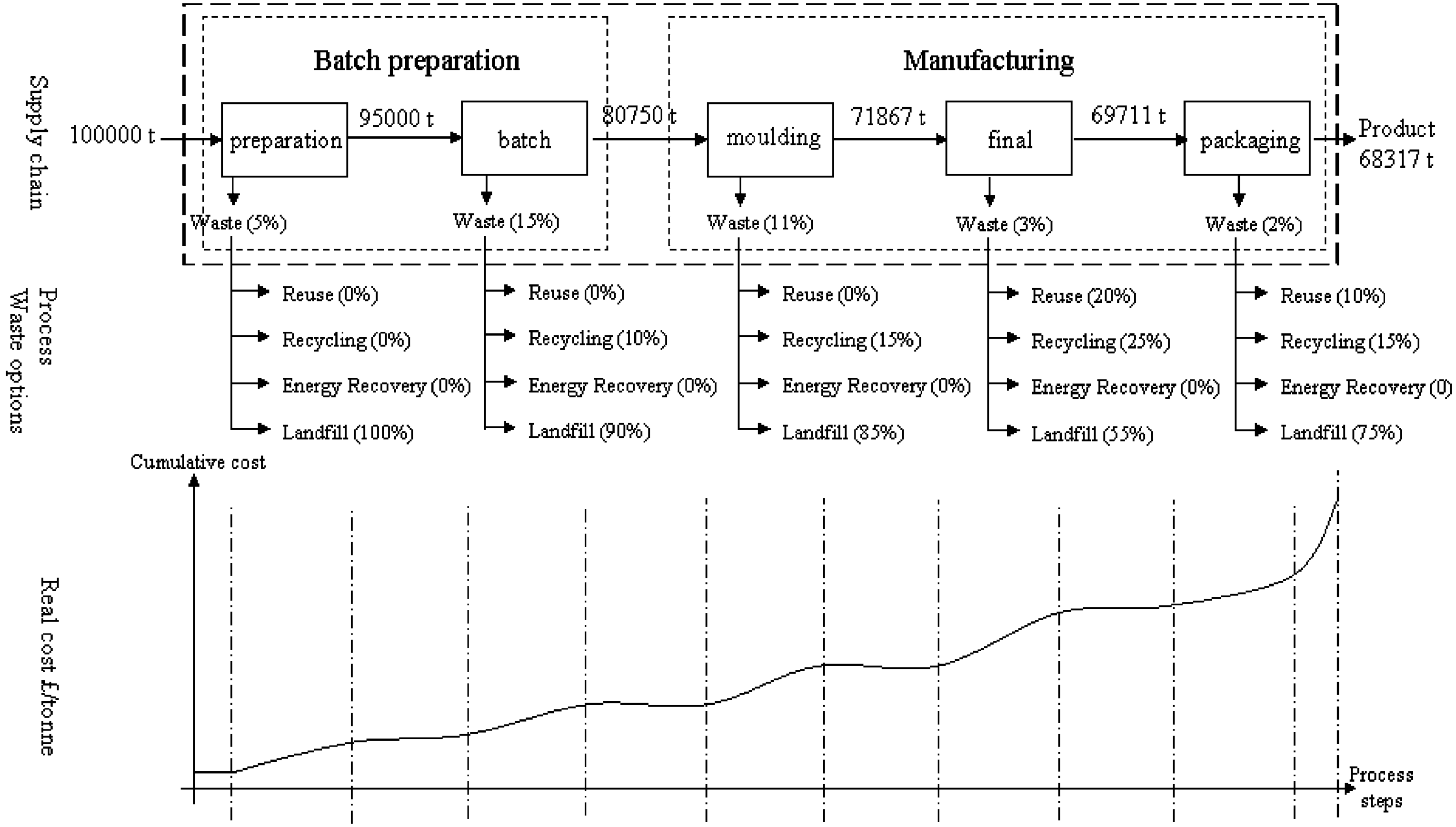

Fig. 2. A functional model of PlasticCo before the application of a new waste management strategy.

Company's manufacturing processes before the waste management practices were reviewed. The internal supply chain is divided into two departments: batch preparation and manufacturing. Initially, the total input of raw material was 100,000 tonnes per year, with 68,310 tonnes of product (68%) and 31,690 tonnes of waste (32%). The Company stated that it did not wish to make any changes to the manufacturing processes or interconnections between processes, because such change was perceived to be expensive, time consuming and disruptive. The application of the functional model therefore focused upon physical waste and excluded non-physical waste.

The first process is preparation, which involves obtaining material from storage, weighing, quality checking and washing. The waste arises from raw material contamination. The second process is batching in which solvents and dyes are added. The materials are then mixed in appropriate quantities for processing. Waste can arise from incorrect quantities, poor mixing or contamination. The material then goes to an injection moulding process. Waste may arise due to rough edges, incorrect wall thickness or the breaking of the material during release from the mould. The product is then trimmed and inspected. Some waste is flash from the moulding process, but the majority is defective product that does not conform to specification. The finished product is then packed after inspection. At this final process, waste may arise due to labelling errors and physical damage. It is also possible that some product may perish if it is stored for too long.

