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**Contributions to a Concept Development for
Material Flow Analysis for Sony DADC Austria**

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Statement of Independence

I declare that this diploma thesis is my own work, based on my original research and expressed in my own words. Any use made within it of works of others in any form (e.g. ideas, figures, text, tables) is properly acknowledged at the point of use. I have not submitted this thesis for any other course or degree.

Graz, 18 November 2010

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Abstract

Aims for a sustainable and resource-conserving production are increasingly gaining in importance in recent years. For this purpose especially large global companies make additional effort to improve their environmental performance. Environmental management systems as well as resource management and waste management are dealing with that issue, which is also essential at Sony DADC.

For making the production processes and their material influencing factors more transparent, an adequate concept was designed within this diploma thesis, which makes a monthly analysis of the processed raw and packaging materials possible. The concept is based on the approach of material flow analysis (MFA).

To find out the requirements and benefits of a periodical MFA system, a MFA was carried out at Sony DADC Austria in Anif for the fiscal year 2009. All processes of CD-, DVD-, and Blu-ray Disc-production between the company's receiving and shipping department were investigated. The main task of the MFA was to balance the quantities of material inputs and outputs of the respective processes in the departments.

This MFA was the basis for the concept development. Because of the requirement to making this MFA automated as far as possible, the use of a supporting software solution was obvious. After a thorough research it has turned out that the software Umberto is best suitable for the given problem. Umberto provides the possibility, that process networks can be modelled and specified, and afterwards filled with data. With an implementable connection to the Sony DADC database system, Umberto can be used for balance, visualize, compare and evaluate the material flows monthly with a suitable effort. On basis on this concept, a MFA system for further Sony DADC locations can be constructed and applied.

By realization of this concept the transparency of the processes can be increased significantly. Hence, weak spots and potentials for improvements can be revealed and also alternative scenarios can be simulated. Thus, an efficiency tool is provided, for showing ways for resource savings, avoidance of waste and decreasing environmental loads. These applications supply extensive information for production- and product-specific decision-making processes.

Kurzfassung

Ziele zur nachhaltigen und ressourcenschonenden Produktion gewinnen in den letzten Jahren zunehmend an Bedeutung. Zu diesem Zweck wird vor allem in großen globalen Unternehmungen vermehrter Aufwand betrieben, um die Umweltleistung zu steigern. Betriebliches Umweltmanagement, aber auch Ressourcenmanagement und Abfallmanagement behandeln diese Thematik, welche auch bei Sony DADC von großer Wichtigkeit ist.

Um die Produktionsprozesse mit deren materiellen Einflussfaktoren bei Sony DADC transparenter zu machen, wurde im Rahmen dieser Diplomarbeit ein adäquates System konzipiert, welches eine monatliche Analyse zu den verarbeiteten Roh- und Verpackungsmaterialien ermöglicht. Das Konzept beruht dabei auf dem Ansatz der Materialflussanalyse (MFA).

Um die Anforderungen an das System einer periodischen MFA und den zu erwartenden Nutzen zu ermitteln, wurde eine MFA am Sony DADC Austria Standort Anif für das Finanzjahr 2009 durchgeführt. Untersucht wurden alle Prozesse der CD-, DVD- und Blu-ray Disc-Produktion vom fabrikseigenen Wareneingang bis zum Warenausgang. Die Hauptaufgabe war es, Input- und Output-Materialmengen der jeweiligen Prozesse Abteilung für Abteilung übersichtlich zu bilanzieren.

Diese MFA bot die Grundlage zur Konzeptentwicklung. Die Anforderung zur gewünschten weitgehenden Automatisierung der MFA legte die Verwendung einer unterstützenden Softwarelösung nahe. Nach einer gründlichen Recherche wurde die Software Umberto als geeignet für die Problemstellung befunden. Umberto bietet die Möglichkeit, Prozess-Netzwerke zu modellieren und zu spezifizieren und anschließend mit Daten zu versorgen. Durch eine realisierbare Anbindung an das Sony DADC Datenbanksystem kann so Umberto verwendet werden, um die Materialflüsse auf monatlicher Basis mit praktikablen Aufwand zu bilanzieren, zu visualisieren, zu vergleichen und zu bewerten. Auf Grundlage dieses Konzepts kann ein MFA System an weiteren Sony DADC Standorten global aufgebaut und eingesetzt werden.

Durch Umsetzung des Konzepts kann innerhalb der Prozessflüsse die Transparenz signifikant erhöht werden. Dadurch können im weiteren Schwachstellen und Potenziale für Verbesserungen aufgezeigt und alternative Szenarien simuliert werden. Somit steht ein effizientes Werkzeug zur Verfügung, um Wege zu finden, Ressourcen sparsamer einzusetzen, Ansatzpunkte zur Abfallvermeidung zu geben und Umweltbelastungen zu verringern. Diese Anwendungsmöglichkeiten liefern umfassende Informationen für produktions- und produktbetreffende Entscheidungsfindungen.

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1 Introduction

This diploma thesis is dealing with the issue 'concept development for material flow analysis for Sony DADC', which was elaborated in 2010 for Sony DADC in Anif. After a general introduction the Chapter logistic management is discussed, before the main issue of material flow analysis is explained in theory. Chapter 4 and Chapter 5 describe the carried out material flow analysis and its resulting concept development. The last Chapter concludes this thesis.

This very first Chapter introduces the company Sony DADC, the problem description and target definition, and the approach to this work.

1.1 Sony DADC

Sony DADC is a solution and technology provider for the entertainment, education and information industries, who offers optical media replication services and supply chain solutions, as well as software services with quality leadership. The main products that are manufactured are optical discs like CDs (Compact Discs), DVDs (Digital Versatile Discs) or BDs (Blu-ray Discs). For the production Sony DADC leads a global replication network, which comprises 14 plants in Europe, Japan, China, the USA, Australia, Canada, Mexico, Brazil, Mexico and India. The cooperation within this network is intense. This is why an internationally homogenous quality and high performance standards can be reached.¹

To be prepared for the future Sony DADC expends collective effort to be flexible and meeting the market by focussing on the production of promising formats. Therefore to supply the customers with the most up-to-date technology, Sony DADC heavily engages in research and development and already offers content-based services like Digital Asset Management. The majority of Sony DADC Group sales are achieved with new formats that are younger than four years. For example during the last two years Sony DADC has become a first-rate partner for Blu-ray Disc services, which resulted in company growth. The commitment to progress ensures that Sony DADC remains the one-stop-shop service provider for a wide range of customers.¹

The replication facilities of Sony DADC include all important capacities for a product of high quality, like extensive pre-mastering operations, high-volume mastering capabilities (explanation mastering see Chapter 4.2), precision replication systems and high-speed disc printers. A special fulfilment centre handles full-service disc packaging, warehousing and direct-to-retail product shipping.¹

¹ Cf. Sony DADC (2010a), access date 13.10.2010

Facts and Figures of Sony DADC Europe

Founded in 1986 at the start of the optical storage media revolution, Sony DADC is now a leader in its field of optical media replication services and software services.²

The headquarters of Sony DADC Europe is located in Anif/Salzburg, Austria. Sony DADC Europe has three production facilities. Two are in Austria (Anif and Thalgau) and one is in the UK (Southwater). The European distribution services are handled by distribution centers in Germany, France, Spain, Sweden and the United Kingdom.²

Data for Sony DADC Europe for the three manufacturing locations:²

- Annual Turnover: 510 million Euro (April 2008 – March 2009)
- Fixed Headcount: 1.600 employees
- Customers: over 3.000 customers in Europe in music, games, software and film industries
- Yearly Output: more than 690 million discs

Sony DADC Europe manufactures pre-recorded discs like CDs, DVDs, Blu-ray Discs, UMDs (Universal Media Discs), DualDiscs and PlayStation Discs. Also the recordable discs CD-R (Compact Disc-Recordable) and DVD-R (Digital Versatile Disc-Recordable) are manufactured at Sony DADC.²

The manufacturing capacities at Sony DADC Europe are stated in thousand units in Table 1.

	Location Anif	Location Thalgau	Location Southwater
CD-Capacity per Day	410 k	440 k	140 k
Blu-ray Disc Capacity per Day	260 k	610 k	-
DVD-Capacity per Day	240 k	850 k	210 k

Table 1: Capacities at Sony DADC Europe²

The daily capability at Sony DADC Europe is 2.000 orders. The current logistics network covers 12.600 active distribution destinations, in 90 countries. Daily shipments of up to 6.4 million discs with a 24 hour service to major European metropolitan areas and countries are realized.²

² Cf. Sony DADC (2010b), access date 13.10.2010

1.2 Problem Description and Target Definition

In this Chapter the starting situation is described by defining the problem and the target of this thesis.

Problem Description

Sony DADC uses a lot of different materials in the production processes. Needed materials are diverse metals, plastics, acids, bases, solvents, lacquers, colours or cartons, to give just a few examples. Aim of this work was to develop the basis for a more automated inventory of the used materials. Sony DADC monitors all quantities of used raw materials as well as consumed electricity and so forth. To have a detailed overview of the material consumptions of the production processes a material flow analysis (MFA) should be carried out. At the beginning transparency of material flows was limited and therefore the potential for increased efficiency of the processes hardly to point out.

Several external and internal requirements regarding consumption and handling of materials have to be fulfilled at Sony DADC. The different requirements will be introduced in Chapter 4.1. Currently all data to material consumptions which are needed for legal or other requirements are collected manually, either on a monthly or a yearly basis, which is a quite time consuming task.

Target Definition

Target of this work is to figure out solutions for improvement of the before mentioned manual collecting of data. The described problem can be solved by applying a systematically MFA, the cornerstones are as follows:

- Concept development of MFA at Sony DADC Austria (Anif)
- The developed concept should exactly describe how MFA can be carried out at Sony DADC in Anif at least once on a yearly basis. In addition, the concept should serve as a platform for other Sony DADC production plants.
- For a better identification of the benefits and difficulties of MFA a full input/output analysis for a certain fiscal year (FY 2009) should be carried out for the production processes of Sony DADC in Anif.
- The concept should be developed on the basis of this MFA and should consider the special requirements at Sony DADC.
- After implementing the concept, it should be possible that the periodical material flows for CD, DVD and BD production are balanced, reported and clearly visualized. This should maximise the transparency of the production processes.

- The automated MFA should then provide the opportunity to reveal weak points and primarily material consumptions should be easily identified, controlled and compared.

1.3 Approach to this Diploma Thesis

The defined problem was elaborated in the period from the beginning of May 2010 until the middle of November 2010. The diploma thesis was divided in four basic phases.

Phase 1: The first phase contained analysis of literature, getting acquainted of the products, production processes and the Sony DADC Austria requirements, and comparison of software solutions. Four weeks were necessary for phase 1.

Phase 2: After two weeks phase 2 was started parallel to phase 1. This phase was the material flow analysis of the production processes at Sony DADC Anif. By carrying out the MFA it was shown, which requirements need to be fulfilled if implementing the MFA concept and which potentials can be recognized by doing this analysis. Several meetings with the different departments took place. Basically three and a half month were needed for this phase.

Phase 3: In the third phase the solution concept was developed. This phase had to be handled parallel to phase 2. At first the solution was elaborated, next the solution was tested, reviewed and edited. The documentation of the MFA concept was the last part of the solution development which was simultaneously the fifth Chapter of this thesis. Phase 3 took three and a half month as well.

Phase 4: In this phase the diploma thesis was written down. Primarily the writing phase was concentrated from the middle of September until the end of the diploma thesis, but also some preparatory work was made before.

The overview schedule in Figure 1 is detailed displayed in the appendix in Figure 67.

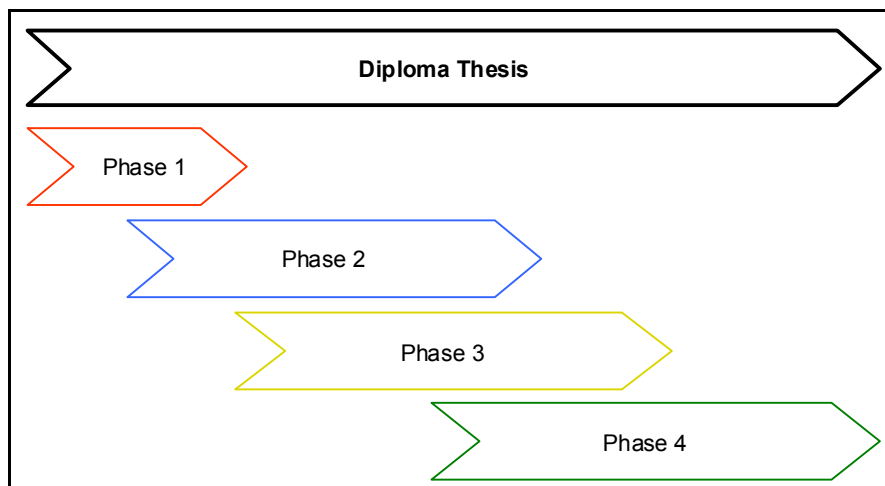


Figure 1: Schedule of the Diploma Thesis

2 Logistics Management

The main issue material flow analysis can be classified with the field of material logistics. That's why the topic logistics management is described in the introductory theory Chapter. This part can be seen as an approach to the main part of material flow analysis. After a general introduction to logistics management the tasks and tools in production logistics will be discussed.

2.1 Definition of Logistics

The word logistics has originated from the Greek word *logistikos* and the Latin word *logisticus*, meaning the science of computing and calculating. In ancient times it was used more in connection with the art of moving armies, and supplies of food and armaments to the war front. Today, logistics has acquired a wider meaning and it is used in business for the movement of raw materials from suppliers to the manufacturer and finally the finished goods to the consumer.³

Logistics is also referred to as physical distribution. Philip Kotler defines logistics as *“planning, implementing, and controlling the physical flows of materials and finished goods from point of origin to point of use to meet the customers’ need at a profit”*.⁴

The American Council of Logistics Management defines logistics as *“the process of planning, implementing, and controlling the efficient, cost effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to point of consumption for the purpose of conforming to customers’ requirements”*.⁵

Paul Schönsleben writes *“logistics in and among companies is the organization, planning, and realization of the total flow of goods, data, and control along the entire life cycle of products”*.⁶

Logistic management is basically an integrative process that optimises the flow of materials and supplies through the organisation and its operations to the customer. Martin Christopher says that *“logistics is essentially a planning process and an information based activity”*.⁷ The ultimate objective of the logistics function is to support corporate goals to delivering products to the customer at a time and place of his

³ Cf. Sople (2007), p. 2

⁴ Kotler (2001) quoted in Sople (2007), p. 2

⁵ American Council of Logistics Management quoted in Sople (2007), p. 2

⁶ Schönsleben (2000), p. 7

⁷ Christopher (1994), p.17

choosing. However, this objective must be balanced against the cost of providing the service.⁸

2.2 Logistics Field of Application

The four main parts of a corporate logistics system are procurement, production, distribution, and disposal logistics.⁹ As shown in Figure 2, procurement and production logistics can be summarized to the umbrella term material logistics.

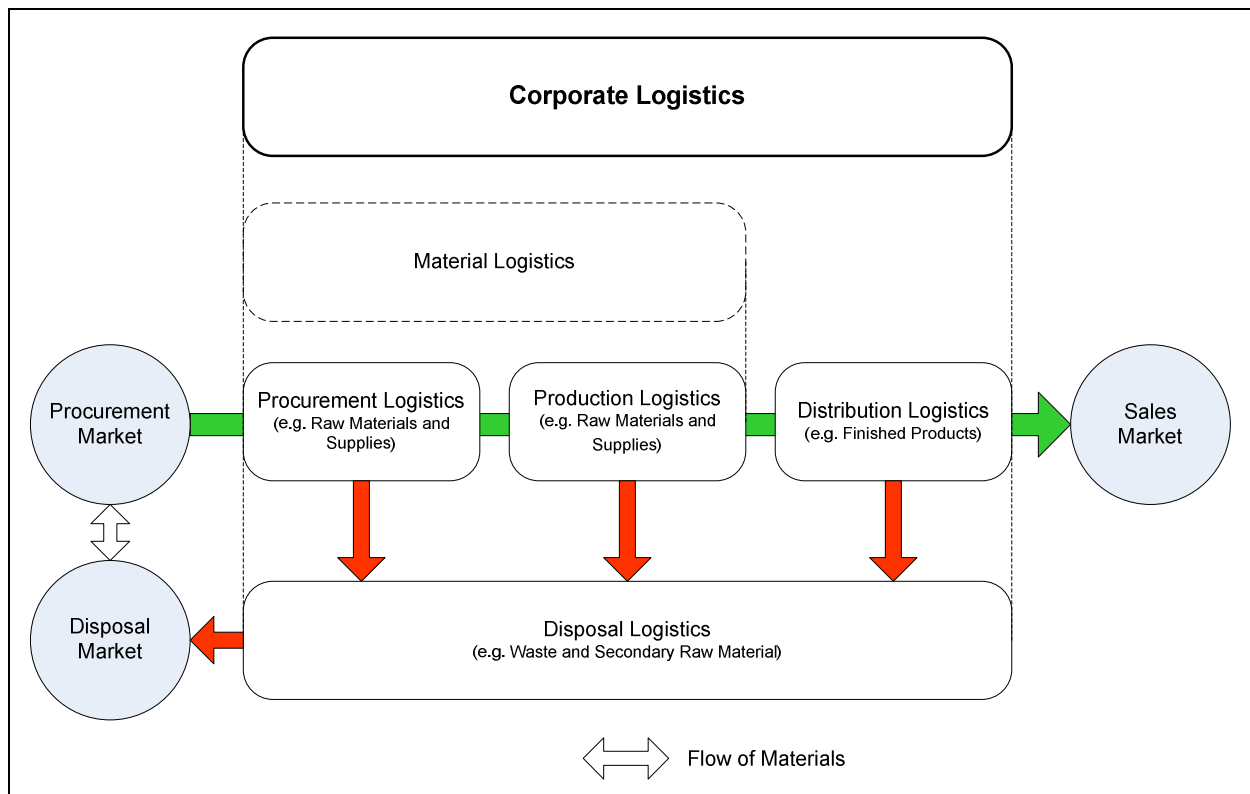


Figure 2: Corporate Logistics and its Components¹⁰

Procurement Logistics

The procurement logistics is a logistic system which is connected with the market. It connects the distribution logistics of a supplier with the production logistics of a company. Objects of procurement logistics can be raw materials and supplies or commodities, which have to be demand-actuated provided to a company. Procurement logistics ends at the storage facilities or in the case of directly supply, at the first production step of a company.¹⁰

⁸ Cf. Sople (2007), p. 2

⁹ Cf. Wohinz (2009), pp. 4-5

¹⁰ Cf. Pfohl (2004), p. 18 and p. 182

Production Logistics

Production logistics connects the material flow of procurement logistics and distribution logistics. Production logistics includes all activities which are required for the supply of the production processes with material (raw materials and supplies, semi finished products or commodities) and the release of the semi finished and finished products to the store.¹¹

Production logistics can be seen as management of material and information flows in a production process.¹²

Because logistics accompanies the life cycle of a product at a level that exceeds the company, logistics within the company must also be viewed as process-oriented, and thus department-transcending, task.¹³

Distribution Logistics

Distribution logistics is as well as procurement logistics a logistic system which is connected with the market. It concatenates the production logistics of a company with the procurement logistics of a customer. Distribution logistics includes all activities, which are necessary to supply the customer with finished products or commodities. The delivery to the customer can start directly from the production processes, from a store in the production plant or from a regional distribution center.¹¹

Disposal Logistics

Disposal logistics handles the material flow to disposal-preparation maintenance, to taking back, to disassembly, and to recycling. For materials, the importance of disposal logistics is currently increasing due to depleting resources as well as to overloaded waste depots. Companies differ in their motivation in this area from each other. Some have to act by legislation, and others view action in these areas as a strategy for success. Important areas of disposal logistics are handled today more pragmatically than systematically.¹³

Material Logistics

Procurement logistics and production logistics contain tasks in purchasing and in production up to the provision of saleable output. In tradition, this has meant all tasks and processes involved in moving (transporting, cargo handling, picking, and putting

¹¹ Cf. Pfohl (2004), p. 193 and p. 211

¹² Cf. FlexLink (2010), access date 12.10.2010

¹³ Cf. Schönsleben (2000), p. 13 and p. 18

together all items of an order) and storing of material. Tasks and processes that result in the physical transformation of materials are not traditionally included here, and this narrower definition has survived. Actually, production processes that change materials physically or in compound have a great influence upon the choice of logistics systems and their efficiency. With the demand for short total lead times, production processes must be a part of logistics planning – by the company producing goods as well as by suppliers.¹⁴

2.3 Logistics Tasks and Objectives

The major task of logistics as defined by Hans-Christian Pfohl's 4r principle is to ensure that a recipient is supplied from a point of origin in accordance with his requirements with the right product (in quantity and variety), in the right condition, at the right time and in the right place at minimum cost.¹⁵

Gudehus and Kotzab write: *"The tasks of analytical logistics are to develop and organize optimal processes, structures, systems and networks for the operative logistics. The main tasks of logistic management are to execute the orders and to fulfil the requirements of consumers and companies at lowest costs with adequate quality."*¹⁶

In principle logistics has to manage physical goods in space and time in order to execute orders. Logistic systems, which execute only the basic logistic tasks transport, storing and handling, are special performance systems. Further performance systems, which execute also non-logistic tasks, are part of logistics in a broader sense. In this case, the tasks of logistics are to design, set up, operate and optimize systems, which produce physical goods and generate immaterial services. These enhanced tasks are overlapping with the fields of process technology, production planning, operations research, industrial engineering, informatics and other areas of technology and economics.¹⁷

Logistics has a significant influence on company goals in areas of quality, costs, delivery, and flexibility. This means that logistics considerably affects a company's performance. Company objectives which are affected by logistics are:¹⁴

- Target Area Quality:
 - Main goal: to meet high demands for product quality
 - Main goal: to meet high demands for process quality

¹⁴ Cf. Schönsleben (2000), p. 18 and pp. 13-14

¹⁵ Cf. Pfohl (2004), p. 12

¹⁶ Gudehus and Kotzab (2009), p. 3

¹⁷ Cf. Gudehus and Kotzab (2009), pp. 3-4

- Main goal: to meet high demands for organization quality
- Partial goal: high transparency of product, process and organization
- Target Area Costs:
 - Main goal: low physical inventory and low work in process
 - Main goal: high capacity utilization
 - Main goal: low cost rates for administration
 - Partial goal: complete and detailed bases for calculation and accounting
- Target Area Delivery:
 - Main goal: high service level, or short time to delivery
 - Main goal: high delivery reliability rate
 - Main goal: short lead times in the flow of goods
 - Partial goal: short lead times in the data and control flow
- Target Area Flexibility:
 - Main goal: high degree of flexibility to enter as a partner in logistics network
 - Main goal: high degree of flexibility in achieving customer benefit
 - Main goal: high degree of flexibility in the use of resources

In contrast to goals in the areas of cost and delivery, logistics and planning & control have only a limited influence upon the achievement of company goals with regard to quality and flexibility.¹⁸

Target Area Quality

Whenever many people need to work together efficiently, products and services with the processes producing them, have to be declared as explicit business objects. This is also a requirement for effective logistics. Products, processes and organization then become transparent and understandable to all persons who are involved. But this can be seen as just one prerequisite to quality. It's obvious that product and process design as well as the choice of production infrastructure, employee and partners in the logistic network are the main determinants of the quality of products, processes and the organization.¹⁸

¹⁸ Cf. Schönsleben (2000), pp. 14-15

Target Area Flexibility

The main objectives listed above are certainly the most significant with regard to the influence of logistics. The flexibility to act as an efficient partner in logistics networks is, first of all, a question of the total culture of an enterprise. The potential for flexibility in achieving customer value, as for quality, develops through product and process design and the selection of production infrastructure. Flexibility in the use of resources is determined primary by the qualifications of personnel and by the choice of product infrastructure. Efficient logistics allows flexible use of the potentials developed in the day-to-day production.¹⁹

2.4 Applications of Logistics in Production

Logistics plays a crucial role in the production of every company. To attain and maintain a competitive advantage it is necessary to constantly improve and reevaluate products and production processes. In addition to high quality standards and the price of products, the logistic factors delivery time and delivery reliability take on increasingly more importance as possibilities with which a company can position itself in the market. Production, as the primary function for fulfilling orders, is thus continuously called upon to improve effectiveness. The objective therefore is to organize the entire material flow in the supply chain in such way that the company can react to the market in shortest time span. The basic goals of production logistics can thus be formulated as the pursuance of greater delivery capability and reliability with the lowest possible logistic and production cost. As shown in Figure 3, the fulfilment of these goals shapes the logistics key performance indicators for production firms.²⁰

There are different sub areas and systems of logistics which are concentrating on process control and design of products and processes.

A logistic system comprises logistics tasks, functions and methods, processes, flow or sub logistics, and also it encompasses the trigger events, order and process management of its processes. A logistics system is responsible for fulfilling the order itself. It is this strict control of the trigger events to the process that characterizes value-adding oriented organizations.²¹

¹⁹ Cf. Schönsleben (2000), p. 15

²⁰ Cf. Nyhuis and Wiendahl (2009), pp. 1-2

²¹ Cf. Schönsleben (2000), p. 25

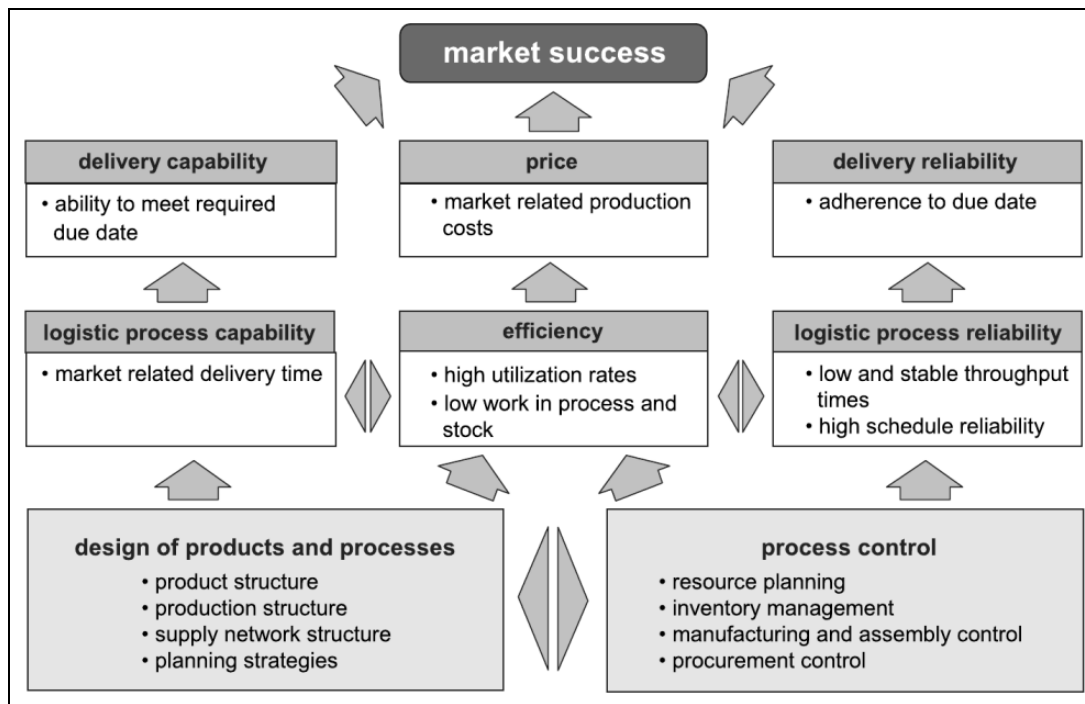


Figure 3: Logistics Key Performance Indicators for Production Firms²²

Production planning and control in logistics is concerned with the flow of materials from raw material receipt through manufacturing and processing stages to supply of finished stocks.²³

In Table 2 the fundamental goals of production logistics are displayed with their connection to the production reference processes.

		production reference processes		
		production and testing	transport	storage and supply
logistic objectives	schedule adherence	high schedule reliability	high schedule reliability	low delivery delay
	throughput time	short throughput time	short transport throughput time	short storage time
	output rate	high utilization	high utilization	
	inventory	low work in process	low work in process	low stock
	costs	low costs per unit	low costs per transport operation	low storage costs

Table 2: Logistic Objectives for the Production Processes²⁴

²² Gläßner quoted in Nyhuis and Wiendahl (2009), p. 3

²³ Cf. Magee et.al. (1985), p. 3

²⁴ Nyhuis and Wiendahl (2009), p. 10

To facilitate a planning and control of these objectives, the logistic objects of a production of a company have to be clearly structured, in so called performance systems and its process chains.

Structure and Processes in Production Logistics

Performance systems are defined as networks of stations generating certain services and performances. As sketched in Figure 4, material and data flow through this network. Separate from the production and administrative processes within the different stations, any performance system can be seen as a logistic system.²⁵

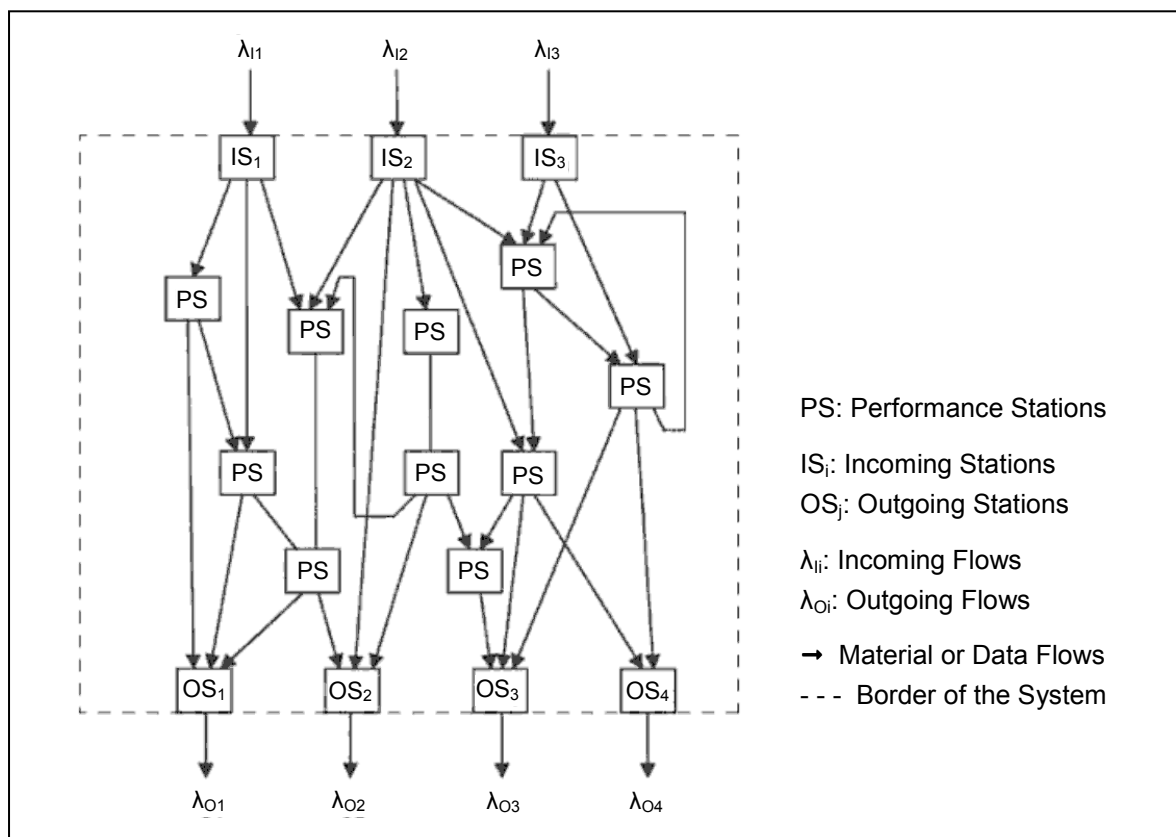


Figure 4: General Structure of a Logistic System²⁶

Performance and logistic systems can either be seen from a stationary point of view under the structural aspect or from a dynamic point of view under the process aspect. Some problems, for example process optimization, can be solved easier from the dynamic point of view. For other problems, such as design of system networks, the stationary aspect is preferable. For the extensive tasks of logistics in modern times,

²⁵ Cf. Gudehus and Kotzab (2009), p. 7

²⁶ Gudehus and Kotzab (2009), p. 8

both aspects must be taken into account. That's why a logistician has to apply process-, structure-, and system-oriented thinking.²⁷

Process Chain

A process chain, performance chain or a value creation chain is a chronological cycle of operations executed in a spatially limited chain of organization units and performance stations, which results in a product or service of certain value. Performance stations can be classified as operative or administrative stations. This depends on whether the operations refer to tangible or intangible objects. For that reason a process chain is, as shown in Figure 5, a logistic chain, an order chain or an information chain.²⁸

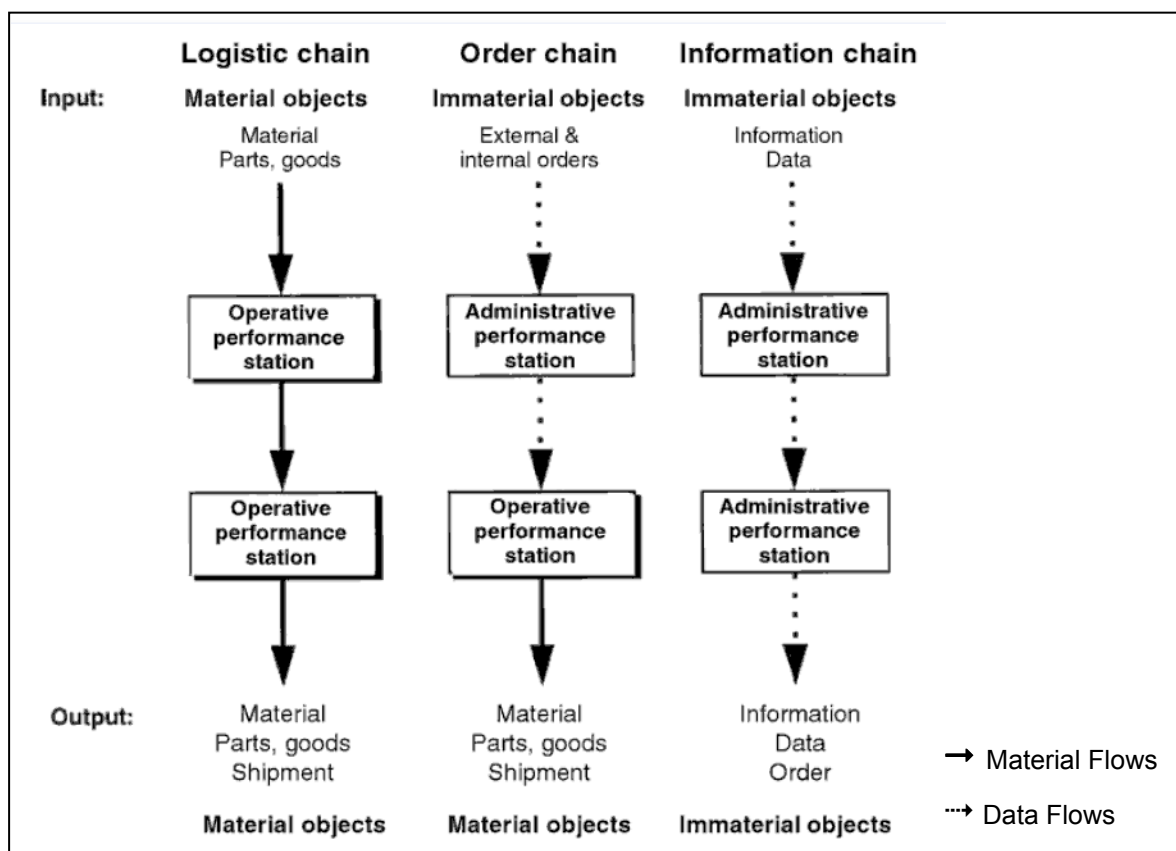


Figure 5: Logistic Chain, Order Chain and Info Chain²⁹

A logistic chain is a string of operative stations which is passed by material objects. In- and outgoing objects of logistic chains are material units that change in space and time during the processes. The flow of objects through such a logistic chain is called material flow.²⁸

²⁷ Cf. Gudehus and Kotzab (2009), pp. 7-8

²⁸ Cf. Gudehus and Kotzab (2009), p. 22

²⁹ Gudehus and Kotzab (2009), p. 22

An information chain is a sequence of administrative stations which is passed by intangible, immaterial objects such as data or information. The flow of these objects through the information chain is termed information flow or data flow.³⁰

The information flow in logistics describes the planning and control of information which is required to fulfil the customers demand across all steps of a company. The synchronisation of information and material flow is a prerequisite for efficient logistics.³¹

An order chain is defined as a cycle of administrative and operative stations, which are passed at first by orders and later by its generated objects. Therefore the administrative stations have to accept, process and control the orders.³⁰

A full process chain includes all performance stations between the source and the sink of its tangible or intangible objects. The chain can be divided into external and internal logistic chains. External logistic chains involve stations outside a company and deal with transport connections between shipping locations, transshipment points, logistic centres and destinations. An internal logistic chain includes stations and connections inside a company, plant, station, transshipment point or also a logistic centre.³⁰

Possibilities how to analyse, design, set-up and optimize internal logistic chains are explained in Chapter 2.5.

2.5 Material Flow Analysis in Logistics Management

Material flow analyses (MFA) find widespread application and are a useful tool in logistics management, especially in the area of logistics planning and control of production processes. Internal logistic chains can be analysed and improved or designed by using MFA.

Along the definition, a material flow not only consists of the transportation, storage and handling of materials but also of the processing of materials.³²

Basically, there are two different approaches of material flow analysis which can be carried out within a firm. By adding these two types you get transparency of the total internal material flow which includes as defined the transportation, handling, storing and the processing of materials along the process chain.

³⁰ Cf. Gudehus and Kotzab (2009), pp. 22-23

³¹ Cf. ten Hompel and Heidenblut (2007), p.127

³² Cf. Jünnemann and Schmidt (1999) quoted in Pfohl (2004), p. 193

Two Major Types of Material Flow Analysis

The first type of MFA, delineated as MFA A in Figure 6, concentrates on the transportation and handling of materials between the processes of a firm. The storage of materials is also considered. Material movements are analysed to improve storage, conveyor or duration of transport processes for effective production. Therefore the processes usually are treated as black box. This type of MFA is a common tool in production logistics and is often used for layout-planning.

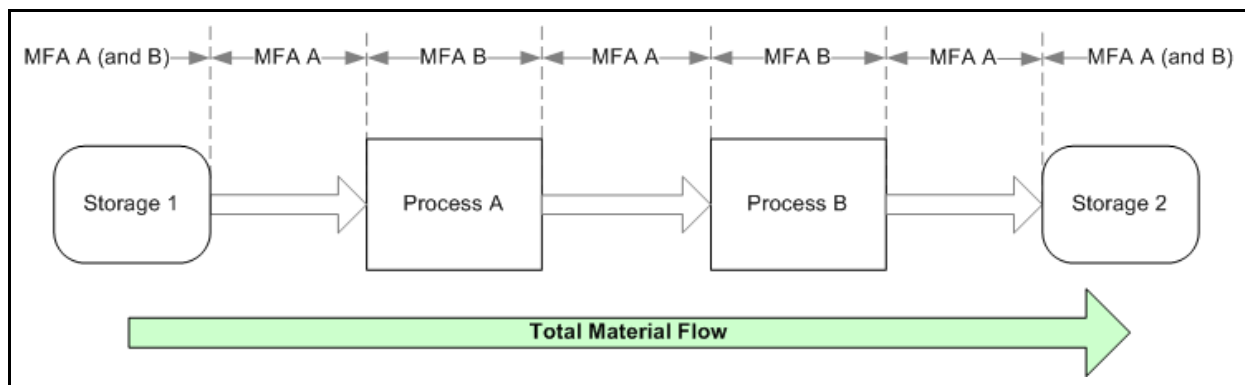


Figure 6: Difference of the two MFA Types

The second type of MFA, delineated as MFA B in Figure 6, investigates material consumption of the processes in the same process chain in detail. The focus is on analyse how effective these materials are processed, which waste is produced or which hazardous substances are handled within these processes. The goal of this type of MFA is to give transparency, reveal weak points, and show possibilities for efficiency improvements of the processes. This application can be seen as an overlap of logistic management with environmental management and engineering, resource management, or waste management. This second type of MFA will be extensively described in the following Chapter 3.

3 Material Flow Analysis

Chapter 3 summarizes the theory of material flow analysis and describes the benefit of implementing it. Then different software solutions are introduced and evaluated.

3.1 Definition

Paul Brunner and Helmut Rechberger define the term Material Flow Analysis in their book *Practical Handbook of Material Flow Analysis*: *“Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, and the intermediate and final sinks of a material. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process. It is this distinct characteristic of MFA that makes the method attractive as a decision-support tool in resource management, waste management, and environmental management. An MFA delivers a complete and consistent set of information about all flows and stocks of a particular material within a system. Through balancing inputs and outputs, the flows of waste and environmental loadings become visible, and their sources can be identified.”*³³

With the aid of material flow analysis import, export, input and output flows of materials within a pre defined system are quantified and the processes are balanced. The balance has to be carried out in consideration of the principle of conservation of mass. The investigated system can be a single process or a linkage of many processes including subprocesses (ÖWAV 2003).³⁴

3.2 History of Material Flow Analysis

Long before MFA became a tool for managing resources, wastes and the environment, the mass-balance principle has been applied in such various fields as medicine, chemistry, economics, engineering and life sciences. The basic principle of any MFA – the conservation of mass, or input equals output – was first claimed by Greek philosophers more than 2000 years ago. Detailed chronicles to MFA descend from a time a few years later from Santorio Santorio.³⁵

³³ Brunner and Rechberger (2004), p. 3

³⁴ Cf. ÖWAV (2003), p. 12

³⁵ Cf. Brunner and Rechberger (2004), p. 5

Santorio's Analysis of the Human Metabolism

One of the first experiments which can be seen as an analysis of material flows was developed in the beginning of the 17th century by the Italian Santorio Santorio (1561-1636). Santorio was a physician and professor at the University of Padua and at the University of Venice and was a part of the circle of learned men that included Galileo.³⁶

Santorio studied the process of human metabolism by observing the weight fluctuations in his own body over the course of a day, and during various metabolic processes such as digestion, sleeping, and eating. By weighing all the food and beverages that he ingested and all the excreta that he passed, he tried to balance inputs and outputs of his body. As he figured out that there were substantial differences in his own mass balance, he carried out special measurements to investigate the missing output to close this balance. He used a set of specially constructed devices, including a balance scale, a pulse monitor, a hydrometer to measure the moisture content in gas, and a chair suspended from a steelyard which was designed to measure what he referred to as 'insensible perspiration'.³⁷

The experiment of Santorio allows conclusions similar to recent MFA studies, like without knowing the material flows and stocks it is still impossible to evaluate and optimize anthropogenic systems. Also that it is difficult to balance a process or system if basic information to major input and output goods is missing. Another point is that it happens quite often that inputs and outputs of a process or a system do not balance, pointing to new research questions.³⁸



Figure 7: Santorio Santorio's Experiment³⁹

³⁶ Cf. Castiglione quoted in Van Helden (1995), access date 05.10.2010

³⁷ Cf. Advameg, Inc.(2010), access date 05.10.2010

³⁸ Cf. Brunner and Rechberger (2004), p. 7

³⁹ University of Kansas Medical Center (2000), access date 05.10.2010

Material Flow Analysis in the 20th century

In the 20th century, MFA concepts have appeared in diverse fields of study at different times. Before the term MFA had been invented and before its comprehensive methodology had been developed, many researchers used the law of conservation of mass to balance processes. It was common practice in chemical engineering, to analyze and balance inputs and outputs of chemical reactions. In the economics field, Leontief invented input-output tables in the 1930s, thus laying the base for wide spread application of input-output methods to solve economic problems.⁴⁰

Leontief's Economic Input-Output Methodology

Wassily W. Leontief (1905-1999) was a Russian economist. In his middle and final decades Leontief were increasingly preoccupied by input-output researches, for which he was awarded the Nobel Prize in 1973. He developed input-output tables, which were used to analyse sectors of the whole US economy.⁴¹

These input-output tables afford a method for systematically quantifying the mutual interrelationships among the different sectors of a complex economic system. Goods, production processes, deliveries, and demand are connected in a stationary as well as in a dynamic way. The production system is described as a network of flows of materials between the various production sectors. Input-output analysis of economic sectors has become a common tool in economic policy making. It proved to be highly useful for forecasting and planning in market economies as well as in centrally planned economies. It was also often applied to analyze the sudden and large changes in economies due to restructuring.⁴⁰

Development after 1970

The first studies in resource conservation and environmental management were made in the 1970s. The two original fields of application were the metabolism of cities and the analysis of pollutant pathways in regions such as watersheds or urban areas. In the following decades, MFA became a widespread tool in many fields, including process control, waste and wastewater treatment, water-quality management, resource conservation and recovery, product design, life cycle assessment (LCA), and others.⁴⁰

⁴⁰ Cf. Brunner and Rechberger (2010), p. 5 and p. 8

⁴¹ Cf. Samuelson et al. (2004), p. 6 and p. 12

3.3 Different Types and Applications of Material Flow Analysis

Robert Ayres and Leslie Ayres distinguish in their book 'A Handbook of Industrial Ecology' between two basic types of material flow-related analyses in this context.⁴²

Type of analysis	I		
	a	b	c
Objects of primary interest	Specific environmental problems related to certain impacts per unit flow of:		
	substances e.g. Cd, Cl, Pb, Zn, Hg, N, P, C, CO ₂ , CFC	materials e.g. wooden products, energy carriers, plastics excavation, biomass	products e.g. diapers, batteries, cars
	within certain firms, sectors, regions		
	II		
	a	b	c
	Problems of environmental concern related to the throughput of:		
	firms e.g. single plants, medium and large companies	sectors e.g. production sectors chemical industry, construction	regions e.g. total or main throughput, mass flow balance, total material requirement
	associated with substances, materials, products		

Table 3: Types of Material Flow-Related Analysis⁴³

As shown in Table 3, there are following different types of material flow analysis:⁴²

Material Flow Analysis Type Ia

Substance flow analysis (SFA) has been used to determine the main entrance routes to the environment, the process associated with these emissions, the stocks and flows within the industrial system as well as the trans-media flows, chemical, physical, biological transformations and resulting concentrations in the environment. Spatiotemporal distribution is of high concern in SFA. Results from these analyses are often used as inputs to further analyses for quantitatively assessing risks to substance-specific endpoints.

⁴² Cf. Ayres and Ayres (2002), pp. 80-84

⁴³ Cf. Bringezu and Kleijn (1997) adapted in Ayres and Ayres (2002), p. 81

Material Flow Analysis Type Ib

Selected bulk material flows have been studied for various reasons. Resource extraction by mining and quarrying was studied to assess the geomorphic and hydrological changes due to urbanization. The flow of biomass from human production has been studied to relate it to biomass production in natural ecosystems in order to evaluate the pressure on species diversity.

Material Flow Analysis Type Ic

When the environmental impact of certain products and services is the primary interest, the approach is normally denoted life cycle assessment (LCA). In general, the system boundary of LCA, which investigates the production processes from the cradle to the grave of the product, corresponds with the systems perspective of the anthroposphere, technosphere or physical economy. Some methods of evaluation may be used for LCA and MFA as well.

Material Flow Analysis Type IIa

If a type IIa MFA is used, the primary interest may lie in the metabolic performance of a firm or household, a sector or a region. In this case there may be no or insufficient information about specific environmental problems. Often the main task is to evaluate the throughput of those entities in order to find the major problems, support priority setting, check the possibilities for improvement measures and provide tools for monitoring their effectiveness.

Accounting for a physical throughput is becoming more and more commonplace, at least for bigger companies. It is found in corporate environmental reporting. Material accounts are used for environmental management. Eco-efficiency at the firm level has been indicated in reports. Flow analyses of materials have been applied for optimization within companies.

Material Flow Analysis Type IIb

When the primary interest is devoted to certain industrial sectors or fields of activity, MFA of type IIb may be used to identify the most critical fluxes in terms of quality and quantity.

Material Flow Analysis Type IIc

A major field of type IIc MFA represents the analysis of the metabolism of cities, regions and national or supranational economics. The accounting may be directed to selected substances and materials or to total material input, output and throughput.

The use and policy relevance of type II analyses have been enlarged in recent years in the following ways:⁴⁴

- Support for policy debate on goals and targets, especially with regard to the resource and eco-efficiency debate and the integration of environmental and economic policies
- Number of companies providing firm and product accounts
- Provision of economy-wide material flow accounts for regular use in official statistical compilations
- Derivation of indicators for progress towards sustainability

Summary to Types of Material Flow Analysis

The different types show clearly, that MFA has been applied as a basic tool in the diverse fields of economics, environmental management, resource management, and waste management. Within MFA different systems like firms, sectors or regions can be investigated. The most important application areas of MFA in the face of firms are to be discussed in Chapter 3.4.

3.4 Application in the System Boundary of a Firm

In firms the physical balance of inputs and outputs is increasingly being used as part of an environmental performance report and affords extensive information for environmental management.⁴⁵

Environmental Management and Engineering

To provide transparency is one of the major aspects of MFA for environmental management and engineering. With a clear periodically balancing of material flows of a system, starting points for improvements can be given and weak points can be

⁴⁴ Cf. Bringezu (2000) quotes in Ayres and Ayres (2002), p. 84

⁴⁵ Cf. Bringezu (2003), p. 22

revealed. By modelling alternatives to the current process scenarios, comparisons can be drawn and evaluated.

Resource Management

An efficient utilization of resources is a major target of resource management. The possibility of reviewing the production processes makes MFA to a tool for efficiency monitoring of the exploitation of resources, such as plastics, metals, wood, chemicals, water, energy, etc. MFA also can be used for analysis, planning and allocation of resources.

Waste Management

MFA can contribute to the design of better products that are more easily recycled or treated once they become obsolete and turn into waste. These practices are known as design for recycling, design for disposal, or design for environment.

An MFA-based total material balance shows if given goals have been achieved. An MFA balance also identifies the processes that have the highest potential for improvements.⁴⁶

Summary to Application Possibilities

All these applications of MFA can be the basis for identify saving potentials, increase material and energy efficiency, lower material and production costs, an improved environmental performance and decision-making on a well found database.

Knowledge obtained from such a MFA can be used to explore alternatives that could reduce the use of materials, enlarge recycling of materials, and decrease industrial effluents. Decisions based on such knowledge would lead to industrial systems that are more efficient, sustainable, and more protective for the environment. MFA provides a suitable basis for economic evaluation of material use. Hence, MFA enhances a decision maker's ability to make effective environmental decisions.⁴⁷

⁴⁶ Cf. Brunner and Rechberger (2004), p. 19

⁴⁷ Cf. Xue et al. (2004), access date 06.10.2010

3.5 Objectives of Material Flow Analysis

MFA is a suitable tool to investigate the flows of any material-based system. The objectives of MFA are:⁴⁸

1. Delineating a system of material flows and stocks by well-defined, uniform terms
2. Reducing the complexity of the system as far as possible while still guaranteeing a basis for sound decision making
3. Assessing the relevant flows and stocks in quantitative terms, thereby applying the balance principle and revealing sensitivities and uncertainties.
4. Presenting results about flows and stocks of a system in a reproducible, understandable and transparent way
5. Using the results as a basis for managing resources, the environment, and wastes, in particular for:
 - a. Early recognition of potentially harmful or beneficial accumulations and depletions of stocks, as well as for timely prediction of future environmental loadings
 - b. The setting of priorities regarding measures for environmental protection, resource conservation and waste management (what is most important; what comes first?)
 - c. The design of goods, processes and systems that promote environmental protection, resource conservation and waste management (green design, ecodesign, design for recycling, design for disposal, etc.)