The waste stream from each process is identified in terms of the waste hierarchy. The detailed material flows are shown in Table 1. Overall, 570 tonnes of material was reused (1.8%), 3.505 tonnes was recycled (11%) and 27,606 tonnes was sent for landfill (87.1%).

The model was presented to the senior management team. They immediately recognised the potential cost savings that could be achieved through improved waste management practice. There were two strategic options: to minimise the amount of waste produced or to maximise the utilisation of waste. The minimisation of waste required the reconfiguration of processes and changes to the product design and the technologies used. Senior management considered waste minimisation as an important long-term objective. However, PlasticCo recognised that external supply chain relationships could be developed in the short-term to maximise the utilisation of waste, through increasing the proportion of waste that was reused or recycled. This approach required minimal investment, added considerable value and ensured future legislative compliance. This therefore became the main focus of the research.

The strategic impact of future national and international environmental legislation and regulation (for example, the Landfill Directive, OJ L 182, 1999) was considered by senior management to be very important. Management also recognised that early compliance could provide a competitive advantage arising from increased efficiency, reduced disposal cost and new value streams arising from the establishment of secondary supply chains.

After analysing the supply chain in Fig. 2, the research team identified that supply chain relationships could be developed to increase the proportion of waste that was reused or recycled. The model of the waste streams after the implementation of improved waste management is shown in Fig. 3 with the detailed material flows in Table 2.

Table 1
Initial mass flows in waste streams (tonnes)

	Preparation	Batches	Moulding	Final	Packaging	Total	%
Reuse	0	0	0	431	139	570	1.8
Recycling	0	1,425	1,332	539	209	3,505	11.1
Energy recovery	0	0	0	0	0	0	0.0
Landfill	5,000	12,825	7,551	1,186	1,045	27,607	87.1
Total	5,000	14,250	8,883	2,156	1,394	31,683	100.0