By fulfilling these objectives, the MFA gives insight into the behaviour of the material-based system. If the MFA is combined additionally with other disciplines such as energy-flow analysis, economic analysis and consumer oriented analysis, it facilitates the control of an anthropogenic system.⁴⁸

⁴⁸ Cf. Brunner and Rechberger (2004), p. 28

3.6 Approach

Chapter 3.6 describes how MFA has to be carried out. Therefore important terms and procedures of an MFA are discussed.

3.6.1 Important Terms of Material Flow Analysis

To ensure the consistence of the MFA it is necessary to define terms and procedures exactly and afterwards apply them consequently. To make MFAs comparable among each other, these terms have to clearly delineate of one another. The basic terms of a MFA are:

Substance

In chemical science a substance is defined as any chemical element or compound composed of uniform units. They are characterized by a unique and identical constitution and are thus homogenous.⁴⁹

E.g. nitrogen, carbon, copper but also compounds like ammonia, carbon dioxide or copper sulphate are substances. No substances are for instance drinking water, because it consists not only of pure water but also of calcium and other trace elements, or PVC which contains beside polymerized vinyl chloride also additives.⁵⁰

Good

A good consists of one or more substances and is tradable. The monetary value of goods can be positive (fuel oil, mineral water) or negative (residual waste, waste water) or in some cases neutral (air, exhaust air or rainfall).⁵⁰

Material

Material is a general term, which can be used for goods as well as for substances. So material includes raw materials and all human-induced physically or chemically transformed substances. Hence the term material is used if goods and substances are considered.⁵⁰

⁴⁹ Cf. Sax and Lewis (1987) quoted in Brunner and Rechberger (2004), p. 35

⁵⁰ Cf. ÖWAV (2003), p. 11

Process

A process describes the transformation, the transport or the storage of goods and substances.⁵¹ Examples for transformation processes are:⁵²

- the metabolism of a organism (e.g. human, animal)
- procedures in a facility (e.g. manufacturing operations)
- procedures in the environment (e.g. atmosphere, hydrosphere, soil)
- metabolism of a household, a city or a region, etc.

As shown in Figure 8, a process often can be seen as black box, which means procedures within the process are not considered. If thus have to be investigated closer, a process can be subdivided to more subprocesses.⁵²

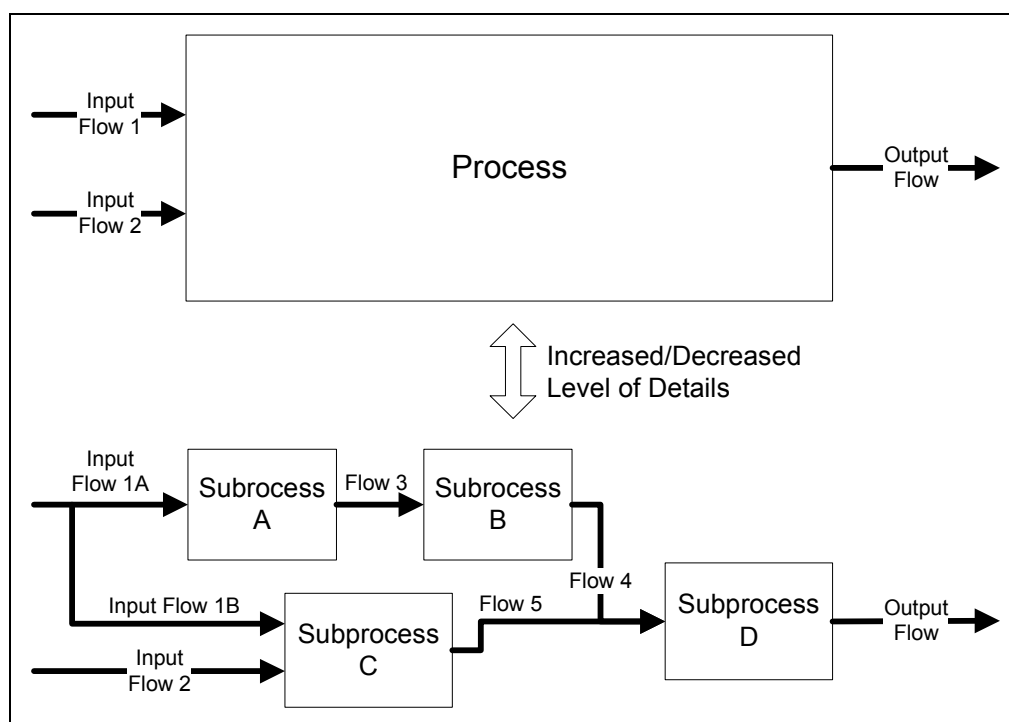


Figure 8: Process with its Subprocesses

System

A system describes the amount of elements and their connections with each other. Within the scope of MFA, elements of the system are defined as processes and flows of goods and substances. A system can be a single process, a firm or a part of a firm, a region, a nation or also a household.⁵²

⁵¹ Cf. Baccini and Brunner (1991) quoted in Brunner and Rechberger (2004), p. 37

⁵² Cf. ÖWAV (2003), pp. 11-12

System Boundary

The system boundary defines the delimitation of time and space of the system under investigation. The time boundary is often a year, a space boundary can be a regional or a company boundary. Material flows into a system boundary are called imports (or inputs), the flows which come out of the system boundary are called exports (or outputs).⁵³

Flow

The movement of material between the processes is called flow and has usually the unit mass per time, so it can also be defined as mass flow rate. Material flows which go into a process are called inputs, flows which leave the process are called outputs. A further term in this context sometimes is flux. A flux is defined as flow per cross section.⁵³

Material Flow System

In Figure 9 the basic elements of a material flow system are displayed. It includes processes, input flows, connection flows, and output flows in a defined system boundary.

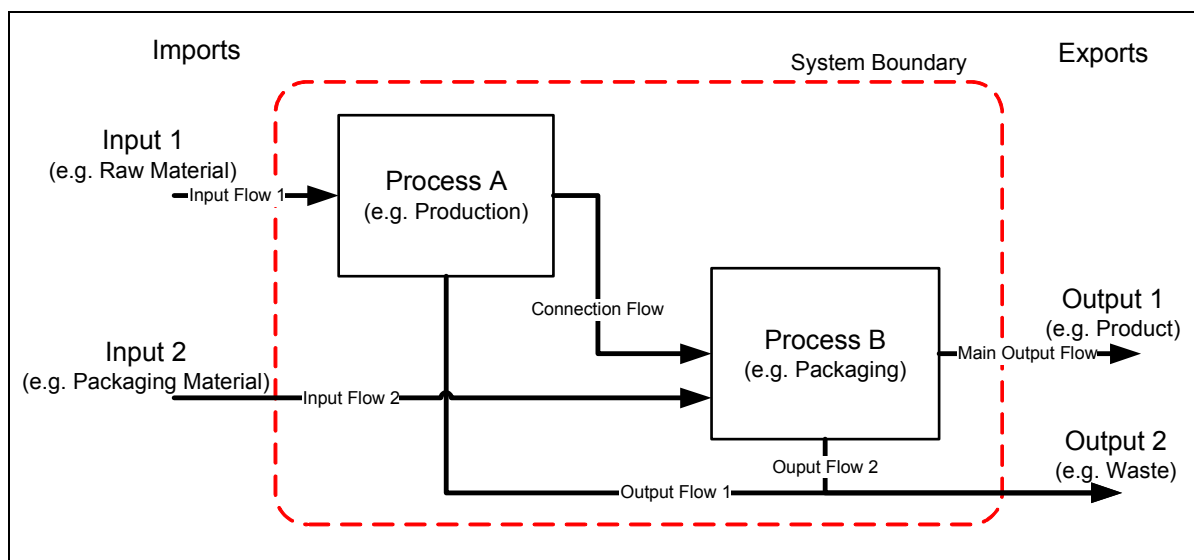


Figure 9: Basic Elements of a Material Flow System

Balance

A balance in economical sense is defined as a structured comparison of all at balance date applied values allocated by source (assets) and application (liabilities) of funds.

⁵³ Cf. ÖWAV (2003), pp. 12-13

This guideline can be transferred to a material flow balance. The flows which come into the system are contrasted with the respective outputs of the system within a certain observation period.⁵⁴

Transfer Function and Transfer Coefficient

A transfer function describes the allocation of material inputs to the different outputs within a process. A transfer coefficient quantifies the mass fraction of an input material in an output of a process.⁵⁴

Material Accounting

Material accounting is a periodically and an efficiently quantitative capture of the most important material flows of a system. The basic assumption of material accounting is that it is possible by reference to some selected key processes to infer to the total material flows of a system. The basis for material accounting is a detailed material flow analysis. Compared to often repeated MFAs, similar information can be gained with significantly lower use of resources.⁵⁴

Scenarios

Scenarios describe an optional working step of MFA. Scenarios are used if statements of the future development of material flows should be given or if the impact of different measures should be quantified and compared. Here different system parameters of current material flows are changed or alternative processes are included, to simulate a modification of the present state and compare the results.⁵⁴

3.6.2 Procedures

An MFA consist of several steps. As shown in Figure 10, an MFA begins with the definition of the problem and of adequate goals. Then relevant materials and appropriate system boundaries and processes are selected. Next, mass flows of materials within the system are assessed and calculated and uncertainties are considered. The results are presented in a suitable way to visualize conclusions and to facilitate implementation of goal-oriented decisions. It is important to say that these procedures must not be executed in a strictly consecutive way, because they have to be optimized iteratively. The selections and provisions that are taken during the implementation of the MFA have to be checked continuously. If it is necessary, they

⁵⁴ Cf. ÖWAV (2003), pp. 12-13 and 35

must be adapted to accommodate the objectives of the project. In general, it is best to start with rough estimations and provisional data, and then to more and more refine and improve the system and data until the required certainty of data quality has been achieved.⁵⁵

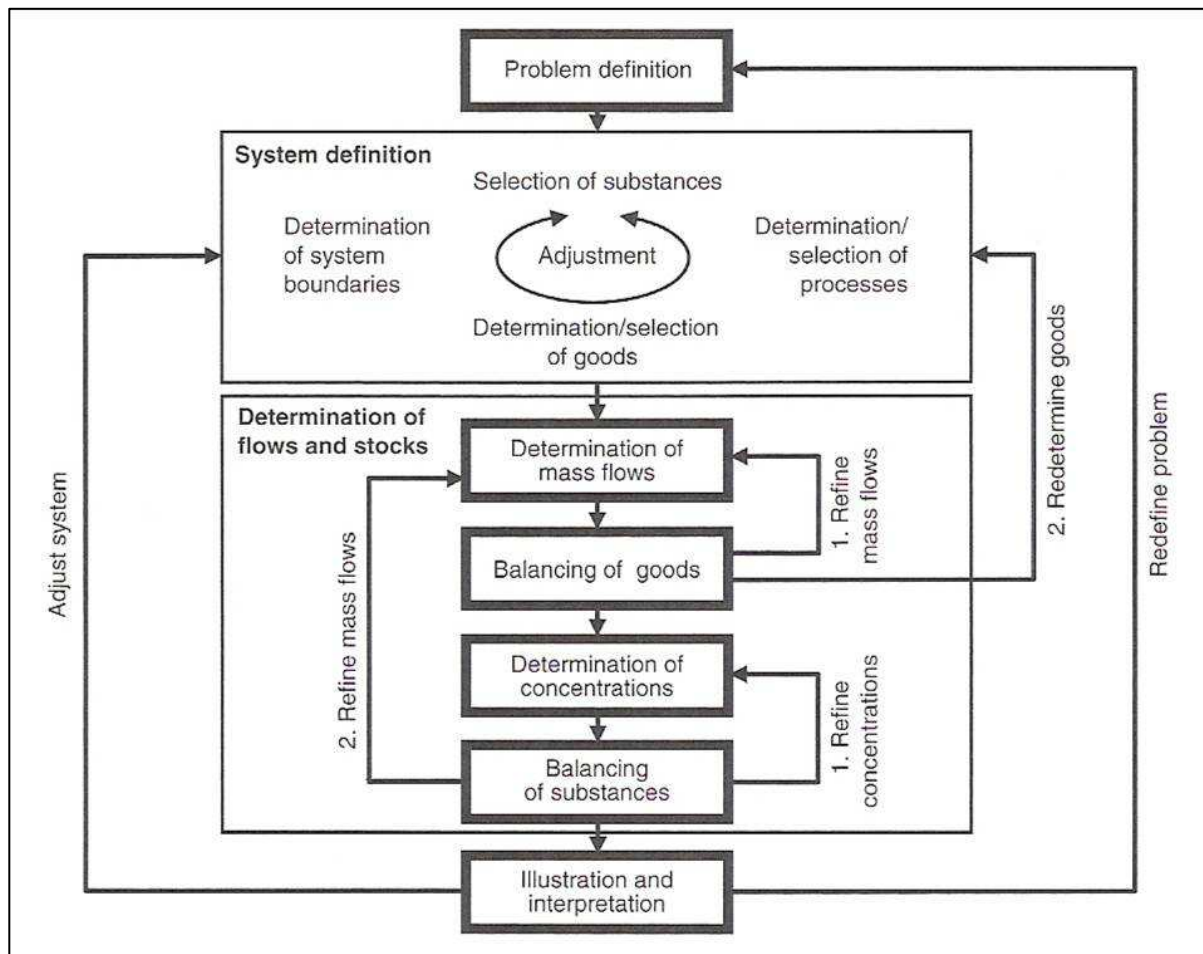


Figure 10: Procedures of Material Flow Analysis⁵⁶

To reduce the complexity of a system is necessary to gain meaningful results of the MFA. Bouman therefore distinguishes the six aspects of simplification: focus, aggregation, linearity, optimisation, time and uncertainty.⁵⁷

System Definition

After defining the problem, the system definition is one of two main parts of the MFA.

As shown in Figure 10, the results of the system definition should be:

- Determination of the system boundaries (in space and time)

⁵⁵ Cf. Brunner and Rechberger (2004), pp. 53-54

⁵⁶ Brunner and Rechberger (2004), p. 54

⁵⁷ Cf. Bouman et. al. (2000), pp. 19-20

- Determination/selection of processes and subprocesses (optional)
- Determination/selection of materials (goods and substances)

The data availability and quality is crucial for the structure and level of detail of the system. The working step for system definition can be an iterative one, if conclusions suggest a subsequently adjustment of the system.⁵⁸

Determination of Flows and Stocks

The determination of flows and stocks is the second main part of the MFA.

Information about the material flows usually is taken from the database or can be measured directly or indirectly on site. After a rough collecting of available information and data, a first rough balancing of the material flows should be made. This is necessary to check if the defined system is appropriate for the given problem. The material flows of the single processes, of the subsystems and of the total system have to be balanced.⁵⁹

After a rough balancing sensitivity analysis can be carried out. The aim of this analysis can be an optional adjustment of the system definition or a check and redefining of the target description.⁵⁸

After the final adjustment of the system definition data has to be collected, processed and balanced in more detail. Flows with their keys and transfer coefficients, have to be calculated, aligned and calibrated to inputs and outputs. Next the balances have to be reviewed, checked and revised if necessary.⁵⁸

Illustration and Interpretation

After satisfying results are achieved, they should be illustrated and interpreted in an appropriate way.

The results of an MFA should be presented first in a comprehensive technical report and then in an executive summary, to make the results also for persons with no technical or scientific background comprehensible. The reports and summaries should include explanations to gaps and uncertainties of the data. The average values and results of the material flow analysis should be displayed in tables, balances and flow charts.⁵⁸

⁵⁸ Cf. ÖWAV (2003), p. 17, p. 30, and p. 33

⁵⁹ Cf. Baccini and Bader (1996) quoted in ÖWAV (2003), p. 29

To maximize the impact of the MFA findings, figures that visualize the results or conclusions are of fundamental importance.⁶⁰

Visualizations can be made for example with Sankey Diagrams, as explained in Chapter 3.7.3, or charts.

3.7 Methodology

In this Chapter the tools process flow diagrams, Sankey Diagrams and input/output balances for MFA are introduced.

3.7.1 Process Flow Diagrams

Process flow diagrams can be used within a MFA to help in the procedure of system definition. These diagrams facilitate to display which processes have to be analysed in which system boundaries, which materials are processed and how the processes are connected in the system. For this purpose a process flow diagram should be clearly structured and display a complex system in an abstracted way.

One of these process flow diagram types which can be used for this purpose are called block diagrams. As displayed in Figure 11, the block diagram depicts a process or process plant by means of rectangular frames including the relevant inscriptions, interconnected by flow lines.⁶¹

The frames may represent:⁶¹

- processes
- process steps
- unit operations
- process plants or groups of process plants
- plant sections
- equipment

The flow lines may represent streams of materials or energy flows.

⁶⁰ Cf. Brunner and Rechberger (2004), p.64

⁶¹ Cf. ISO 10628 (1997), p. 2

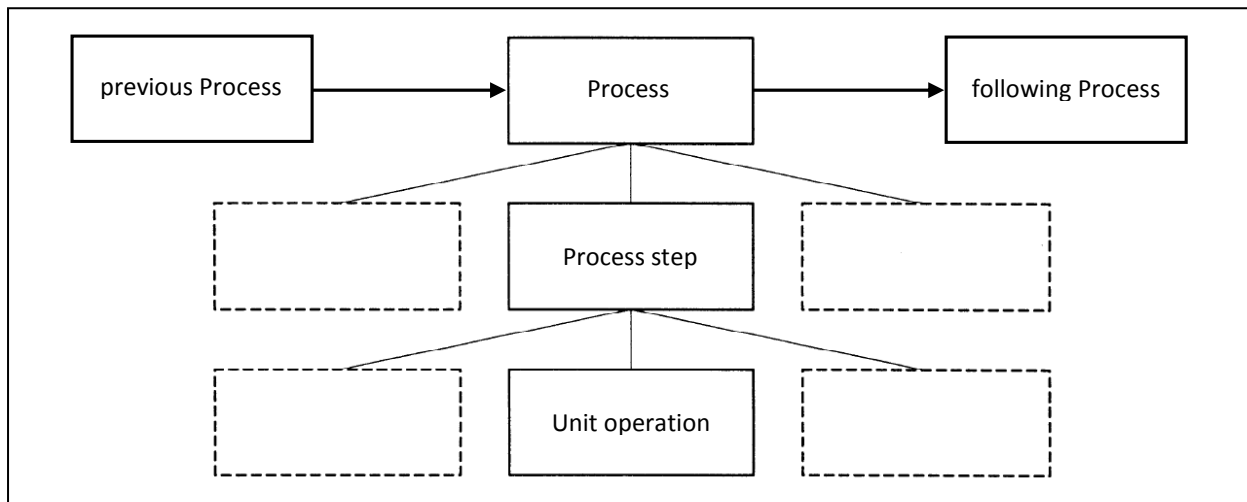


Figure 11: Block Diagram⁶²

Any drawing program can be used to create process flow diagrams. Special process flow diagram programs are for example Microsoft Visio© or SmartDraw©.

3.7.2 Input/Output Balances

In this Chapter is shown how results of an MFA are displayed in an input/output balance (I/O balance).

To balance the material flows in a defined system is a key issue of an MFA. Therefore it is necessary to contrast the inputs and outputs of every selected process of the system. A balance can be made for single processes, a certain selection of connected processes within the system, a product, or a complete plant.

Some guidelines for material flow balances (or I/O balances) are:⁶³

- For complex production systems, it is better to first sketch the material flow balances.
- For splitting up the total complex system, choose simple separate sub-systems. For this purpose process flow diagrams are a useful tool.
- The analysed units should include time factors and production linkages.

⁶² Cf. ISO 10628 modified (1997), p. 3

⁶³ Cf. Bureau of Energy Efficiency (2010), access date 07.10.2010

The material flow balances along the above guidelines, are required to be developed at the various levels:⁶⁴

- Overall material flow balance: This involves the in- and outgoing material streams of a complete plant.
- Section-wise material flow balances: In the analysis of material flows, the I/O balances can be required to be made for each section, department, or cost centre. This helps to prioritize potential areas for efficiency improvements.
- Equipment-wise material flow balances: Material balances for key equipment are used to assess the performance of equipment or a process, which helps to identify and quantify material avoidable losses.

Figure 12 compares a commercial business balance with an input/output ecobalance.

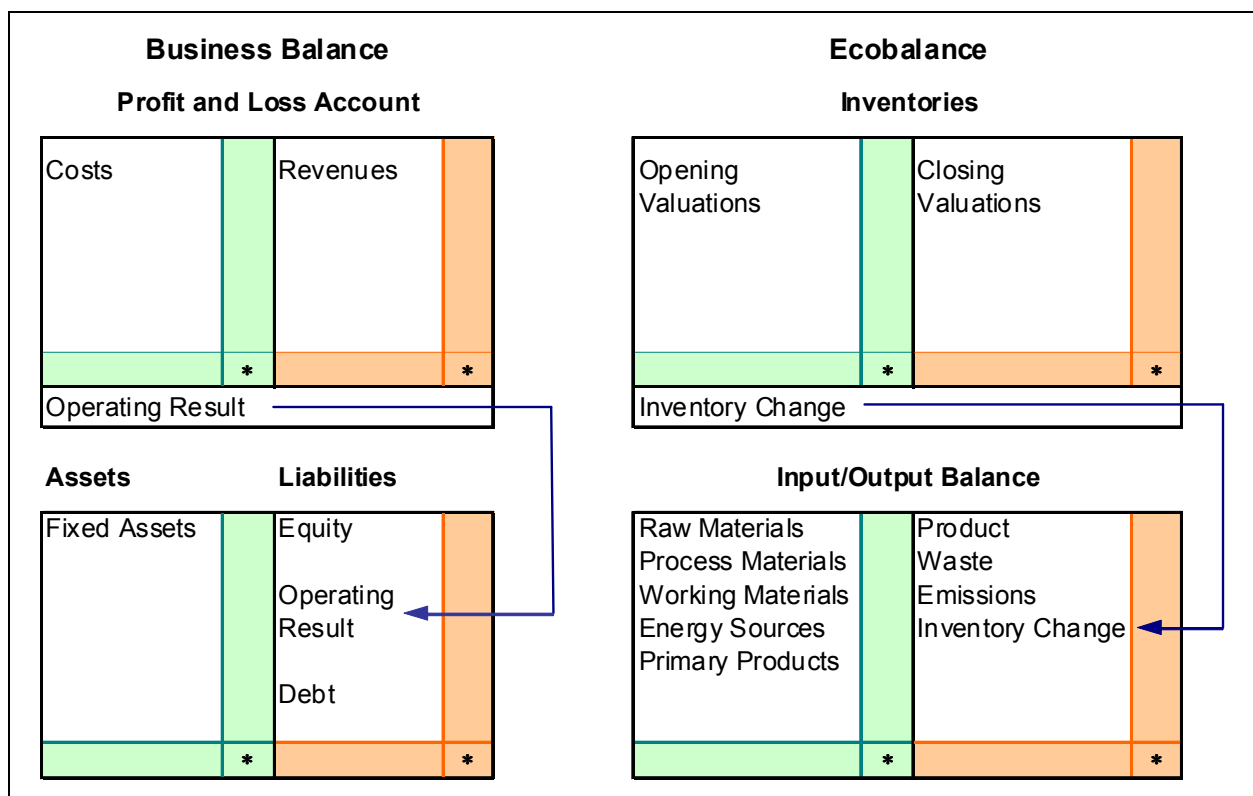


Figure 12: Comparing a Business Balance with an Input/Output Ecobalance⁶⁵

⁶⁴ Cf. Bureau of Energy Efficiency (2010), access date 07.10.2010

⁶⁵ Cf. Möller (1995) quoted in Schmidt and Häuslein (1996), p. 23

3.7.3 Sankey Diagrams

To illustrate the results of an MFA in meaningful figures is an important task. In this Chapter the visualization possibilities of the results of an MFA with the aid of Sankey Diagrams are introduced.

An important aid helping to identify inefficiencies or saving potentials when dealing with resources, is the so called Sankey Diagram. It was first used 100 years ago by the Irish captain Riall Sankey for analysing the thermal efficiency of steam engines and has since been applied to illustrate the material and energy balances of complex systems. Since the 1990s these diagrams have become standard for displaying data in Life Cycle Assessments of products or are used for map value flows in systems at operational level, or along global value added chains.⁶⁶

Sankey Diagrams are attention grabbing flowcharts that help to visualize the distribution and losses of material and energy in a process. The width of the lines used in drawing the diagram is proportional to the quantum of material or energy.⁶⁷

The Sankey Diagram is very convenient tool to represent and allegorize material or energy flows in any equipment or system after carrying out material or energy balance calculation. This diagram represents visually various outputs and losses so that managers can focus on finding improvements in a prioritized manner. A Sankey Diagram is also a powerful tool to sell concepts and ideas within a group or to the top management.⁶⁷

Figure 13 and Figure 14 are examples for different Sankey Diagrams. The Sankey Diagram in Figure 13 represents the material inputs and outputs of a country, the unit for the quantities is million tons. The total material input contains products, resources, domestic resources, and reused and recycled materials. The right output side of the diagram shows to which outputs the input materials were transformed.

⁶⁶ Cf. Schmidt (2006), p. 2

⁶⁷ Cf. Sahasranaman (2006), access date 06.10.2010

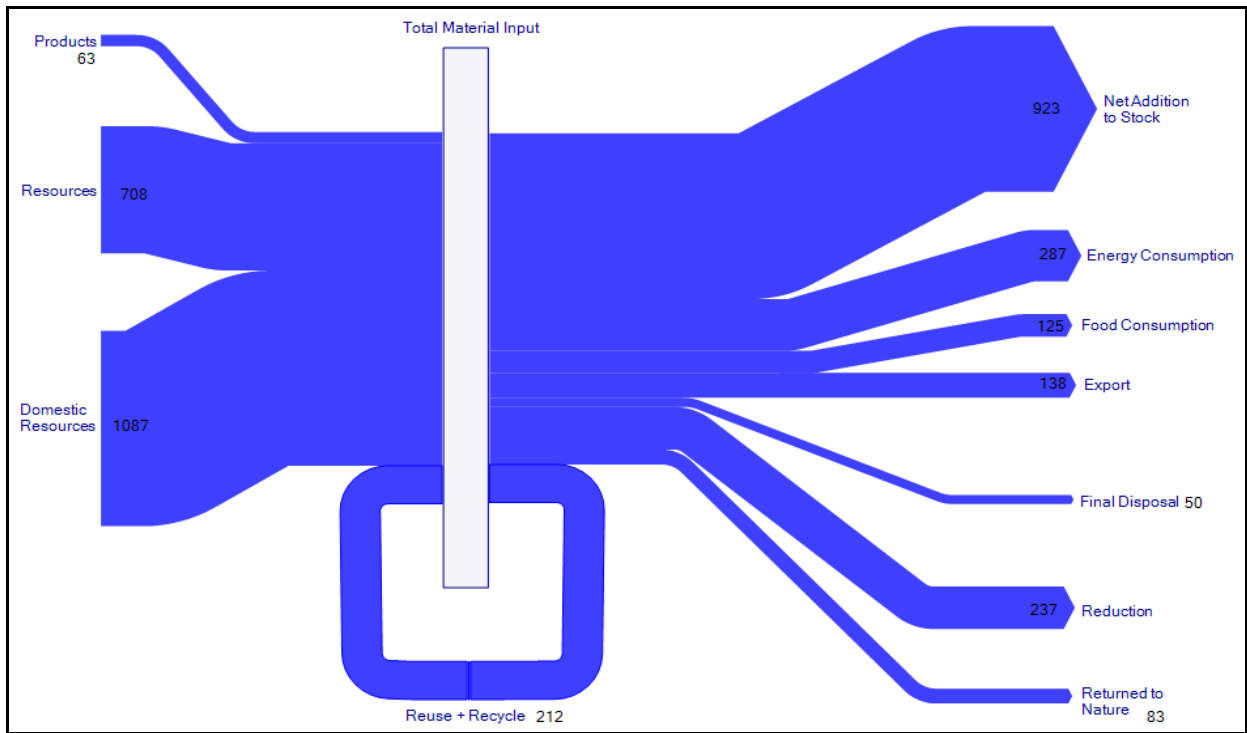


Figure 13: Sankey Diagram Material Inputs/Outputs of a Country⁶⁸

The costs of a production are depicted in the Sankey Diagram in Figure 14. The Figure shows the cost rates of the production and points out the potential of cost savings of material and energy costs.

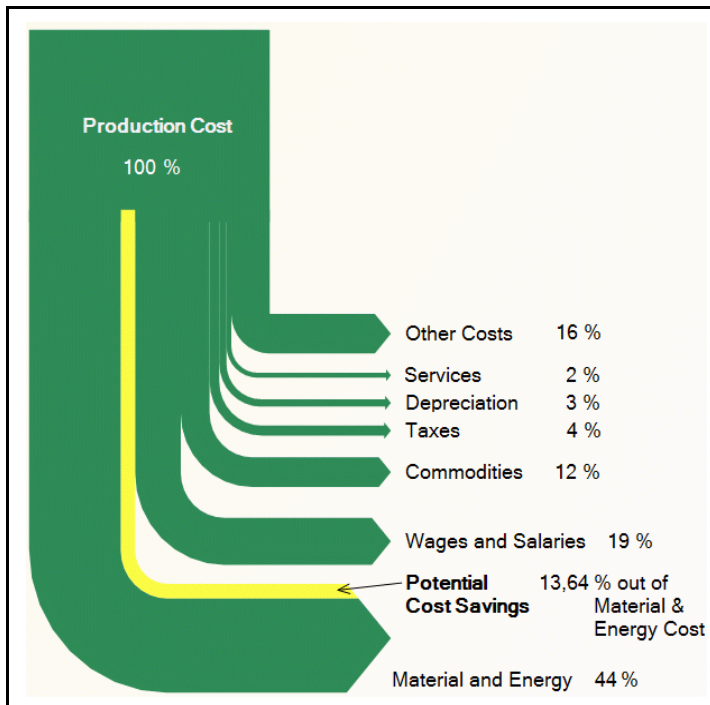


Figure 14: Sankey Diagram of Production Costs⁶⁹

⁶⁸ ifu Hamburg (2010a), access date 07.10.2010

⁶⁹ ifu Hamburg (2010b), access date 07.10.2010

Special available software solutions for Sankey Diagrams are for example e!Sankey© of ifu Hamburg or S.Draw©. As will be described in Chapter 3.8.2, Sankey Diagram features are also included in different MFA software solutions.

3.8 Software for Material Flow Analysis

In this Chapter the question is discussed, which MFA software solutions are available and which are best suitable in the scope of MFAs within a company.

3.8.1 Requirements for Software for Material Flow Analysis

Beside basic software requirements like detailed documentation, user friendliness, support and maintenance, stability, cost benefit, compatibility with other software applications or flexibility,⁷⁰ the software must meet the following demands:⁷¹

- **Terminology:** The terminology is compatible with MFA, i.e., it is possible to deal with materials on different levels (goods and substances) and relations (concentrations).
- **Methodology:** The methodology is compatible with MFA, i.e., it can create material flow systems such as networks by assembling elements in an interactive way. The standard symbols are easily adjustable. It should be possible to define subsystems to enhance understanding and clarity. The software can deal with feedback loops and storages with delayed output.
- **Data:** The software has the following data-handling capabilities:
 - Input: Data in the form of values, functions, or graphs can be imported from databases (Microsoft Access, Dbase, Oracle) or accessed with the help of scripting languages. All parameters can be easily changed. Data from remote databases can be requested and incorporated.
 - Data storage: The entire input information and all results can be stored in databases. This facilitates the comparison of different scenarios and the exchange of data with other databases.
 - Output: The user can present the results in various ways (tables, figures, graphs, flowcharts, Sankey Diagrams). The user can freely choose layout and content of the display.

⁷⁰ Cf. Schmidt and Häuslein (1996), pp. 4-5

⁷¹ Brunner and Rechberger (2004), pp. 82-83

- **Uncertainties:** The software allows consideration of data uncertainties an application of different kinds of statistical distributions. The propagation of these uncertainties is taken into account by using Gauss's law-of-error propagation and/or Monte Carlo simulation methods. Sensitivity analysis and optimization of measured data for an over determined system are featured.
- **Calculations:** The software can provide the following information:
 - Description of the actual state of a given system 'model'.
 - Simulations of scenarios with new processes, new goods, or new input data (e.g. mass flow, chemical composition, transfer coefficients).
 - Comparison of scenarios with the original system (deviation)
 - Simulation of the dynamic behaviour of a system as well as its static behaviour. Single processes as well as whole systems can be balanced.

3.8.2 Available Software Solutions

Based on these requirements a number of software was analysed and tested:

- **Excel** can be used e.g. for input/output balancing.
- **STAN** is a free material flow analysis software from TU Vienna and can be downloaded online.
- In **GaBi** material flow analysis are possible, but it is only one of many features and the focus is on LCA (Life Cycle Assessment).
- **Umberto** is used for Input/Output balancing, visualization of material flows, process optimization, etc.
- **Tecnomatix Plant Simulation** from Siemens PLM Software is a Material Flow Simulation-Software, which is used mainly for factory planning. It includes tools for simulation, 3D-display, etc., and is especially designed for material flow optimization in a logistical point of view.
- **SAP Environment, Healty & Safety** (SAP EH&S) needs SAP as prerequisite, which can not be fulfilled at Sony DADC. The main application is on manage risk and comply with EHS regulations.
- In **VisTABLE** the focus is on visualization and planning of whole factories with included material flows. It is primarily used for MFA for logistics optimization.
- **Simbox** is another material flow analysis tool, which was usually developed for internal use. Simbox is not as mature as the competition software solutions Umberto and GaBi.

- Further programs are **SimaPro**, which is similar to GaBi but not that good developed.
- **AggFlow** is another MFA software which was especially designed for mining industry.

After a pre-investigation of the software solutions it turned out that best suitable for the given requirements are Umberto 5 and Gabi 4. Because it's on nearly every working station available, also Excel was considered closer. To complete the investigation of MFA software STAN was tested in detail as well.

To give an overview the features of the pre-selected software solutions, they are introduced in the next Chapters.

3.8.2.1 Microsoft Excel

It is possible to use Microsoft Excel to perform MFA, event tough it has not been specially designed for this purpose.

With Excel clearly structured flow charts can be created. The user manually defines which cells display processes, flows, or other parameters. The user than has to state formulas that show how to calculate unknown quantities to compute a flow quantity and balance an adjacent process.⁷²

Excel can be an important additional tool if a MFA is performed with other software solutions. It can be used for data collection and handling, material quantity calculations or reporting of MFA results. Often data import to MFA programs can be made via Excel. Excel is also very adequate for the creation of material flow balances.

3.8.2.2 STAN

STAN (short for '**Stoffflussanalyse**' or **substance flow analysis**) is a freeware of TU Vienna that helps to perform material flow analysis in compliance with ÖNorm S 2096 (material flow analysis - application in waste management).⁷³

At first a graphical model with predefined components (processes, flows, system boundary, text fields, etc.) has to be build. Afterwards data to mass flows, concentrations, transfer coefficients, or stocks can be entered or imported for different materials (or energy) and periods to calculate unknown quantities. The material flows

⁷² Cf. Brunner and Rechberger (2004), p. 87

⁷³ Cf. Cencic (2010), access date 08.10.2010

can be displayed with the aid of Sankey Diagrams and the graphical picture of the model can be printed or exported. For data import and export Microsoft Excel can be used as an interface. There is also a possibility to consider data uncertainties. The calculation algorithm uses mathematical statistical tools like data reconciliation and error propagation.⁷³

A screenshots to STAN is shown in the appendix in Figure 68.

3.8.2.3 GaBi

The GaBi 4 software system for life-cycle engineering was developed by the Institute for Polymer testing and Polymer Science (IKP) at the University of Stuttgart in cooperation with PE Europe GmbH. GaBi stands for “**G**anzheitliche **B**ilanzierung” or in English “life-cycle engineering”. GaBi 4 is primarily used as an LCA tool in industry, academia, and consultancy. Also cost evaluation of the investigated system can be carried out. The multifunctional features of GaBi 4 also make it useful as a tool for simply and quickly modelling and analyzing complex and data-intensive problems for MFA projects.⁷⁴

PE’s support companies with services to enhance the sustainability of plants, processes, services and products of companies as well as to provide related tools and databases. They also support companies to be in compliance with standards, regulations and restrictions from the environmental point of view.⁷⁵

GaBi 4 is a tool for integrating all sustainability criteria on a facility, process and product life cycle level. It’s possible to identify weak points within the added value chain and pinpoint areas with room for improvement. With a rather simple creation of production and use of scenarios, balance analyses with interactive report templates can be made. Support in the development of new products by addressing design questions, such as material and process uncertainties. A centralised database with environmental information on individual production steps and energy provision, production of materials and transportation is available for GaBi.⁷⁵

Screenshots to GaBi are shown in the appendix in Figure 69 and Figure 70.

3.8.2.4 Umberto

Umberto is designed for material- and energy-flow analysis. It was developed by the Institute for Energy and Environmental Research Heidelberg Ltd. (IFEU) in cooperation with the Institute for Environmental Informatics Hamburg Ltd. (ifu Hamburg).⁷⁴

⁷⁴ Cf. Brunner and Rechberger (2004), p. 89 and p. 114

⁷⁵ Cf. PE International (2010), p. 2 and pp. 12 -13

Ifu Hamburg GmbH is a software-developing and consulting company. Umberto has been sold more than 850 times. This makes ifu Hamburg the market leader in material and energy flow analysis.⁷⁶

Umberto is a very flexible and powerful software tool for modelling, calculation, visualization, and evaluation of material and energy flows. The software keeps track of inventory and simulates processes and systems. The results can give significant support for critical decisions. An efficient use of materials and sensible handling of production resources can offer significant savings potentials. Umberto can be a support in the discovery and utilization of this potential. One of the main tasks of Umberto is to model and optimize production processes. The graphic display of the calculated mass and cost flows uses Sankey Diagrams. Through this visualization, Umberto delivers a basis for decision making as well as for internal and external communication.⁷⁷

Umberto Field of Application

The focus of the software is to balance the production processes of a company, as shown in Figure 15. Furthermore you have the possibility to make corporate environmental balances or an overall life cycle assessment. In this scope for example also carbon footprint calculations can be made.

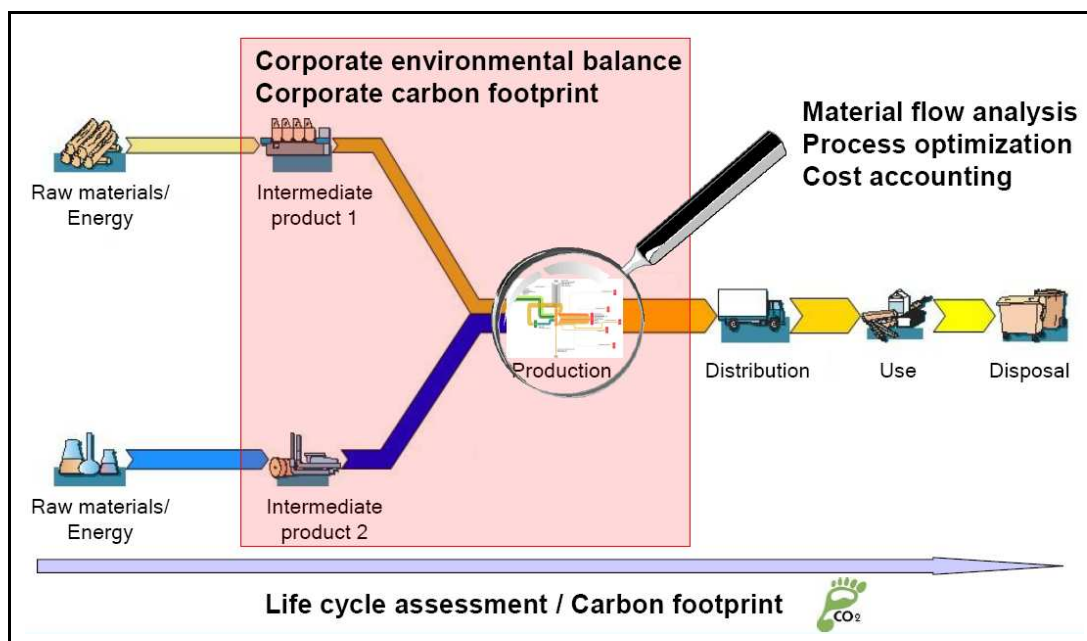


Figure 15: Umberto Field of Application⁷⁸

⁷⁶ Cf. Ifu Hamburg (2010c), acces date 08.10.2010

⁷⁷ Cf. ifu Hamburg (2010d), 07.10.2010

⁷⁸ ifu Hamburg (2010), p. 3

In Figure 16 is displayed, how a complex system can be structured in Umberto. On different levels a company can be broken down to single machines on basis of a top-down approach. Thus, transparency can be given to a whole firm, different departments or processes and subprocesses.

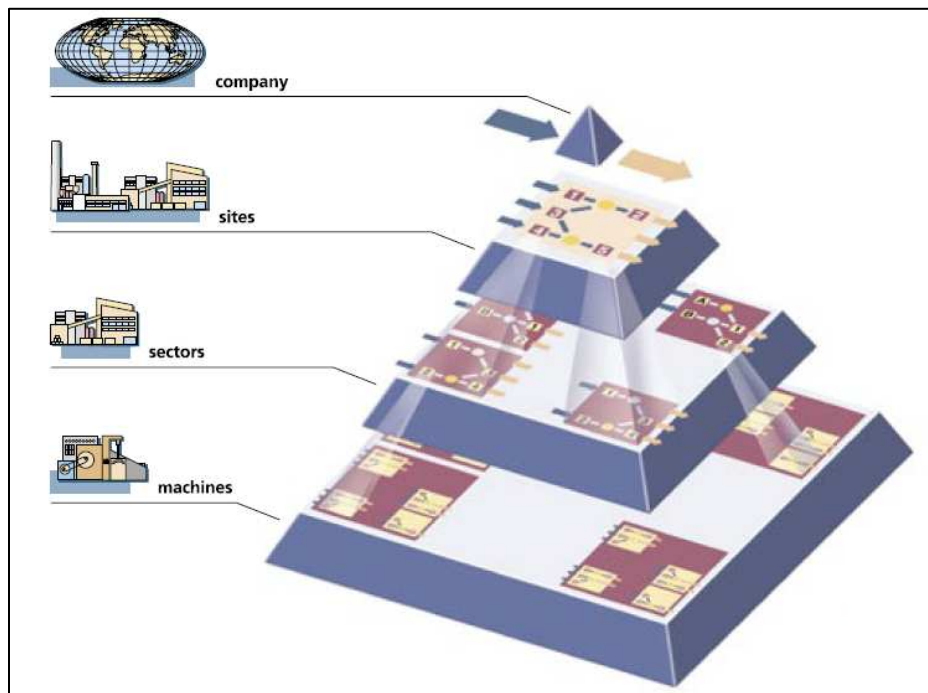


Figure 16: Umberto Network Structure⁷⁹

Umberto can be used as planning tool to optimize production systems. The MFA results from a scenario of the current state and an alternative modelled scenario can be compared. So you can see directly where differences are and which results could be expected by implementing the alternative scenario. Balance sheets can be exported to Excel or edited in diagrams and charts.⁸⁰

Analysis and assessment considering cost aspects is another application possibility of Umberto. For this purpose material and process related costs (variable/fixed), cost accounting regarding cost types, centres and units, calculation of internal prices and marginal income or optional even full cost accounting can be integrated.⁸⁰

⁷⁹ ifu Hamburg (2010), p. 4

⁸⁰ Cf. ifu Hamburg (2010), pp. 17-25

Figure 17 is an example for how the material flows of a production system are visualized in Sankey-style in Umberto.

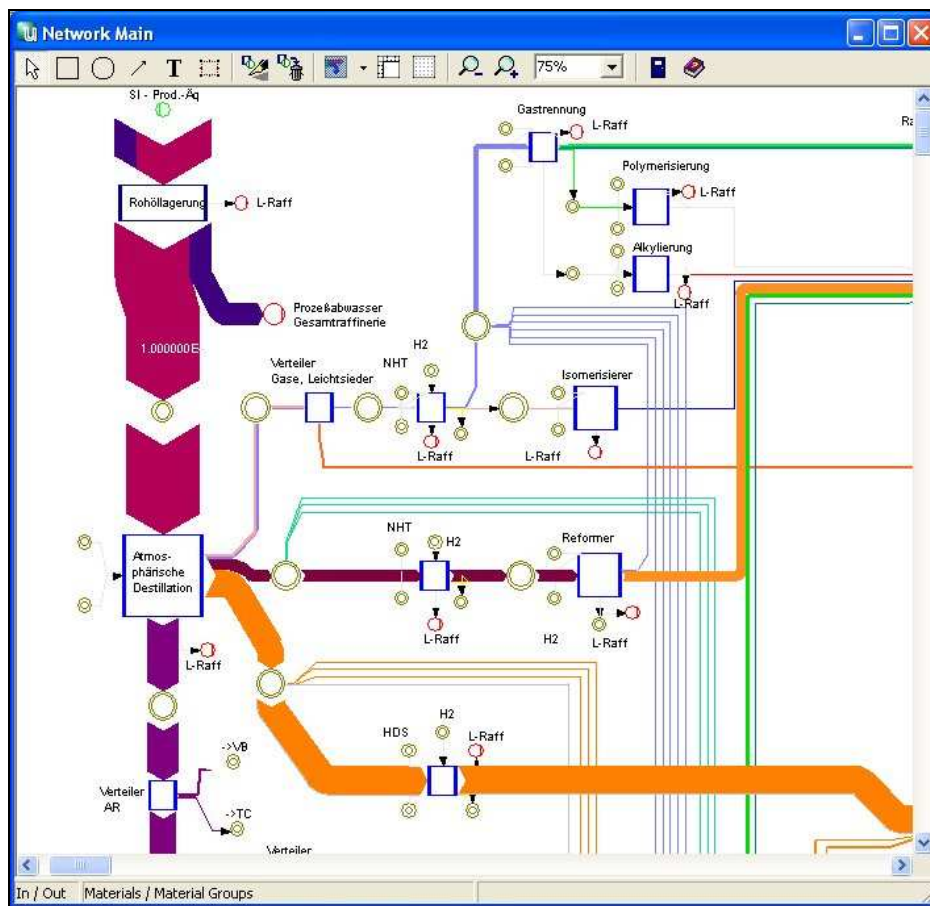


Figure 17: Material Flows of a Modelled System in Umberto⁸¹

The analysis and assessment considering environmental aspects is another useful feature of Umberto. Therefore the usage of standard databases (e.g. Ecoinvent) or assessment with pre-defined valuation systems (e.g. CML method) is recommended. With performance indicators on basis of the CML method the system can be evaluated in regard to acidification, eutrophication, global warming, human toxicity and other environmentally relevant issues.⁸²

With Umberto a useful software solution is provided, which can help to get transparency, speed up analyses and make decisions on a well-founded basis to reach an increased material and energy efficiency, lower production costs and an improved environmental performance.⁸²

⁸¹ ifu Hamburg (2010e), access date 08.10.2010
⁸² Cf. ifu Hamburg (2010), pp. 28-36

3.8.3 Comparison of Software-Solutions

To see which of these four introduced programs fits best for the given requirements, the pros and cons of those were compared. A comparison also was made in the practical handbook of MFA analysis. But as this comparison was made in 2004 and newer version of the software solutions were released, the evaluation was updated and further aspects were added. The results of the comparison are displayed in Table 1.

	Excel	STAN	Umberto 5	GaBi 4
Installation guide	+	+	+	+
User manual	+	+	+	+
On-line help	+	+	+	+
Operating system	MS Windows Mac OS	MS Windows	MS Windows	MS Windows
User friendliness	+	+	+	+/-
Support	+	--	++	+
Stability	+	+	+	+
Trial version	--	+++ free SW!	+	+
Speed	+/-	+	+	+
Programmability	+	+/-	+	--
Data import/export	++	+/-	+	+/-
Static simulation	+	+	+	+
Dynamic simulation	+	--	+	+
Uncertainties	+/-	+/-	+/-	+
Sensitivity analysis	+/-	--	+	+
Monte Carlo error simulation	+/-	--	+	+
MFA terminology/methodology	+	+	++	+/-
Sankey diagram	--	+	+	+
Other diagrams	+	--	+	+/-
Modelling	--	+	+	+
Network	--	+/-	+	+
Compare balances	+/-	--	+	+
Additional features	+/-	--	+	+
Total	+/-	+/-	++	+

Note ++ = very good, + = good, +/- = average, - = satisfactory, -- = not available

Table 1: Comparison of the Suitability of Excel, STAN, GaBi, and Umberto for MFA⁸³

This comparison made clear that Umberto is the best choice for comprehensive MFAs especially if the system boundary of the investigated system is a firm.

If someone wants to gain first experiences of software supported MFA, or if the defined system or problem is not that complex, a combination of Excel and STAN would be a suitable choice.

⁸³ Cf. Brunner and Rechberger (2004), p. 134

4 Material Flow Analysis at Sony DADC Anif

The task of the diploma thesis to develop a concept for material flow analysis for Sony DADC Austria in Anif is described in Chapter 4 and 5. To find out which requirements have to be fulfilled by the system and which results can be expected, a material flow analysis for Sony DADC Anif for fiscal year 2009 has to be carried out.

At first the basic requirements and motivation of Sony DADC Austria for making a MFA are discussed.

4.1 Sony DADC Requirements

In the Sony environmental vision is described that Sony recognizes the utmost importance of a healthy global environment, and has made sustainable development the Group's top business priority. Sony's environmental resources have to be utilized in a way that will also give future generations the possibility to realize their potential in health, wealth and happiness. Therefore Sony aims to show that it is achievable to attain a new symbiosis between humanity and nature by doing more with less, reducing the environmental impact from its use of resources and energy while providing the customers with high-quality and high-performance products and services.⁸⁴

Sony DADC Environmental Policy

The principles of the environmental policy include the compliance with all legislation or requirements such as internal standards, the prevention of pollution and the continuous improvement in the environmental performance.⁸⁵

The main aspects of the Sony DADC environmental policy were defined by Dieter Daum, CEO of Sony DADC International, in 2007: *"We strive to reduce the consumption of direct and indirect materials, energy and water, for the reduction of solvent emission and for the reduction and recycling of waste. Furthermore, we continually work towards the reduction and replacement of such substances in the materials used which are harmful and can have a negative impact on the environment."*⁸⁶

In order to ensure compliance with this policy an environmental management system (EMS) was implemented and environmental audits are carried out on a regular basis.⁸⁵

⁸⁴ Cf. Sony DADC (2010c), access date 22.09.2006

⁸⁵ Cf. Daum (2007), access date 22.09.2006

⁸⁶ Daum (2007), access date 22.09.2006

Since 1998, the EMS of Sony DADC Austria is ISO 14001 certified. Sony DADC constantly puts efforts toward constant improvement and saving natural resources along steady growth of business. Recycling or reusing of waste and using of alternative energy sources is a priority. The Sony DADC efficiency programs Sony Six Sigma, KAIZEN and MUDA support the environmental activities in regard to constant improvement of processes, increased efficiency and avoidance of waste.⁸⁷

ISO 14001

An EMS meeting the requirements of ISO 14001:2004 is a management tool enabling an organization of any size or type to:⁸⁸

- identify and control the environmental impact of its activities, products or services
- improve its environmental performance continually
- implement a systematic approach to setting environmental objectives and targets, to achieving these and to demonstrating that they have been achieved

Therefore an ISO 14001 certified EMS uses the elements 'plan', 'do', 'check' and 'act' for the realization of a continuously improvement process:⁸⁹

- Plan – establishment of the environmental policy, analysis of the current situation, setting of environmental goals, working out of environmental program
- Do – implementation of the environmental program, definition of the organizational structure, information and communication, documentation
- Check – measurements and intern audits on a regular basis, actual and target comparisons
- Act – realization of correction and improvement measures, trainings

GRIDS or Sony Green Partner, are Sony intern regulations or programs, which support to achieve the requirements of the ISO 14001.