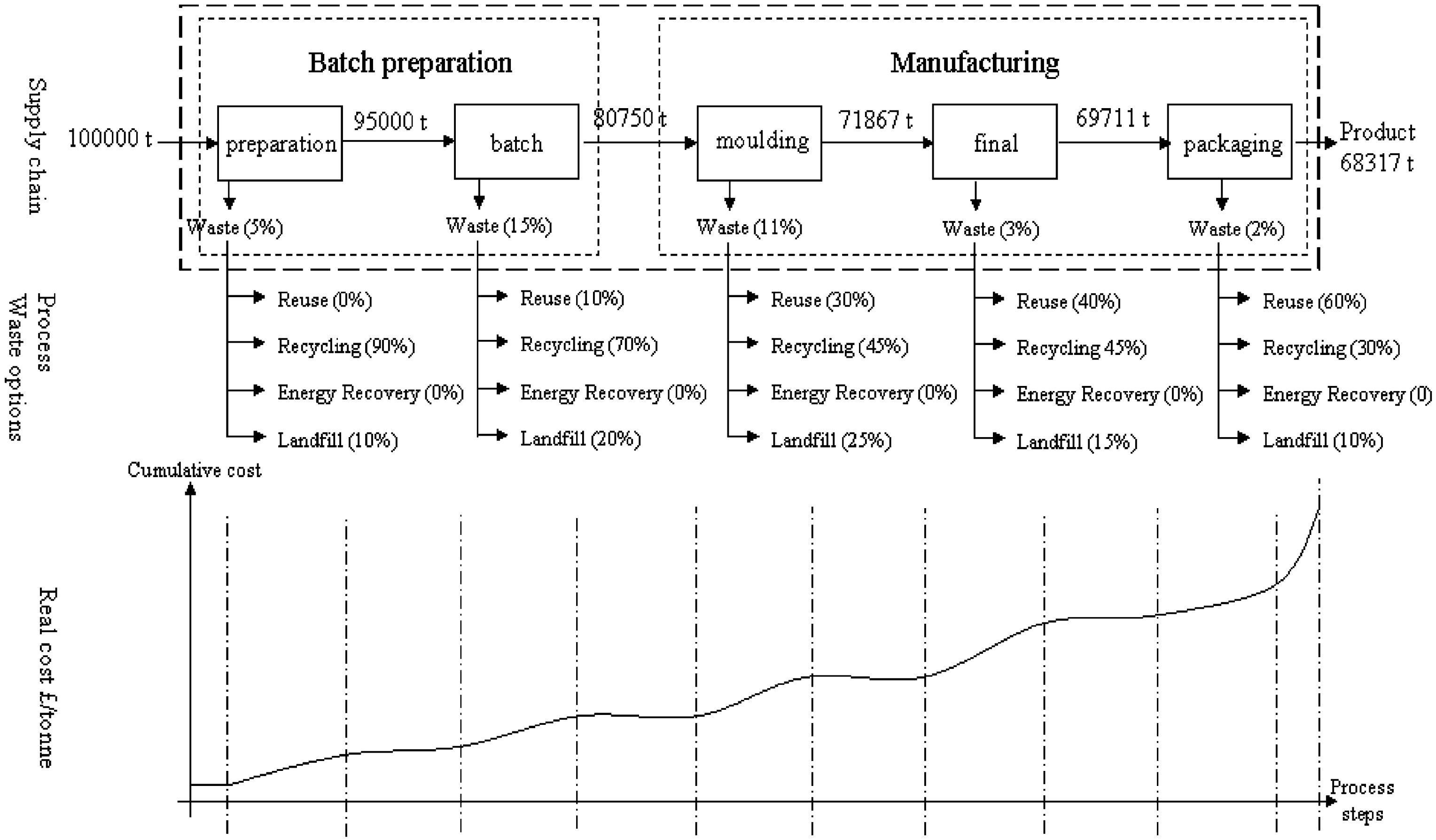

Fig. 3. A functional model of PlasticCo after the application of a new waste management strategy.

Table 2
Final mass flows in waste streams (tonnes)

	Preparation	Batches	Moulding	Final	Packaging	Total	%
Reuse	0	1,425	2,665	862	836	5,788	18.3
Recycling	4,500	9,975	3,997	970	418	19,860	62.7
Energy recovery	0	0	0	0	0	0	0.0
Landfill	500	2,850	2,221	323	139	6,033	19.0
Total	5,000	14,250	8,883	2,156	1,394	31,683	100.0

No changes were made to the manufacturing system therefore the cumulative cost of material at each stage remain the same. However, the development of supply chain relationships recovered a proportion of the cumulative cost associated with each waste stream.

The proportion of waste reused increased from 1.8% to 18.3%. This was due to the identification of secondary functions for the materials (where the physical and chemical properties remained unchanged). Recycling increased from 11.1% to 62.7% through the establishment of secondary supply chains. In each case, both the physical and chemical properties of the material ('waste') were changed by the application of external processes. For example, shredding and injection moulding processes changed the physical properties, whilst the addition of solvents and dyes changed the chemical properties. There were no incineration facilities available; therefore energy recovery was not an option. The remaining waste was not suitable for reuse or recycling and was sent to landfill. The overall effect of maximising the utilisation of waste was to reduce the proportion going to landfill from 87.6% down to 19%. This significantly reduced disposal cost whilst achieving additional added value through the development of new supply chains for the waste materials. Establishing new supply chains for waste materials created new income streams; these generated additional revenues that increased turnover by approximately 1%. Landfill disposal was reduced from 27,607 to 6.033 tonnes. Thus, the environmental impact of the disposal to landfill was significantly reduced. PlasticCo now complies with the current and future requirements of environmental legislation. Landfill cost was reduced by 78%, but this saving only had a relatively small financial impact compared to the income derived from the creation of the secondary supply chains.

The next stage of the research will focus upon the long-term issue of redesigning products and processes to reduce the level of waste produced. This work will be partly financed by the additional income and cost savings generated from maximising the utilisation of waste. Senior management anticipates significant financial and environmental benefits to arise from this exercise.

5. Conclusions

There is a range of interpretations of the word 'waste'. The holistic view is that anything that adds cost but not value is 'waste'. Legislation and regulation is focused on physical waste, its classification, transportation and disposal. Operations managers tend to focus on cost and value whilst environmental managers focus upon physical waste and legal and regulatory compliance.

There may be many barriers to effective waste management. These can arise from a poor integration of organisational functions, particularly when environmental management focuses on legislation and regulation rather than on process improvement, or releasing value through supply chains. Companies in which environmental and waste management pervade all functions are most likely to be effective at minimising waste and maximising their competitive position.

A functional modelling method has been developed for representing material flows and cumulative cost in internal and external supply chains. The model can be used to facilitate communications internally within a company and externally between companies. It provides a mechanism for analysing existing and alternative system configurations.

A case study in the plastics industry has demonstrated that the model can be an effective analysis and communication tool. The research team applied the functional model and presented the results of the analysis to senior management. Short-term and long-term approaches were identified for minimising the amount of physical and non-physical waste. In the short-term secondary supply chains could be developed to recover maximum value from the waste without changing the volume produced. In the long-term, product and process improvements could be made to reduce the amount of waste. The long-term approach would require considerable capital investment, which was not available at the time of the study. The model was used to analyse and communicate material flows, waste production, waste utilisation and cumulative cost. Management chose the short-term approach. The development of external supply chains for secondary materials released significant value and also reduced the cost and environmental impact of disposal. In the long-term, the model will be used to evaluate new product and process improvements and their impact upon material flow, physical waste and cumulative cost.

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