⁸⁷ Cf. Sony DADC Austria AG (2010)

⁸⁸ Cf. International Organization for Standardization (2010), access date 22.09.2006

⁸⁹ Cf. Brauweiler (2002) quoted in Kramer et al. (2004), p. 126

GRIDS

GRIDS describes a Sony intern regulation. For the GRIDS regulation certain material consumptions have to be reported periodically, e.g. chemical substances, waste, sewerage, energy consumption, etc.

Sony Green Partner

Sony Green Partner is a product compliance program to control the upstream supply chain from finished products back to the source of material.⁹⁰

All materials which are used for production at Sony are subject to strict conditions in regard to environmental compatibility. Therefore Sony suppliers must meet certain Sony standards for restriction of hazardous substances. After a successful audit the supplier gets a certification and becomes a Sony Green Partner.

REACH

There are also some external standards and regulations, which have to be considered. One of the most important external regulations is REACH, that's why it's briefly described.

REACH is a regulation of the European Union concerning **R**egistration, **E**valuation, **A**uthorisation and **R**estriction of **C**hemicals.⁹¹

REACH makes industry responsible for assessing and managing the risks posed by chemicals. The main aims of REACH are to ensure a high level of protection of human health and the environment from the risks that can be posed by chemicals, the promotion of alternative test methods, the free circulation of substances on the internal market and enhancing competitiveness and innovation.⁹²

Therefore companies have to register most hazardous substances (e.g. CMR) above 1 ton per year, substances very toxic to the aquatic environment above 100 tons per year, or general substances manufactured or imported above 1.000 tons per year.⁹³

⁹⁰ Cf. Sony DADC Austria AG (2010)

⁹¹ Cf. European Parliament (2006), access date 21.09.2006

⁹² Cf. European Commission (2010a), access date 21.09.2006

⁹³ Cf. European Commission (2010b), access date 21.09.2006

Summary of Requirements and Motivation

As explained, the requirements aim for reduction of material consumptions and improvement of process efficiency. Reports to materials which are processed and consumed in the production and reporting of waste are also a key issue.

The motivation of the Sony DADC in view of these requirements is to introduce a system, which makes it possible to increase the transparency of material flows and to report material consumptions and amounts of waste periodically, at least monthly. In this way potentials for improvements and weak spots in the actual production cycle should be revealed.

4.2 Approach

The problem definition with the Sony DADC requirements served as starting point for the MFA. The main parts of the MFA are the system definition and the determination of flows and stocks.

4.2.1 System Definition

At Sony DADC Anif mainly CDs, DVDs, Blu-ray Discs, CD-Rs, DVD-Rs and UMDs are produced. For analysing the material flows at first a system definition has to be made. As described in Chapter 3.6.2, the system definition includes the determination of system boundaries, the determination/selection of processes and the determination/selection of goods and substances.

The final system definition was:

- System Boundary: Sony DADC Anif
- Processes: complete manufacturing processes of CD, DVD and BD production
- Goods and substances: all used raw materials and packaging materials of CD-, DVD- and BD- production

Explanation to the determined production processes in the system boundary Sony DADC Anif

The first step in disc production is the template manufacturing for the injection moulding process. Therefore six main processes had to be analysed in the so called mastering department, which are glass mastering, master plating, mother plating, stamper plating, dry-finishing and finally, the recycling process of the glass master. In this department,

the digital content provided by the customer of Sony DADC is transferred into a physical structure for the first time.

The next step is the injection moulding of the discs, which is made in the replication department. Here the discs are injection moulded and afterwards coated with metal layers and lacquers for the signal read out on the one hand and to protect the structures on the other hand.

After replication the discs are printed in the printing department. The two different printing technologies are screen print and offset print. The printed discs are stored temporarily until they are requested by the assembly department.

In assembly the discs are packed. For standard packaging there are automated processes for assembly by machines. Special packaging needs to be assembled with the discs either by special machines or manually.

The last step in this production process is the shipping of the discs in the shipping department to Sony DADC Distribution centres or direct to retail.

To analyse the material flows in the system boundary Sony DADC Anif, also the receiving departments, where raw and packaging materials are coming in the firm, receiving 1 and receiving 2 had to be considered.

The material flow connections of the described departments are displayed in Figure 18.

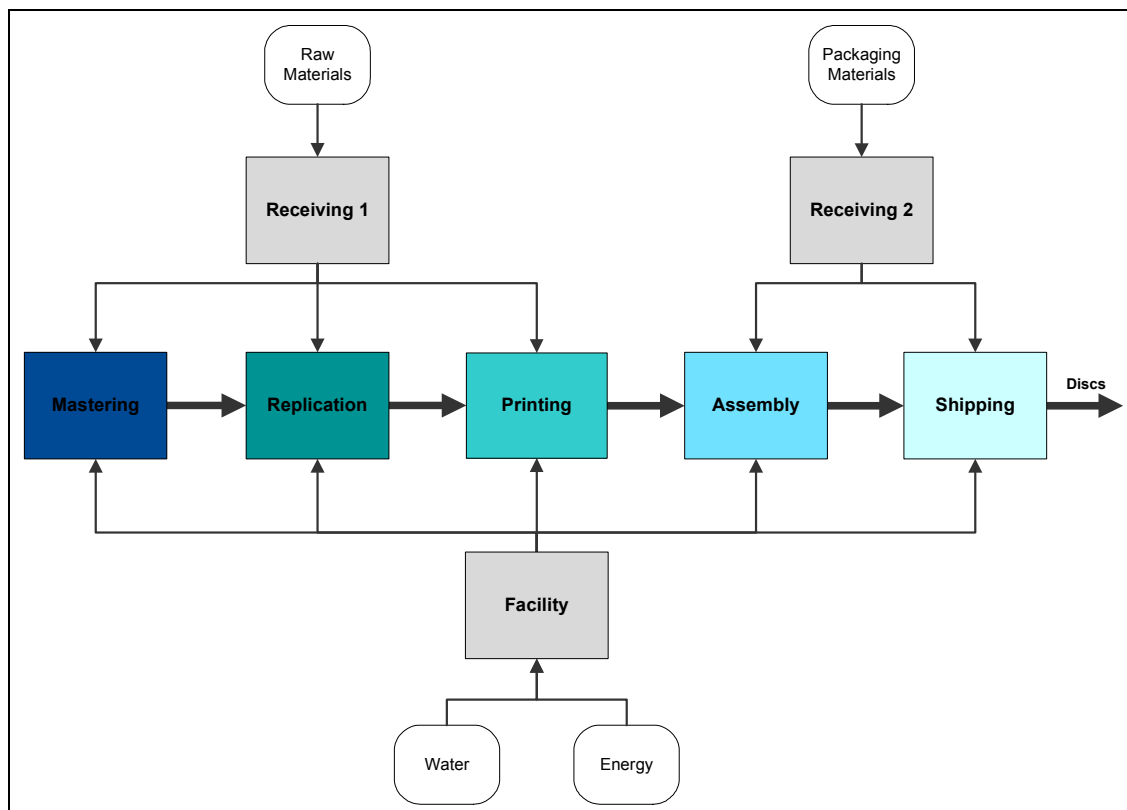


Figure 18: Production Departments of Sony DADC Anif

In the layout in Figure 19 the production departments at Sony DADC Anif are displayed. This layout depicts the ground floor of the production. The area 'standard assembly' of the assembly department is located on the first floor above special assembly of the ground floor.

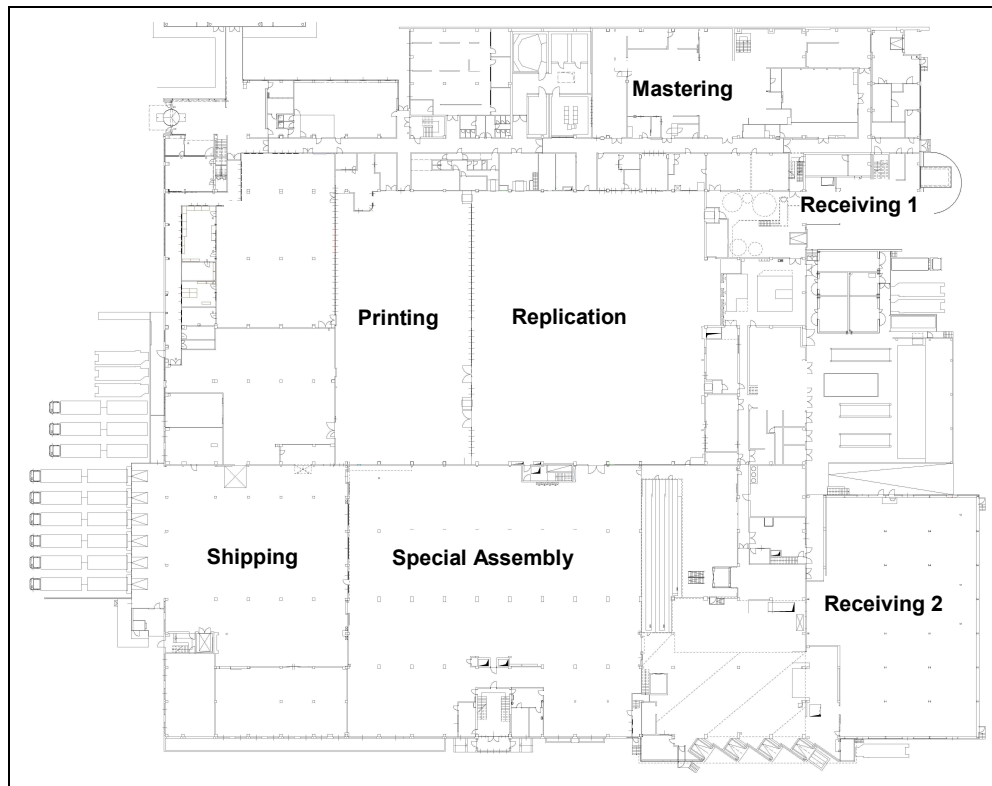


Figure 19: Production Departments of Sony DADC Anif

4.2.2 Determination of Flows and Stocks

After defining the system, the flows and stocks had to be determined by analysing the departments.

Before the analysis of the production departments started, a timetable was arranged. For the whole material flow analysis 15 weeks were scheduled. Each two weeks for mastering, replication, printing, assembly, receiving and shipping. The remaining three weeks were scheduled for facility and purchasing, and for finishing the input/output balances. Facility and purchasing were added for reasons of clarifying open detail questions and to round the whole material flow analysis.

Overall more than 30 meetings were necessary to analyse the material flows. For measure and analyse the DI water (deionised water) consumption in mastering also a trainee collaborates in the project. The results of the MFA will be presented by reference to the CD replication process in Chapter 4.4 and by reference to the production processes of manufacturing a CD in Chapter 4.5.

4.2.3 Eleven Steps for Analysing a Department

For analyse the material flow of a department several steps were necessary. The eleven main points were:

1. Coordinate Analysis with Colleagues
2. Meeting with a Person Responsible for the Respective Department
3. Investigation of Sony DADC Databases
4. Drawing of Process Flow Drafts
5. Meetings with Persons Responsible for Different Processes
6. Review and Edit Process Flows
7. Compile Input/Output Balance
8. Data Collection
9. Fill Input/Output Balance with Data and Information
10. Calculation of Coefficients and Keys
11. Complete Input/Output Balance

1. Coordinate Analysis with Colleagues

At first the analysis of the department was coordinated with the colleagues of the environmental department. Persons responsible for all departments were contacted, information and already collected data was exchanged.

2. Meeting with a Person Responsible for the Respective Department

The next step was to introduce the project and discuss the MFA with a person responsible for the respective department. The questions how should the analysis proceed within the department, which persons are available and can be contacted for meetings, were coordinated. Further meetings with department employees have been arranged to ensure availability of data.

3. Investigation of Sony DADC Databases

Next the IT database network was investigated. In this way more information and data could be gathered. They can be found at the report databases, at a Sony DADC internal document management system called e-doc or at internal published reports and further documents which are accessible in the internal network.

5. Meetings with Persons Responsible for Different Processes

After the person in charge of a certain process was informed about this project from their superior, meetings had to be arranged. The process flow drafts were necessary to get an overview of the processes within a department and to gain understanding of the most important materials, handling and process steps prior to start gathering the data.

To be prepared for the meetings, a checklist with all important questions regarding MFA was made. This list was used as orientation for the meetings.

Questions of the checklist:

- What is the main output of the process and for which end product is it used? (CD, DVD, BD)
- Which working steps shape the process?
- Which materials are in which working step processed?
- In which quantities are these materials consumed?
- How and in which periods can these quantities be calculated?
- Are the input materials manufactured in the main output or do they leave the process as waste?
- To which quantities is the main output produced?
- What are the side-outputs of the process when a main output is produced?
- What are the quantities of side-outputs?
- How have the side-outputs to be treated? (disposal, recycling, etc.)
- How the material consumptions are reported (existing documents)?
- Where in the databases is data to main input and output available?
- How input and output quantities can be calculated?
- From where materials for the process are obtained?
- What is the next process for the main outputs?

In the meetings the processes were reviewed and the process flows were explained in detail. Then open questions of the checklist were discussed. In this way it was possible to gain more detailed information to the process flows and to the used materials in the production. Information to data availability could be gathered as well.

6. Review and Edit Process Flows

With the gained information the drawn process flows in Microsoft Visio could be reviewed and edited. To be able to display the processes in more detail, the main processes were subdivided in working steps. The working steps are displayed beneath their main process and next to them the materials which are processed in the respective working step were listed. Under the last working step of a main process the main output of the process, which is at once the main input of the following process, was named.

Finally, a process flow contains the main processes which are displayed along the dark blue arrows (see Figure 23), all detailed working steps within a main process and all used materials. The process flows for CD/DVD mastering, CD replication, offset printing and standard assembly are displayed as examples on the next three pages.

Example Process Flow of CD/DVD Mastering

Disc manufacturing starts with a process which is called at Sony DADC 'Mastering'. Here the templates for the injection moulding process are manufactured by applying electrochemical processes after a laser writing of the structures into a thin layer of a photo resist on top of a glass plate.

Many processes and many different materials are necessary to produce a 'replication ready' stamper, which is the metal template for the subsequently injection moulding process. Figure 23 therefore displays the complex process flows of CD/DVD mastering. In this Figure you can see how the CD/DVD mastering process is clearly displayed in one process flow. The only difference to the rough process flow is that there is a further main process called 'Glass Mastering Process 2', which is a newer development of the standard glass mastering process. Here all left out processes from the dark blue main flow are included in one machine. The glass mastering process 2 is placed between the grey arrows, which are symbolising the alternative flow.

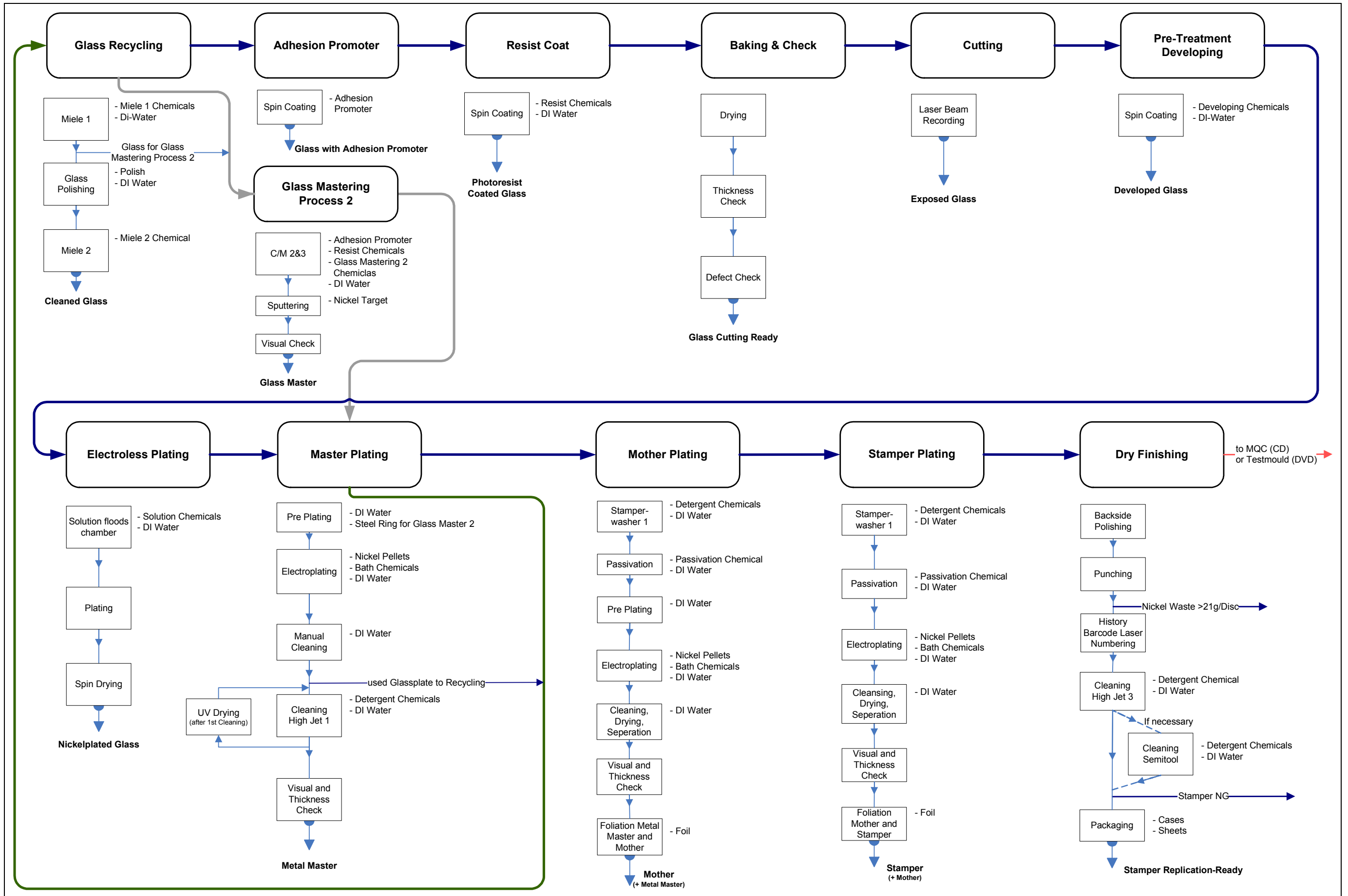


Figure 23: Process Flow CD/DVD Mastering

Example Process Flow of CD Replication

The main processes for manufacturing a 'printing ready' CD are displayed in detail in the process flow in Figure 24. After injection moulding a reflective layer is deposited on top of the polycarbonate substrate to enable the laser in a CD player to read the signal out. This deposition process is carried out by a vacuum coating process which is called sputtering. The CD is usually sputtered with Aluminium, but also sputtering of other materials like gold is made frequently to enhance the life time of a CD.

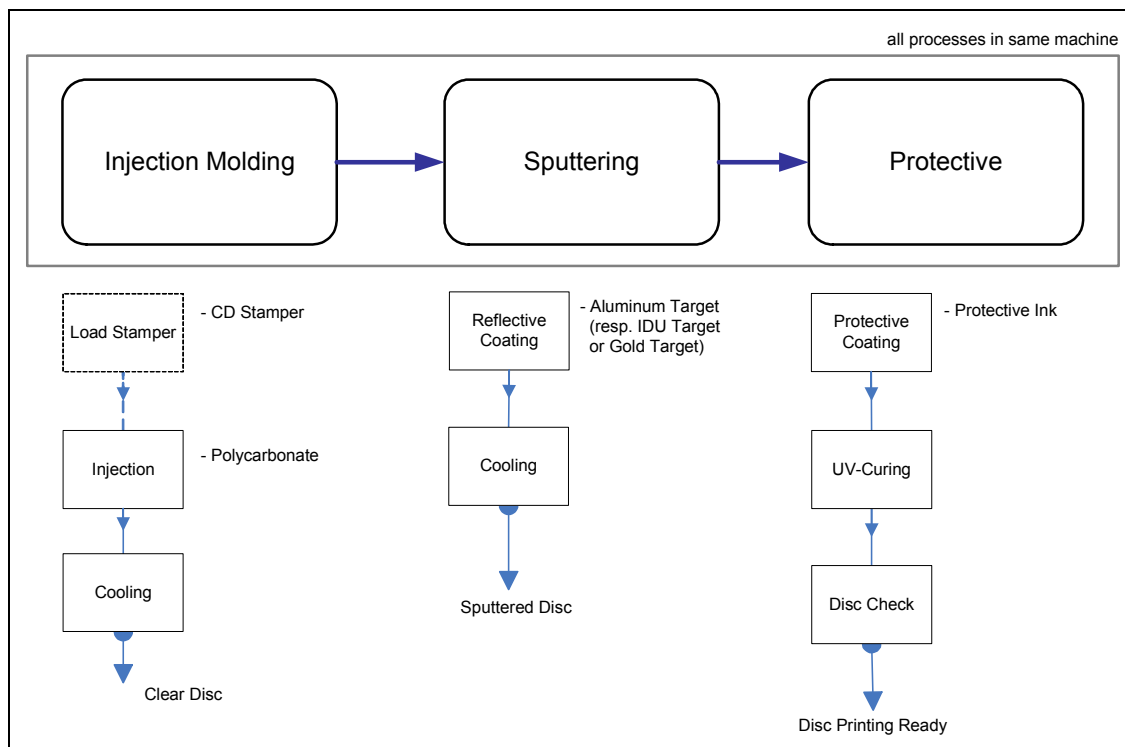


Figure 24: Process Flow CD Replication

Example Process Flow of Offset Printing

Figure 25 shows the process flow for offset printing. After the disc is primed in a screen print process with a non-transparent white colour, four colours can be printed with the offset technique. Alternatively, also a sixth colour can be printed again with the screen print method.

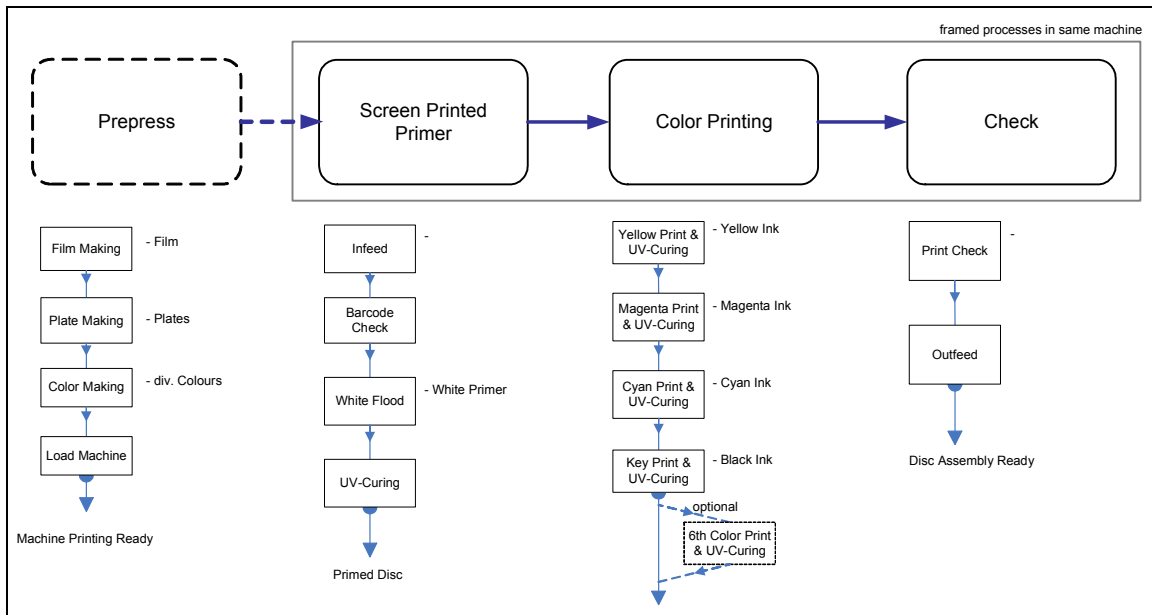


Figure 25: Process Flow Offset Printing

Example Process Flow of Standard Assembly

In Figure 26 you can see the different steps and materials for making the discs 'shipping ready'. The standard assembly process is not that complex than special assembly. Because some packages have to be handled in hand packaging as well, the hand packaging process was also included as alternative process in standard assembly.

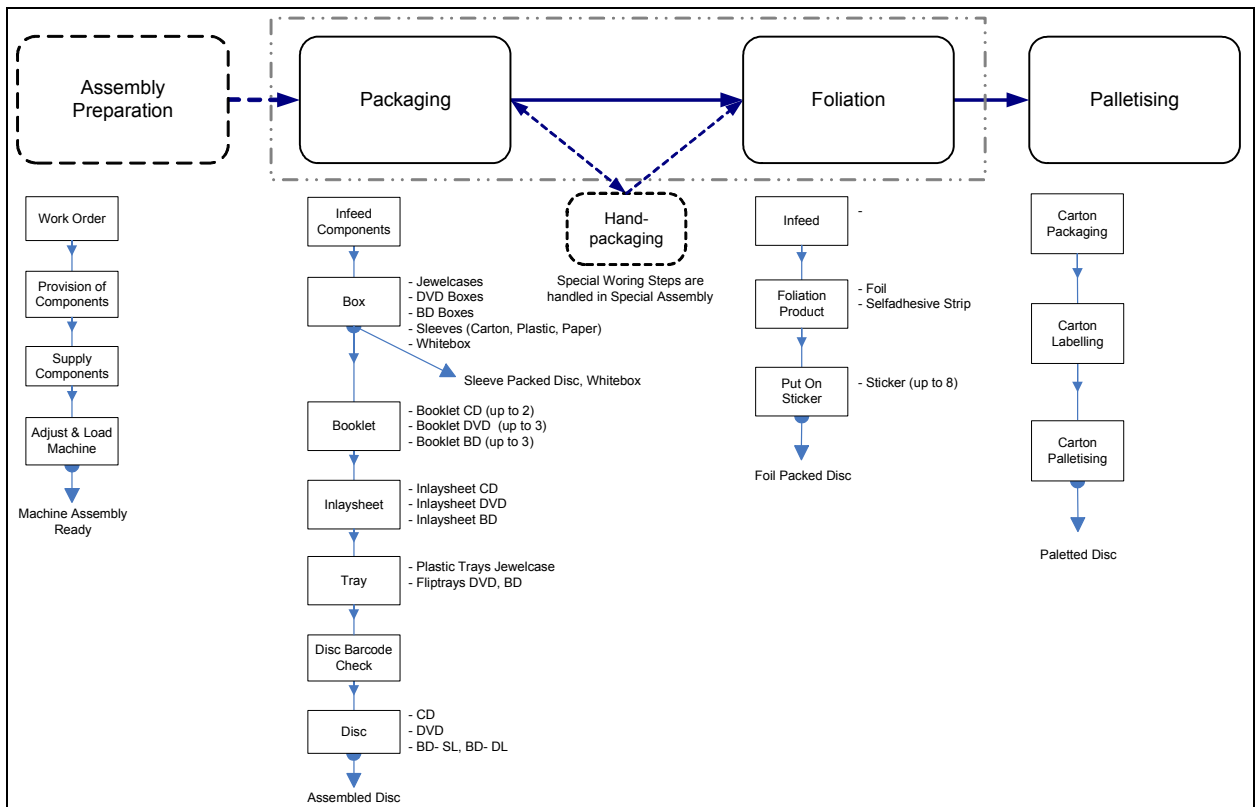


Figure 26: Process Flow Standard Assembly

All this different process flows were the basis for the draft of the Input/Output Balance.

7. Compile Input/Output Balance

For displaying the quantities of material flows clearly, an input/output balance (I/O balance) was worked out. To have all necessary information in the balance, following arrangement of the columns was defined.

In the first column of the balance are the main processes listed, which were taken over from the before drawn process flows. All the rest columns are divided to the input or output side.

Input-Columns

The input side of the I/O balance is consisting of following columns:

- **Main-Input:** the main input of a process (e.g. mother for the process stamper plating)
- **Qty FY09 [k units]:** quantity of the main input for fiscal year 2009 in thousand units
- **Data Source:** describes from which source the quantity value comes from
- **Qty FY09 [t]:** quantity of the main input for fiscal year 2009 in tons
- **Working Step:** lists the different working steps within a process
- **Inputs:** lists the materials which are used for the different working steps
- **Qty per Main Input:** shows which qty. of the material is needed for one main input
- **Unit:** the unit of the quantity per main input
- **Qty FY09:** shows which quantity of the material was needed for the whole FY09
- **Unit:** unit of total quantity of the material for FY09
- **Data Source:** describes from which source the value for Qty FY09 comes from

Output-Columns

The output side of the I/O balance is consisting of following columns:

- **Main-Output:** main output of a process (e.g. stamper for the process stamper plating)
- **Qty FY09 [k units]:** quantity of the main output for fiscal year 09 in thousand units
- **Data Source:** describes from which source the quantity value comes from
- **Qty FY09 [t]:** quantity of the main input for fiscal year 2009 in tons
- **Outputs:** lists the materials which leaves the process as waste

- **Qty per Main Output [g]:** shows which quantity of waste results for one main output
- **Qty FY09 [t]:** shows the quantity of waste for the process for FY09 in tons
- **Data Source:** describes from which source the value for Qty FY09 comes from
- **Classification as Raw Material:** describes how the waste is classified in regard to hazardous ingredients
- **Treatment:** shows how the waste has to be treated

For making a balancing of the materials coherent and comparable, it is necessary to translate the quantities also in weight.

Because it's also environmentally relevant what happens with the waste of a process, the columns 'classification as raw material' and 'treatment' were added to the output side of the balance.

To have an overview of the origin of the different material data, the columns 'data source' for 'main inputs', 'inputs', 'main outputs' and 'outputs' were added as well. In the columns 'data source' a colour was given for the different data sources like for controlling: yellow, for mastering: grey and for replication: green and so forth. In addition to that, the sources were explained with integrated comments. An example for a complete filled in I/O balance can be seen in Chapter 4.4.

8. Data Collection

The next step was to collect the data for the I/O balance. Data was collected for the fiscal year 2009, which is defined as the period between 2009-04-01 until 2010-03-31. In some cases if data was not available for this year, data for one representative month, in that case march 2010, was gathered as well.

Data was available in internal published reports, directly read from machines, reported with special queries of databases, taken over from inventory lists or based on experience.

Some of the collected data could be directly taken over to the I/O balances, some data had to be broken down by calculation to more different processes and in some cases the allocation of data to the different processes was assumed.

9. Fill Input/Output Balance with Data and Information

After the data collection the I/O balance could be filled with data which was directly allocable. For example main input quantities and main output quantities could be taken over from several reports, or quantities to chemicals which were just used in one process could be taken over from inventory lists. The remaining positions had to be calculated with coefficients and keys.

10. Calculation of Coefficients and Ratios

If materials were not directly allocable, because they are used for more than one process, the overall consumption of these materials had to be divided to the different processes. Therefore coefficients or keys had to be collected or calculated.

For example coefficients were available for polycarbonate or Aluminium targets. One polycarbonate shot for manufacturing one CD contains of a certain weight of polycarbonate, and to coat the CD with the reflective a certain amount of Aluminium is needed. By multiplying these numbers with the total produced CD quantities, the total material consumption of polycarbonate or Aluminium for CD production could be calculated.

Ratios or key factors could be calculated by referencing to the amount of produced discs or total weights of the in- or outputs. For example to allocate Nickel-Sulfamate to the different plating processes, a ratio was calculated in reference to the weight of Nickel pellets which were used for the same process.

Assuming that the total amount of Nickel pellets is 10.000 kg and the amount of Nickel-Sulfamate is 5000 kg the key was 0,5. So if a plating process needs (which is the electrochemical procedure to produce metal stampers) 200 kg Nickel, you can calculate the quantity of Nickel-Sulfamate for the process by multiplying the quantity of Nickel with the key factor 0,5.

To allocate e.g. the total amount of used detergent in a process, a ratio was calculated on basis of the different main output quantities where this detergent is used. For example if 8 kg detergent is used for a washing process for three mothers and afterwards for five stampers. The key for mother washing would be $3/(3+5)$ and the key for stamper washing would be $5/(3+5)$. Multiplying the key with the total consumption of detergent for washing, the result will be that 3 kg detergent is used for mother washing and 5 kg for stamper washing.

In this way nearly all quantities of material consumptions could be calculated.

11. Complete Input/Output Balance

After the data collection and calculation of the coefficients and keys, the I/O balance could be completed.

To add additional information to data or calculation details, comments were included in the balances.

Working Step	Inputs	Qty per Main Input	Unit	Qty FY09	Unit	Data Source	Main Output	Qty FY09 [k units]	Data Source	Qty FY09 [t]
Load Stamper	Stamper	~ 1 / 5500	units	17194	units	Controlling	Clear Disc 14,8g	99669,8	Manufact.& Engineering	1475,1
Injection	Polycarbonate	15,10	g	1527,3	t	Printing				
Cooling							Shot NG	1474,2	Manufact.& Engineering	21,8
Reflective Coat Sputtering	Aluminum Target	0,00117	g	116,315	kg	Replication	Sputtered Disk	99148,9	Manufact.& Engineering	1467,5
	alternative: IDU Target	~ 1/159,000	units	626,9	units	Replication				
	Gold Target					Controlling				
Protective Coating	Protective Ink 1	0,107	g	9205,04	kg	Manufact.& Engineering				
	Protective Ink 2			1389,44	kg	Manufact.& Engineering				
UV-Coating						Manufact.& Engineering				
Disc						Manufact.& Engineering	Disc Lotout	1058,1	Manufact.& Engineering	15,8
Injection						Manufact.& Engineering	Colour Disc	quantities see Injection Mold		

Table 4: Section of I/O Balance

Legend Sources	
Controlling	Yellow
Printing	Orange
Manufact.& Engineering	Blue
Replication	Green
Purchasing	Dark Green

Figure 27: Legend for I/O Balance

The data source column shows with colours, like displayed in Figure 27, where the data comes from. As you can see sometimes data was available in more than one source. The second source was used for reviewing the gathered numbers.

Other additional information was always written down next to the balance, for example how DI water factors are calculated, details to raw materials, input or output quantities or other necessary information.

I/O balances were made for the whole production processes for CD, DVD and BD manufacturing. In summary 13 balances were necessary to integrate the material flows. The most complex balances were made for mastering and assembly.

4.3 Résumé and Cross Checking of the Results

Based on the described approach the material flow analysis of the departments was made along the production cycle. An excerpt of the results is presented in Chapter 4.4 and 4.5, but first Chapter 4.3 résumés the MFA and explains how the plausibility of the results can be checked.

4.3.1 Résumé to the Material Flow Analysis

Material Flow Analysis Mastering

At first the material flows of the 'Mastering' department were analysed. Mastering was the most difficult department, because of its complexity and the amount of different materials in usage. Data was available in the so called (internal) report database, internal reports and via SQL queries.

Material Flow Analysis Replication

For analyzing the 'Replication' department four meetings were needed to gather all necessary data for CD, DVD and BD replication. Data for main input and main output were available on the report database, data of raw materials consumption were available in the report from Sony DADC's controlling department. Other data sources have been like earlier described purchasing reports. Material quantities per disc could be directly gathered from a production machine database.

Material Flow Analysis Printing

The main input and main output quantities for the 'Printing' department were taken from a report database, the material consumptions quantities were taken from a controlling report. To allocate the discs to screen print or offset print, a key was calculated on basis of the key performance indicators of production from the certain reports provided by the engineering department.

Material Flow Analysis Assembly

Sony DADC offers more than 2600 different packaging variants, for that reason the 'Assembly' department was also complex to analyse. To take all this packaging variants into account in the analysis, keys and assumptions were set in coordination with the process responsible. Data of packaging materials are available in Avalon and can be queried with Business Objects©.

Material Flow Analysis Receiving

The receiving department was handled in three meetings. The quantities for receiving were gathered via Business Objects reports.

Material Flow Analysis Shipping

Only two meetings have been necessary for the analysis of shipping. Data could be gained via Business Objects queries of the Avalon database. The total pallet quantity was broken down to CD, DVD and BD with the numbers for assembled discs.

Material Flow Analysis Facility and Purchasing

To gather data for DI water consumption and waste water meetings with facility were held. A further meeting was made with the purchasing department to get an overview of how materials are purchased and ordered.

4.3.2 Cross Checking of the Results

To review the plausibility of the outcomes of the different I/O balances, the results had to be cross checked with different sources and numbers.

I/O Balance Mastering

Nickel pellets quantities were reviewed by adding the Nickel quantities of the different plating processes. The sum was compared with the total consumption number of the mastering chemicals inventory list. Due the fact that only CD, DVD and BD plating processes were considered, the numbers proved to be right.

The measured DI water quantities of the different processes were added and compared with the total quantities gathered of facility. The same was made with the waste water quantities.

Generally if a material was consumed in more than one process, a sum of this material consumption was calculated. This sum had to be the same than the total quantities of the material consumption on the inventory list.

I/O Balance Replication and Printing

The cross check for polycarbonate was made by adding polycarbonate needed for CD, DVD, BD SL and BD DL and comparing the sum with the total consumption number of the controlling report.

Reviewing the polycarbonate waste was possible by calculating the sum of clear polycarbonate waste and coated polycarbonate waste of the different disc replication and printing processes. The sums were compared with special disc report, where all polycarbonate waste is reported.

Target consumption cross checks were made by comparing the calculated numbers with the total numbers of the controlling report. The same procedure was made with the different resins.

The numbers proved to be right after cross checking the different positions.

I/O Balance Shipping

Cross checking the numbers of the I/O balance for the shipping department was done by comparing the shipping inputs with the printing outputs, which should be in a similar range. To increase packaging efficiency discs after printing are sometimes transported to the second Sony DADC Austria manufacturing plant to Thalgau, which is situated 35 km north of Anif. Transportations in the opposite way from Thalgau to Anif are carried out as well. Another possibility is that the discs are shipped to an external warehouse in the area of Salzburg. However, by including all different work flows a plausibility check was possible and the results could be confirmed.

I/O Balance Assembly

As described many keys were necessary to calculate the numbers of assembly. As connection balance between printing and shipping, cross checks could be made with the balances of these departments. Plausibility checks of the consumption of packaging materials could be made with different purchasing reports and Business Objects reports of production numbers.

Uncertainties and Résumé of the Results

The less keys and coefficients were necessary, the more robust are the results of the balances. The fewest uncertainties are in the replication, printing and shipping balance. More uncertainties are in the mastering balance and in the assembly balance, because the allocation of materials to single processes had often to be carried out with several calculated or assumed coefficients and ratios.

To reduce the uncertainties of mastering and assembly I/O balances, more detailed investigations are necessary. However, due to the fact, that in the I/O balances which have been completed during this work, the most relevant material flows are reflected, the remaining uncertainties can be considered as minor.

4.4 Results of Material Flow Analysis for CD Replication

To give an insight into the results of the MFA, the input/output balance of the CD replication as well as an appropriate Sankey Diagram is presented in this Chapter. In Table 5 the input side of the I/O balance is shown. Table 6 displays the output side of the I/O balance. The balance is based on the process flow in Figure 24 on page 54. Therefore the balance is divided in the three processes 'Injection Molding', 'Sputtering' and 'Protective' and the respective working steps.

Process	Main-Input	Qty FY09 [k units]	Qty 03/10 [k units]	Data Source	Qty FY09 [t]	Working Step	Inputs	Qty per Main-Input	Unit	Qty FY09	Unit	Data Source
Injection Molding	Polycarbonate Shot	101144,0	7486,0		1527,3	Load Stamper	Stamper	~ 1 / 5500	units	17194	units	
						Injection	Polycarbonate ind. closed loop recycled PC	15,10	g	1527,3	t	
						Cooling						
Sputtering	Clear Disc	99669,8	7376,8		1475,1	Reflective Coat Sputtering	Aluminium Target alternative: IDU Target Gold Target	0,010 ~ 1/159.000	g units	992,0 626,9	kg units	
						Protective	Sputtered Disc	99148,9	7338,3		1467,404	Protective Coating
						UV-Curing Disc Check						

Table 5: I/O Balance CD Replication Inputs

Process	Main-Output	Qty FY09 [k units]	Data Source	Qty FY09 [t]	Outputs	Qty per Main-Output [g]	Qty FY09 [t]	Data Source	Classification as Rawmaterial	Treatment
Injection Molding	Clear Disc 14,8g	99669,8		1475,1	PC Waste clear PC Waste clear*	0,22 0,30	21,8 30,2			Recycling Closed Loop Rec
	Shot NG	1474,2		21,8	Stamper	~ 1 / 5500	0,509 0,127		Xn, R40, R43	Nickel Recycling Storage Stamper
	Sputtering	Sputtered Disc	99148,9		1467,5	Aluminium (target residue)	0,0088	0,875		
	Disc NG Discs Lotout	470,2 50,7		7,0 0,8	PC Waste incl. Aluminium	0,078	7,7 0,00061			Disposal
Protective	Disc Printing Ready	97355,3		1451,4	PC Waste incl. Aluminium and Protect. Ink	0,27	26,7 0,002 0,192			Disposal
	Disc NG Disc Lotout	735,5 1058,1		11,0 15,8	Protective Ink	0,002	0,195		Xi, R36-38, R43, R51/53;	Special Disposal

Table 6: I/O Balance CD Replication Outputs

The I/O material flow balance is visualized with the aid of Sankey Diagrams in Figure 28. Polycarbonate and the Nickel stamper are the inputs for the injection molding process. Nearly one hundred million clear discs were molded in FY 2009. Therefore more than 17.000 stamper were needed. As shown in Table 6 in the 'Treatment' column, the hazardous Nickel stamper were recycled or stored afterwards.

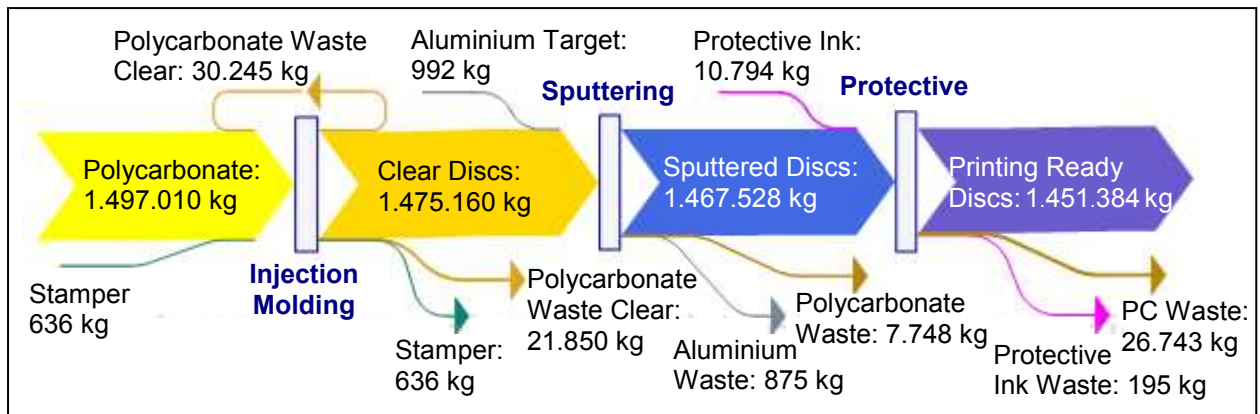


Figure 28: Sankey Diagram Detailed View Material Flows of CD Replication

For visualize the material flows more clearly, a simplified Sankey Diagramm shows input and output flows of CD replication in Figure 29.

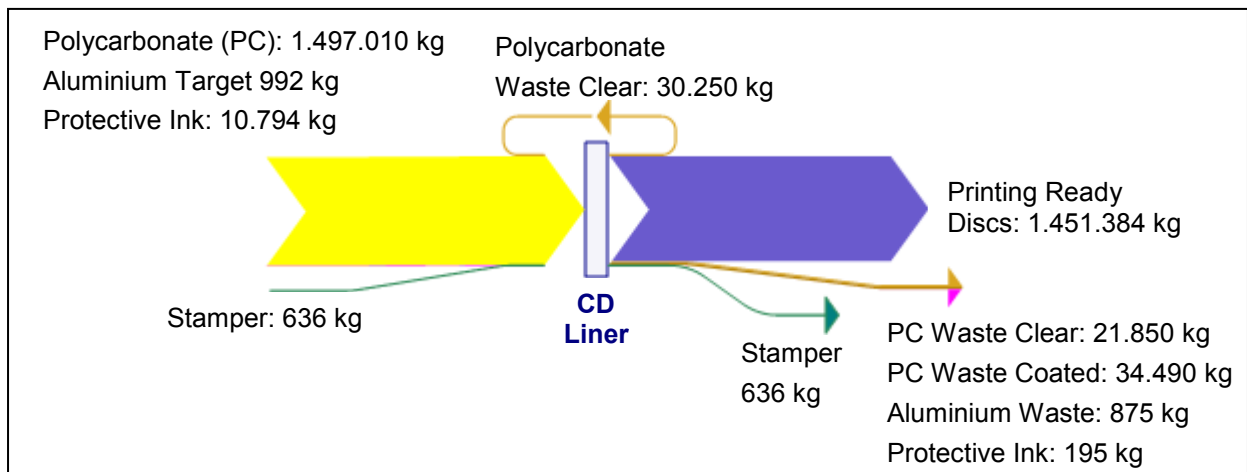


Figure 29: Sankey Diagram Overview Material Flows of CD Replication

Next special characteristics of these results are pointed out. In the sputtering process mainly Aluminium targets were used. As can be seen by comparing the input and output side of 'Sputtering' 117 kg of Aluminium is included in the CDs, but 875 kg of Aluminium is waste and has to be recycled. This corresponds to 12% utilization of the Aluminium target. The Aluminium flow of CD replication is visualized in Figure 30.

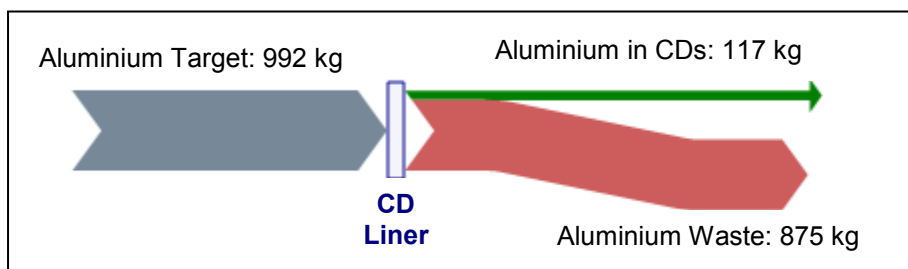


Figure 30: Sankey Diagram Aluminium Flows of CD Replication

More than the half of the clear polycarbonate waste was directly recycled by feeding back the waste as input raw material in the CD liner. The other part of clear polycarbonate waste was recycled. Nearly 35 t coated polycarbonate waste resulted

from the CD sputtering and protective processes. The polycarbonate flows of CD replication are displayed in Figure 31.

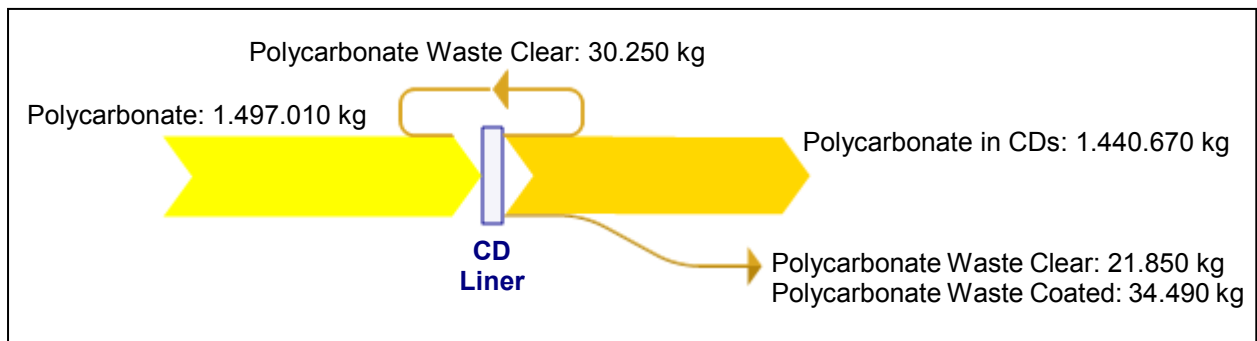


Figure 31: Sankey Diagram Polycarbonate Flows of CD Replication

After the protective process the CDs are ready for printing. The hazardous protective ink waste has to be special disposed. As can be seen in the I/O balance in Table 5 and 6, protective ink was efficient processed in FY09. That's why it is not separate displayed as Sankey Diagram.

The CD replication process is a core competence of Sony DADC, which is obviously already highly optimized. Nevertheless, the analysis points out, for a perfect optimized CD replication process two possibilities can be taken into consideration for efficiency improvements. Those are:

- Reduction of Polycarbonate Waste
- Higher Utilization of Aluminium Targets

A reduction of polycarbonate waste can be achieved by increasing the yield. Therefore an improvement of the injection molding process efficiency will decrease the clear polycarbonate waste and by improving the yield of the protective process coated polycarbonate waste can be reduced. Possibilities for a higher utilization of Aluminium targets have to be proved, but it is generally achievable with the aid of new sputtering technologies.

Material Flow Analysis of other Departments

Such improvement potentials also can be revealed with the aid of the other elaborated I/O balances. The CD and DVD production is already very mature, potentials rather are found in newer production processes like for BD manufacturing. As the focus of this thesis is mainly on the MFA concept development, the available potentials are to be primarily analysed in the respective production departments. Therefore the balances will be examined from specialist of the respective departments. To present further excerpts of the MFA results, the printing department and the DI water consumption of the mastering department are detailed discussed with Sankey Diagrams in the appendix from page 114-115.

4.5 Results of Material Flow Analysis for Manufacturing of a CD

With the collected I/O balances of the departments, you have several possibilities to review the material flows of CD, DVD and BD production. As explained in Chapter 4.4, at first of course the flows of a certain process, e.g. 'CD Sputtering', can be analysed. On the other hand it is interesting to review the entire main processes, e.g. 'CD Replication'. Comparisons of the main processes within a department can be made as well as comparisons of different departments with each other. By adding all material flows of the I/O balances for one product, e.g. for CD, all I/O material quantities along the whole production process can be calculated. Afterwards the results can be reviewed and evaluated in detail.

As an exemplary result of MFA of a product, the results of material flows for manufacturing of a CD are presented and evaluated in this Chapter.

Summary Result CD Manufacturing

By adding all materials of the I/O balances which are used for CD production, a calculation of the average material consumption for manufacture a CD can be done. The results are displayed in the I/O balance in Table 9 and charts in Figure 33-36, broken down on one CD which was shipped from the site Sony DADC Anif in FY09, defined as 'Shipped CD'. Figure 32 displays the containing materials of a 'Shipped CD'.

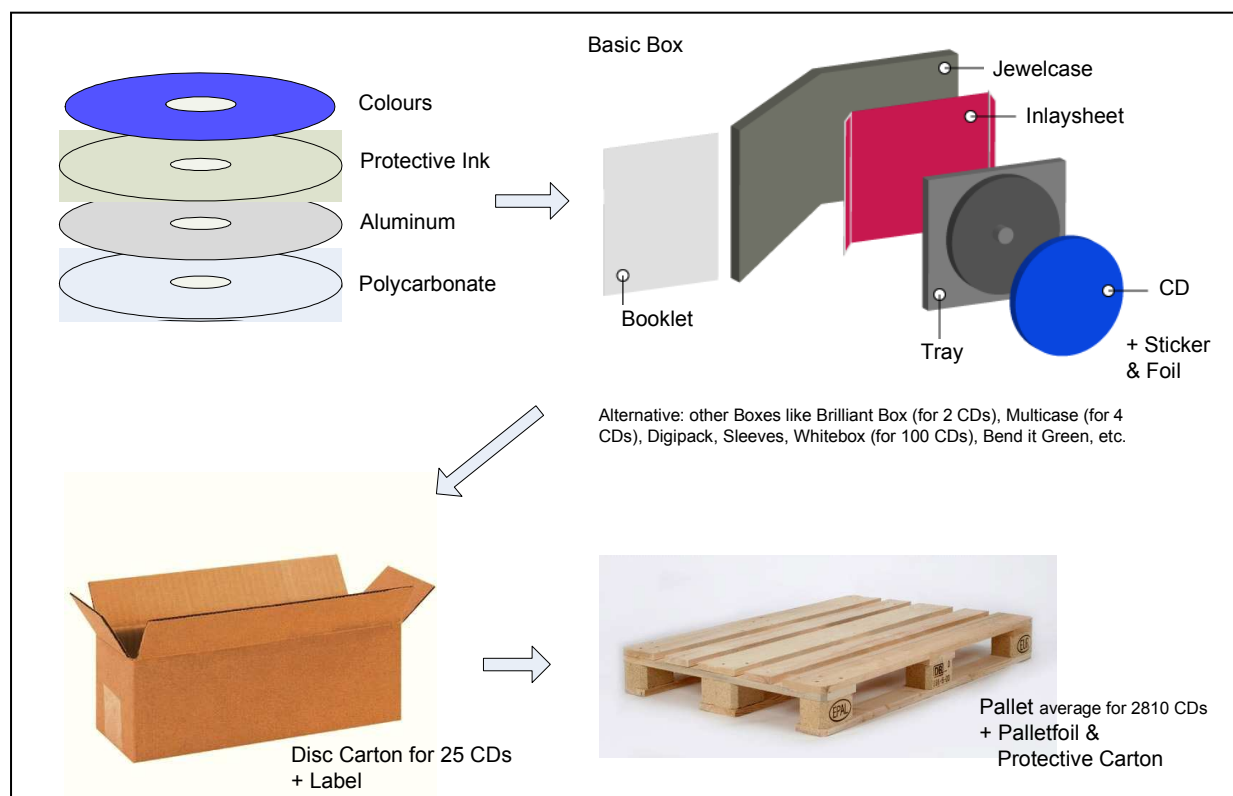


Figure 32: Definition of a Shipped CD

(picture top right: onedisc.com, picture bottom left: embalajeyemalaje.com, picture bottom right: Sony DADC)

The I/O balance in Table 7 is an overview for CD manufacturing. Some positions in the balance like mastering chemicals or boxes are summarized displayed, otherwise the balance would be just too long and confusing. The reason why colours screen print and colours offset print are written down, is because about 80% of CDs are printed with screen and 20% with offset print.

Comparison of Inputs and Outputs

To get a clear overview of the result, three main input and four main output categories were summarized. The input categories are raw material, packaging material and water. The output categories are the shipped CD, waste water and overall waste. Figure 33 visualizes the results of these categories with the aid of a Sankey Diagram.

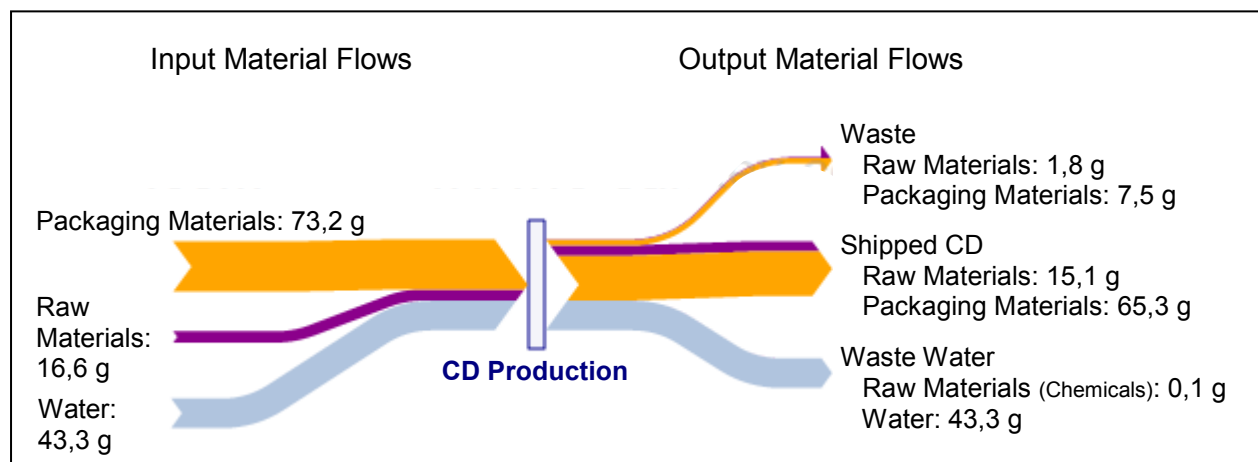


Figure 33: Sankey Diagram of Basic Material Flows Regarding a Shipped CD

For the comparison of inputs and outputs, also the average weight of a box (based on weight of Jewel Case, Brilliant Box, Multi Case, Sleeve, etc.), booklet, inlay sheet, tray and sticker have been taken into account. This leads to a total amount of 133,1 g of materials (including different raw materials, packaging materials and water), which were necessary in the manufacturing processes. All data are based on one shipped CD for FY 2009 in Sony DADC in Anif. By considering the output, beside the components of 80,4 g which were included in a shipped disc, 43,4 g of waste water (= water + chemicals) and 9,3 g of waste was produced.

To get an idea, which materials are included in the different positions, a split to each category is displayed with charts in Figure 34-36.

Average Mass Rates of a Shipped Disc with 80,4 g

As shown in Figure 34, the heaviest component of a shipped disc is the respective box (e.g. jewel case) with its tray, with nearly 56% of the total weight. Second heaviest component is the CD with its 14,8 g polycarbonate, protective ink, Aluminium and

colours. The pallet contributes 12% of the total weight. Artwork (includes booklet, inlay sheet, sticker and speciality), foils and cartons complete the weight of a shipped disc.

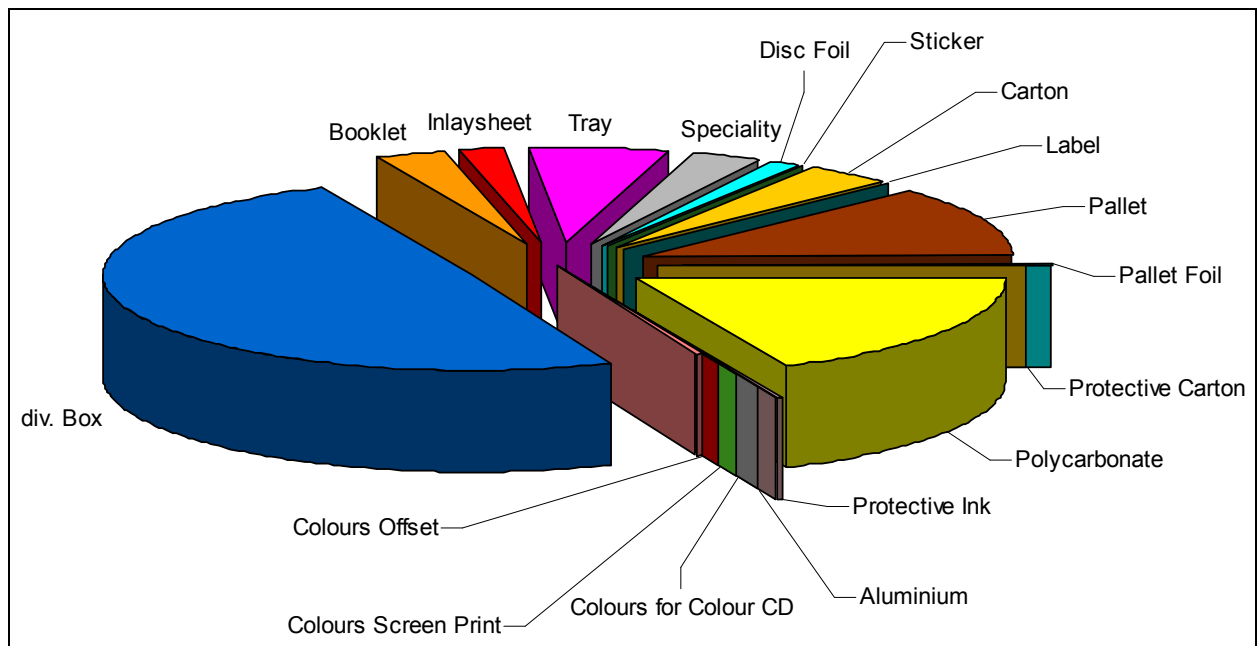


Figure 34: Mass Rates of a Shipped Disc

Mass Rates of 43,4 g Waste Water of a Shipped Disc

Acid and base waste water (A/B WW) contributed with 89% the largest amount of waste water at Sony DADC Anif in FY09. In mastering beside the 15% of A/B waste water, Nickel containing waste water was produced per shipped disc in the 'Mastering' department. Aluminium containing waste water was with less than 4% the smallest part of the waste water. The mass rates of waste water are displayed in Figure 35.

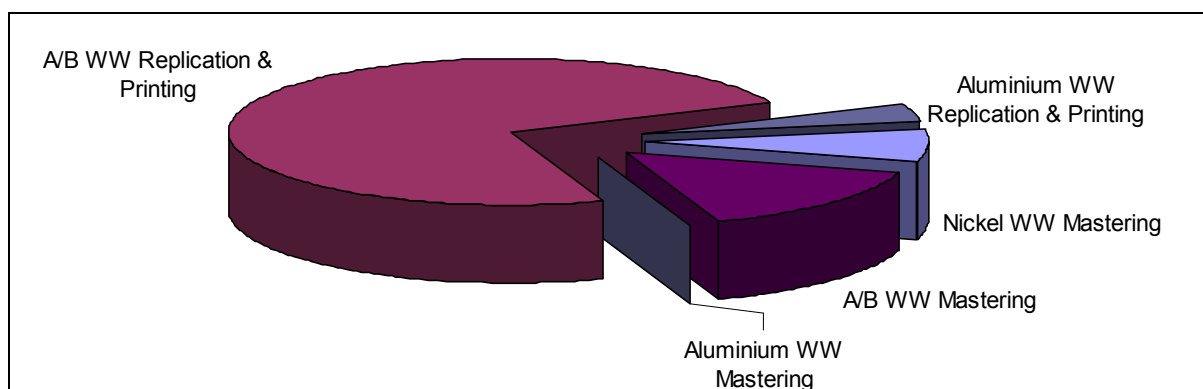


Figure 35: Mass Rates of Waste Water of a Shipped Disc

All different types of waste water are collected and piped in different streams to special waste water treatment systems. Nickel containing waste water undergoes first a precipitation, where by adding of agents and adjusting the pH-value, the solved Nickel precipitates. Afterwards the waste water is piped through an ion exchange system, where all residual Nickel is captured. Acid and base waste water is neutralized and the

Aluminium containing waste water undergoes a treatment as well. All waste water is always under strict control to ensure correct handling and the protection of the environment.

Average Mass Rates of 9,3 g Waste of a Shipped Disc

The average mass rates of waste which was produced in the manufacturing processes of a shipped CD are displayed in Figure 36. Around 47% of waste is declared as paper & carton. Artwork components are as well included as packaging components of the different received materials, rejected packaging materials and working sheets.

Nearly 20% of waste is polycarbonate, but it's differentiated between polycarbonate clear, polycarbonate closed loop and polycarbonate coated. The part of 3,4% polycarbonate closed loop waste can be feed back directly in the replication machines. This process is called closed loop recycling. The major part of clear polycarbonate (which means the polycarbonate is neither coated with reflective layer nor with a lacquer) is recycled at Sony DADC Thalgau and a small part is sold. Coated polycarbonate is shredded at Sony DADC Anif and sold afterwards to external recycling companies.

The polystyrene and polypropylene waste consists to a large part of the different trashed disc boxes.

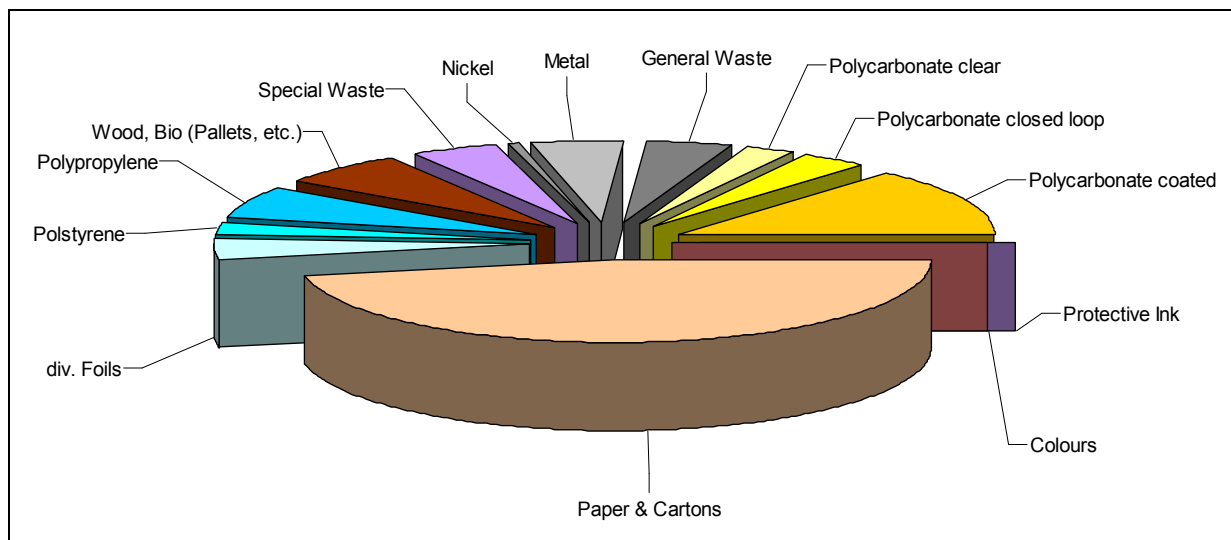


Figure 36: Mass Rates of Waste of a Shipped Disc

The wood waste results primarily of pallets which had to be rejected. Wood waste at Sony DADC Anif is currently recycled by a chipboard manufacturer. A new project at Sony DADC Austria provides that the wood waste is utilized for company's in-house heat production in the future.

The special waste includes hazardous wastes like solvents, acids, bases, lacquers or Nickel sludge. Nickel and Aluminium are the two basic metals which are needed for the

manufacturing of a CD. Considering other consumed metals and metal packaging waste, in summary more than 5% of waste is metal waste.

Foils and general waste with more than 4% each, round up the result.

4.6 Interpretation Possibilities of the Results

As shown in Chapter 4.4 - 4.5, by analysing the material flows a lot of information is given. For an interpretation of the results, detailed questions to the material flow can be answered.

With the aid of the elaborate I/O balances, as displayed in Chapter 4.4, following information is available:

- In the I/O balances is shown which materials are used in which quantities for the different manufacturing processes.
- The output side of the balance displays where waste is produced in which quantities along the manufacturing process.
- Which chemicals discharge into the waste water is shown in the 'Output'-column of the I/O balance.
- Also at which processes do these chemicals discharge into the sewerage is shown.
- The 'Specification as Raw Material' column states which hazardous materials are used and where they are processed.
- Where chemicals are used which have to be special disposed, how has the waste to be treated and which materials can be reused or recycled is defined with the 'Treatment'-column.

The answers which can be obtained with the I/O balances, provide detailed information regarding process efficiency:

- By comparing the inputs and output materials it can be seen how efficiently the different processes are and how efficiently the materials are processed.
- This facilitates to find out where is potential for material savings.

As shown in Chapter 4.5, by adding the material quantities of the I/O balances along the production processes, detailed information to the respective products is given and the following details become acquainted:

- quantities of materials which are included in an end product
- total quantities of materials which were needed for producing the end product
- amount of waste and waste water which incurred for producing the end product

By comparing I/O balances of different periods, the quantities of waste and yield can be reviewed. As the MFA was carried out only for one period, the next questions can be answered as recently as the material flow of further periods is analysed:

- How develops the production efficiency?
- Does the process efficiency increase compared to earlier periods?
- Where have the processes regarding efficiency decrease?

If also energy flows, cost accounting and environmental performance indicators are included in the MFA, these questions can be answered:

- Which processes need the most energy?
- Which are the most cost-intensive processes?
- Where are the most cost-intensive materials processed?
- Where is potential for cost savings?
- Which processes have share of the performance indicators?

If the material flows of other sites of Sony DADC are analysed as well, the different I/O balances of same production processes can be compared and the next questions can be answered:

- Which processes are more efficient than in other sites?
- Where is potential to improve the processes?
- Where are significant efficiency differences?

4.7 Requirements for a Material Flow Analysis System

Based on this carried out MFA requirements for automated MFA at Sony DADC Anif can be set.

Data are available in the Sony DADC Austria database system. There are many different databases (e.g. Avalon, BDE system, etc.) which provide information to material consumptions, production numbers or purchased material.

To ensure material flow analysis can be performed in a moderate time frame, queries of the Sony DADC database system has to be made. Data should be queried to all material consumptions where it's possible. This data has to be imported in the system and automatically allocated to the respective processes.

It should be possible to balance the data automatically and display the results graphically. The questions from Chapter 4.6 have to be answered. As MFA should be made once a month, the effort for the operator should be as low as possible.

Data queries for material consumptions can be made with Business Objects, SQL or even Excel. That means data are available to a large part at the database system of Sony DADC Anif.

If materials are used in more than one process, they have to be allocated via main input or main output numbers, or consumptions within one process step to the respective processes.

5 Concept for Realisation of Automated Material Flow Analysis at Sony DADC

For preparing material flow analysis at regular intervals in a reasonable expenditure of time, it's necessary to make the analysis automated wherever possible. Therefore the analysis has to be carried out software-supported. As shown in Chapter 3.8.3, the software Umberto is according to the detailed investigation described in this work, most qualified for material flow analysis in the given scope. The software was tested with support of ifu Hamburg over a period of two months and was proved to be suitable. The testing-phase contained a modelling phase with four conference calls with internet linking to personal monitors to clear questions. Furthermore ifu Hamburg performed support by email and by phone.

The main steps for implementing the MFA concept after integrating Umberto in the company network are displayed in Figure 37. The first step 'Modelling of Network' will be introduced in Chapter 5.2. Chapter 5.3 will introduce the 'Specification of Network' step. In Chapter 5.4 the possibilities for data import are discussed. Chapter 5.5 is concerned with the output results and Chapter 5.6 gives an preview how the developed concept can be globally integrated at Sony DADC. Chapter 5.7 finally will give a schedule and cost overview for the implementation of the concept.

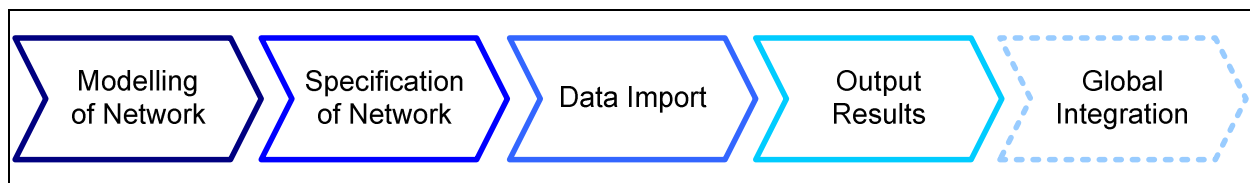


Figure 37: Concept Implementation Steps

5.1 Integration of Umberto

With one licence Umberto can be installed on as many PCs as desired, but always only one version per licence can be active used. It depends on how many persons want to work parallel with Umberto, but for the beginning one or two licences should be enough.

If there is more than one user, the software should be installed on the company's network. The licence key should then also be installed on the network, which gives automatically access to Umberto when opening the program and a licence is available.

The installation should be made by the Sony DADC helpdesk, details for installation can be found in the Umberto user manual.

5.2 Building and Editing Material Flow Network

This Chapter describes how the different production processes of Sony DADC Anif can be modelled in Umberto.

At first a new project has to be opened in Umberto and then a new scenario has to be created. In the scenario the system can be modelled.

For modelling a process, a transition and at least one input place and one output place to which the transition is connected with arrows have to be created. The materials for a process are coming from the input place. Then the materials are processed in the transition. After the transition the material flows to one or more output places.

If places are located between two transitions they have to be defined as 'Connection' or 'Storage'. In a connection place materials are just passing through to get to the next transition. In storage places material is stored before it comes to the next transition. Special places are 'Input/Output', if a place is input and output place in one, and 'Port'. Port places represent the link between two network layers, thus between a net and its subnet. If a subnet for a net transition is created, the places which are connected with the transition are automatically transferred in the subnet as port places.

5.2.1 Symbols in Umberto

The following symbols in Figure 38-42 are used for shaping a process:⁹⁴

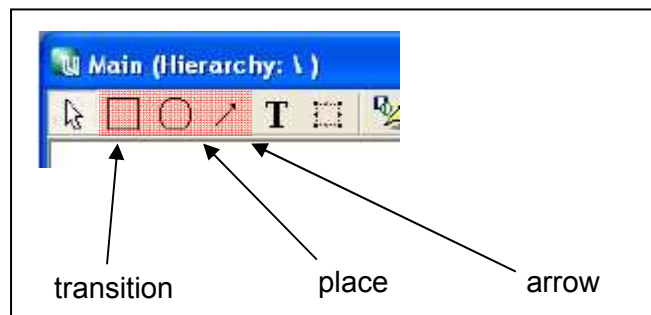


Figure 38: Basic Symbols in Umberto

- Transitions: for transforming materials and energy

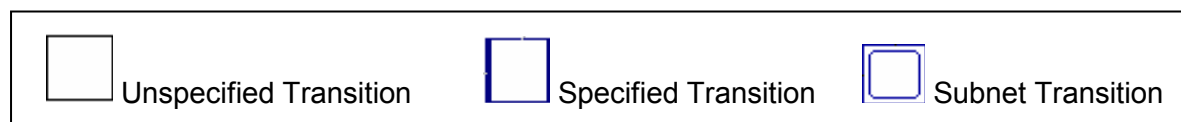


Figure 39: Transitions in Umberto⁹⁴

⁹⁴ Cf. ifu Hamburg (2010), pp. 7.25 - 7.55

- Places: materials and energy are distributed or stored

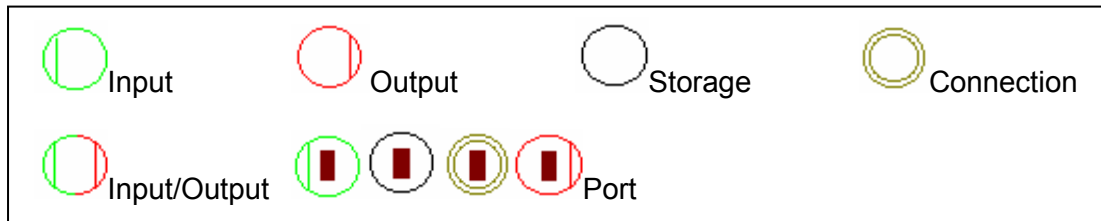


Figure 40: Places in Umberto⁹⁴

- Example for Basic Process

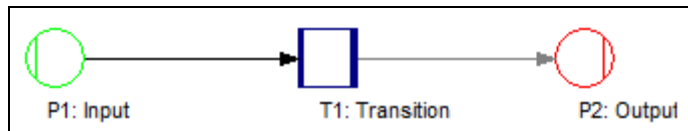


Figure 41: Basic Process in Umberto

- Section of a process with a subnet transition, connection place and a specified transition

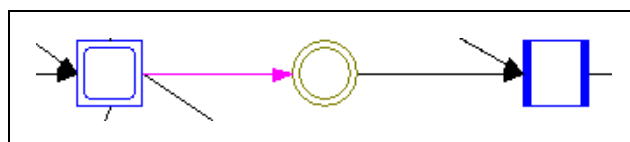


Figure 42: Example for a Process in Umberto

Transitions and places must alternate in a net, so every transition has to be between two or more places and a place only can be connected with a transition.

A transition has to be specified, to define what happens in a process. Therefore a transition could be directly specified or could consist of one or more subprocesses. Subprocesses can be arranged in a subnet behind the transition. To create a subnet you simply have to right click on a transition and choose the instruction 'Create Subnet'. The subnet will be opened in a new window and you can continue to model the system. Input and output ports from the main transition will be directly assigned to the subnet. How to specify a transition will be described in Chapter 5.3.1.

With the other icons for modelling as displayed in Figure 43, text fields or boxes can be created.

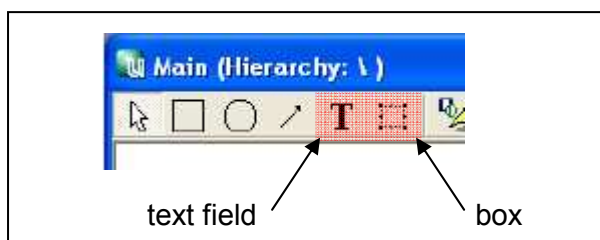


Figure 43: Text Field and Box Icon in Umberto

Boxes can be used for drawing system boundaries, inserting pictures or graphics. Pictures or graphics in boxes, transitions or places can be inserted in 'Extended Windows Meta File'- or 'Windows Meta File'-format (emf or wmf). To insert them you have to right click on the element and then you have to chose 'Edit Icon'.

A clipart database is available in Umberto, which can be used to insert graphics. To insert pictures in Umberto, common picture files (jpg, bmp, gif) have to be converted in an emf- or wmf-file. Therefore it's recommended to use an image editing software like IrfanView©. IrfanView is a graphic viewer freeware which can be downloaded on www.irfanview.de.

5.2.2 Material Flow Network for Sony DADC Anif

After introducing how a system has to be modelled, it is described how the material flows of Sony DADC Anif can be set up in Umberto.

By including a top down approach, a structure of nets and subnets based on the graphic in Figure 44 was build for Sony DADC Anif.

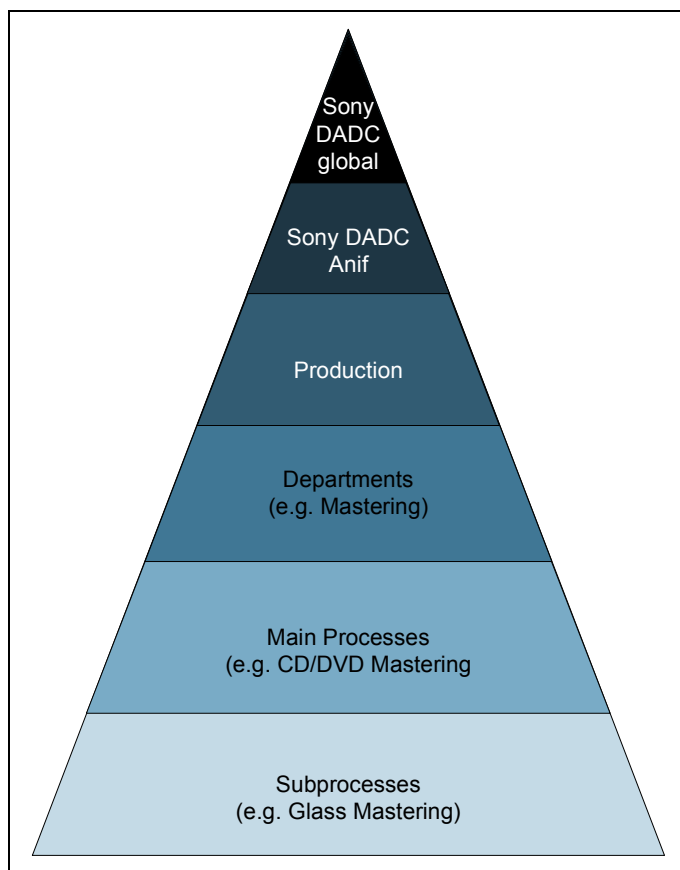


Figure 44: Process Network Structure for Sony DADC

Starting from the peak, the whole production system can be broken down to the production of each location and further to the departments with its main processes and subprocesses. In this way all production processes at Sony DADC can be integrated in

the process network model in a clear structure. In the testing phase of Umberto, a process network for Sony DADC Anif was modelled. How the nets of the tiers or layers could be looking like is presented by introducing examples for each tier on the following pages.

Sony DADC Global

The peak of the pyramid is symbolising the global Sony DADC manufacturing network. As the system boundary for this work was defined only for Sony DADC Anif, the first tier which is briefly described is Sony DADC Anif. A possibility how to create the top layer will be discussed in Chapter 5.6.

Sony DADC Anif

Figure 45 depicts the starting window of a project, which serves as user interface after the system is implemented. Here the system Sony DADC Anif is abstractly displayed. The whole site is reduced on the two input places 'Raw Material' and 'Packaging Material', two output places 'Discs' and 'Waste' and one main transition called 'Production'. The dash dotted box symbols a system boundary, in this case the system boundary Sony DADC Anif. The production transition contains all sub-networks of Sony DADC Anif. By clicking on the transition the next window will appear, which is the level 'Production'.

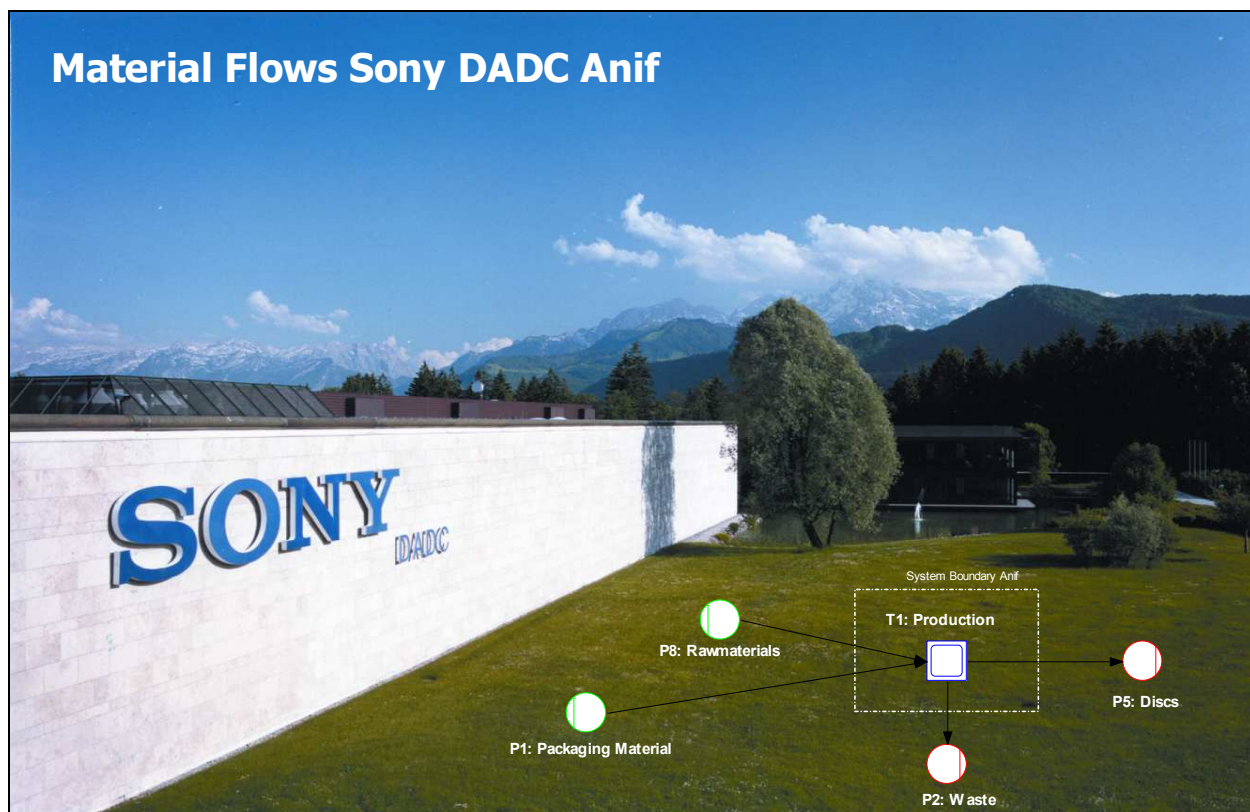


Figure 45: Umberto User Interface

Production

In the network 'Production' all production departments are arranged as transitions, which are connected along the overall process flow with port, storage or connection places. Figure 46 shows the modelled production of Sony DADC Anif in Umberto.

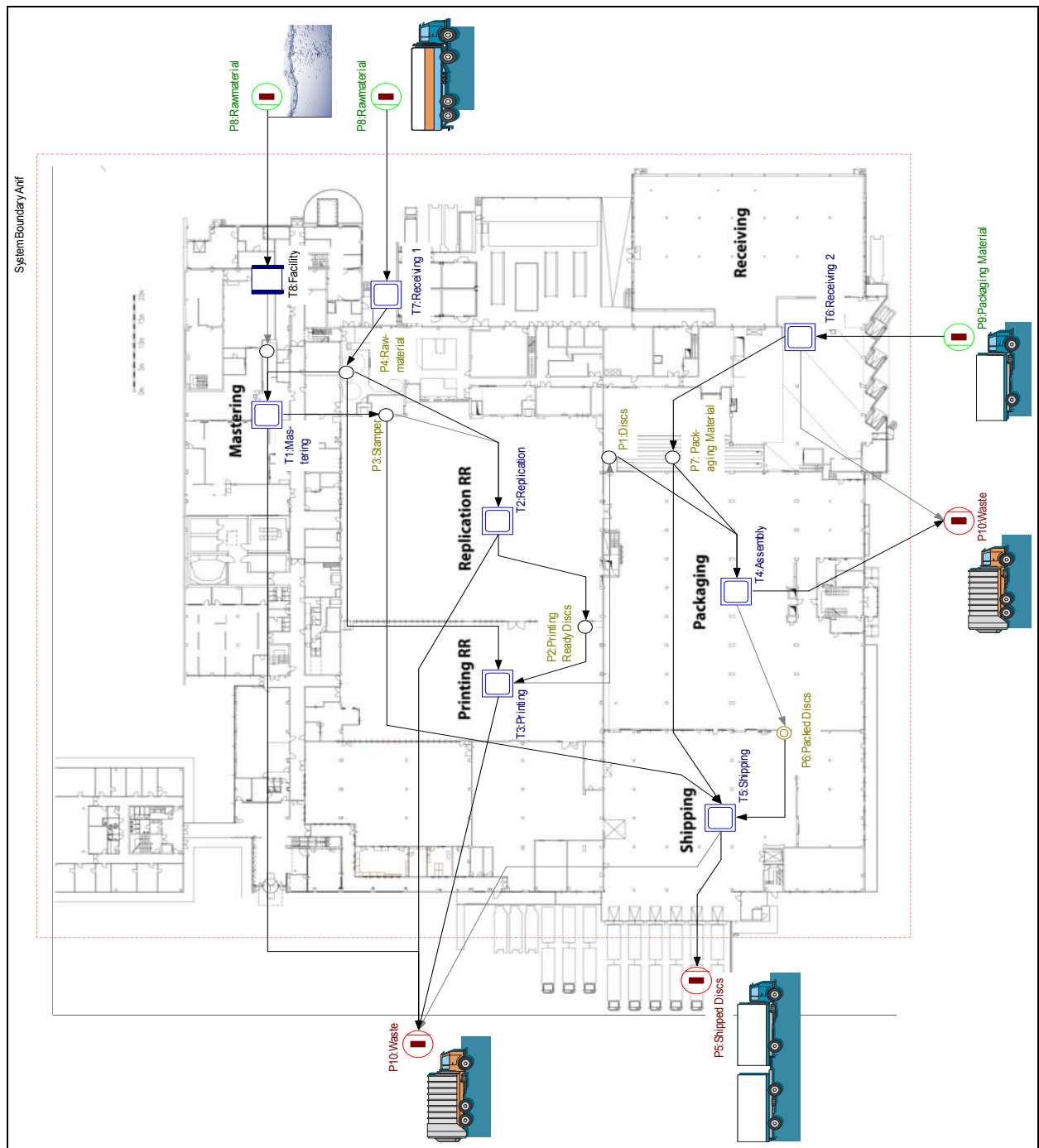


Figure 46: Production Sony DADC Anif in Umberto

The intention of modelling this level was that an overview of material flows over the whole production can be given. However, all transitions, except for facility, are containing sub-networks to describe and display the processes in more detail. As the facility department provides the production especially with water, it is only modelled as

a simple specified transition. If energy should be included later on for the processes, it would have to be obtained from facility as well.

Waste is produced in nearly every single process, but to depict the system clearly, the waste outputs are summarized in two representative output places. After raw material is received at receiving 1, it is stored at some different places. In the shown example all stored raw material is summarized to one storage places for reasons of clarity.

By clicking on a transition with sub-network, the next level opens, which is called 'Departments'.

Departments

In the department tier a department with its basic processes are displayed. For example the mastering department is divided in CD/DVD mastering and BD mastering, the replication department is divided in CD, DVD and BD Liner, the printing department in offset and screen print or the assembly department in standard and special assembly. In this way you get more and more into detail the deeper you advance in the process network.

Figure 47 displays the subnet 'Mastering' with the processes CD/DVD mastering and BD mastering. Inputs are the water of facility and the raw material from receiving 1. The main output of mastering is the replication ready stamper. The coloured field with the dotted frame symbols the system boundary mastering.

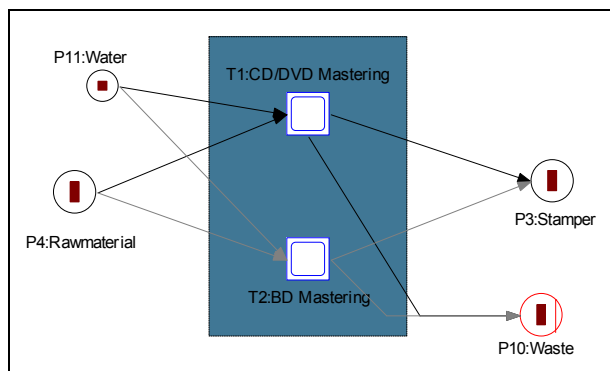


Figure 47: Mastering Department in Umberto

Figure 48 shows the department net of replication. The basic processes are called CD liner, DVD liner and BD liner. Inputs are stamper and raw material, outputs are the printing ready discs and waste. The connection places above each liner were modelled to display the closed loop recycling of polycarbonate, which is mainly caused by the sprues.

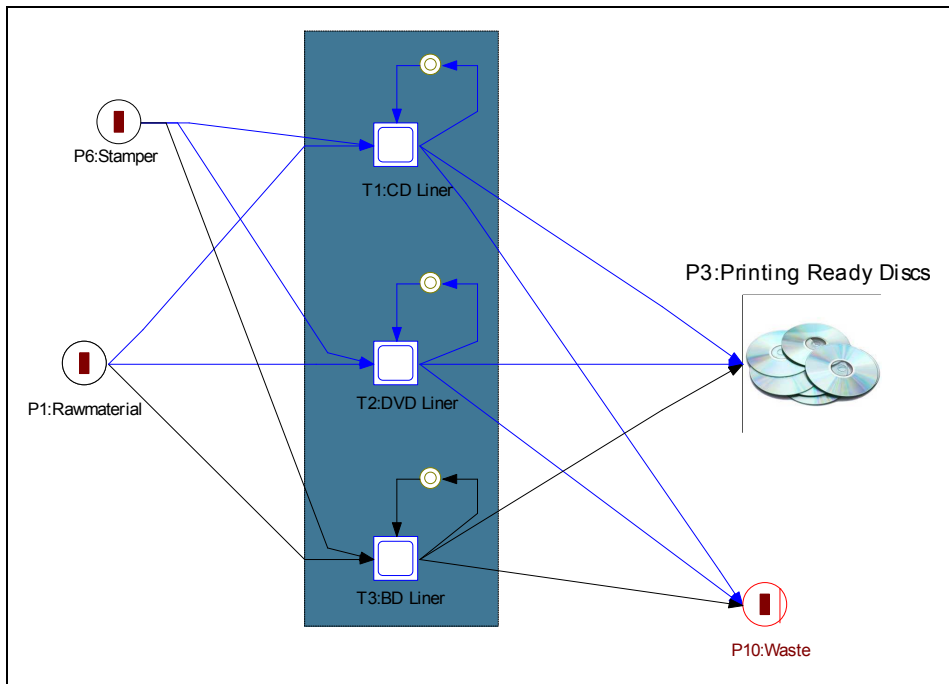


Figure 48: Replication Department in Umberto

The raw material input can be also split to more different inputs. For example the input port raw material, which was overtaken from the layer 'production', can be divided for replication in targets, polycarbonate and resins. The other way is to just remain on one overall raw material input as shown in the two previous examples. The results of the MFA are the same, but the style of display is different. For reason of clarity in some cases it could be better to split the inputs.

Again the transitions are arranged with subnets, which are displayed on the next deeper layer, the 'Main Processes'. Except for shipping, receiving 1 and 2 are no more subnets necessary, because the processes can be displayed clearly in the department net.

Main Processes

As the name suggests, in the subnet 'Main Processes' the main processes within a department are modelled. Arrived at this layer, in many cases no more subnets will be necessary. It is the final net for printing, replication and if applicable for assembly.

If the transition CD/DVD mastering of the mastering department net is selected, the main process subnet 'CD/DVD Mastering' opens. The main processes 'Glass Recycling', 'Glass Mastering', 'Plating' and 'Finishing' were defined to shape this net, which is displayed in Figure 49.

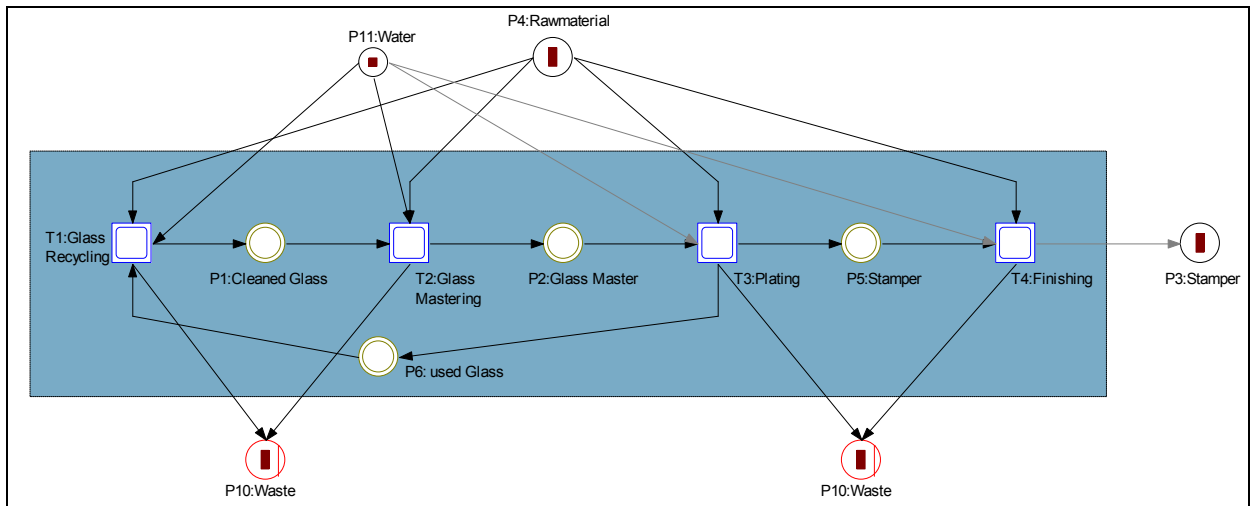


Figure 49: Main Processes CD/DVD Mastering in Umberto

If the transition BD liner of the replication department network is selected, the main process subnet 'BD Liner' opens. The two BD varieties single layer and dual layer are manufactured on two different machine types. For this reason a transition for each machine type was created, which are displayed in Figure 50.

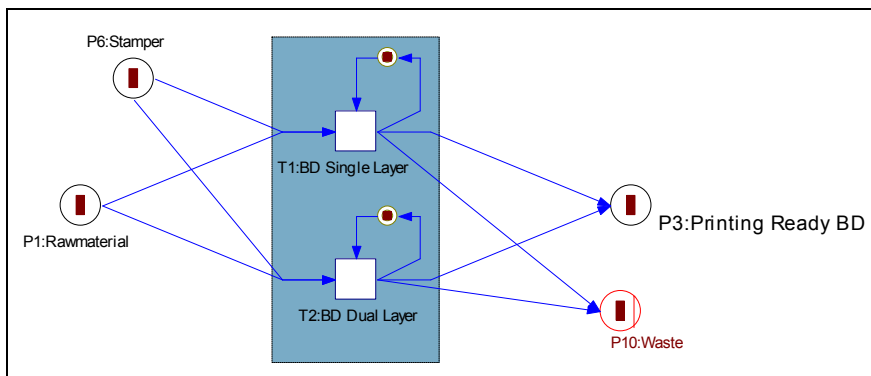


Figure 50: Main Processes BD Liner in Umberto

The transitions of some main processes especially of mastering are again arranged with subnets. The subordinated transitions are copied in the last layer.

Subprocesses

The bottom tier finally includes all subprocesses. This network only is necessary for complex processes, where it's better to split the main processes in more detailed and smaller ones. Subprocess-networks are used only in the mastering department or optional in the assembly department as well.

If the transition glass mastering of the CD/DVD mastering network is selected, the subprocess sub-network 'Glass Mastering' opens. The processes 'Pre-Cutting', 'Cutting', 'Developing', 'Electroless Plating' and the 'Glass Mastering 2 Process' are defined to shape this network, which is displayed in Figure 51.

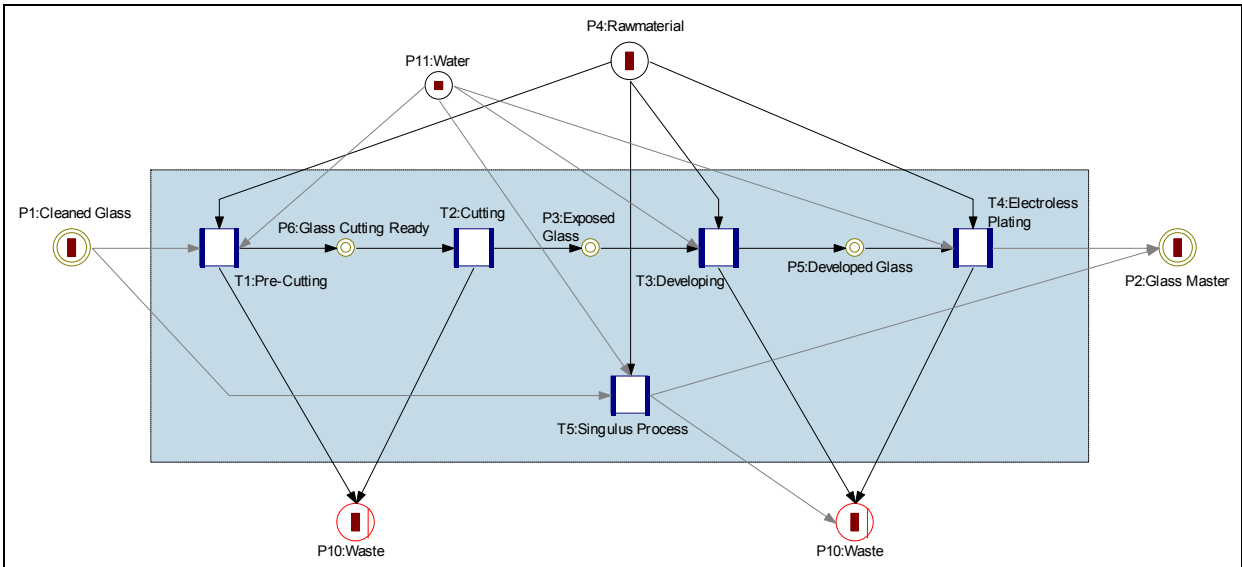


Figure 51: Subprocesses Glass Mastering in Umberto

If the transition plating of the CD/DVD mastering network is selected, the subprocess sub-network 'Plating' opens. As shown in Figure 52, the processes 'Master Plating', 'Mother Plating' and 'Stamper Plating' were set to form this network.

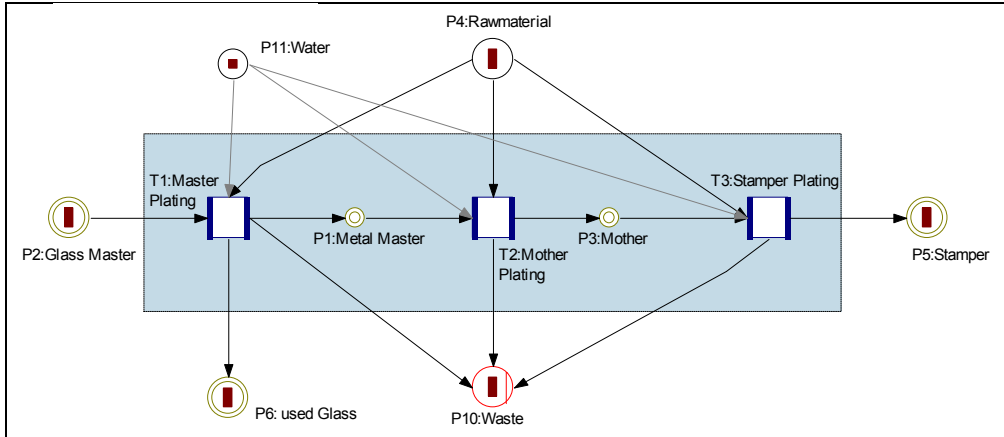


Figure 52: Subprocesses Plating in Umberto

Furthermore the creation of a sub-network for each plating subprocess can be considered. For example for 'Mother Plating' the processes 'Cleaning Stamperwasher', 'Passivation', 'Pre Plating', 'Electroplating' and 'Post Plating' could be specified. Nevertheless, this exemplary model ends with 'Subprocesses', because the gained transparency of the processes in this model was deemed to be adequate.

So all processes are neatly arranged in a basic structure contains of four basic levels: production, departments, main processes and subprocesses. To fill this modelled system with data, the attributes of the processes (transitions) have to be set.

5.3 Specification Material Flow Network

Specification of a material flow network means to provide data for the elements of the network. As basis for setting attributes of processes at first materials have to be defined in the material list of the project. All materials should have the basic unit kg. By editing the materials you can create more units, e.g. litre for liquids or units for disc quantities. Materials don't have to be defined necessarily if they are imported later on and their unit is kg.

After the definition of the material list the next step is to specify the processes.

Possibilities of Process Specification

There are several different ways to specify a modelled process. The five main possibilities are:⁹⁵

1. manual state of inputs and outputs of a transition with coefficients
2. define the relations of a transition between input and output flows by a set of mathematical functions
3. transition specification by import existing data for input/output relations
4. import of existing data for material flows of diverse arrows
5. load pre-defined transition module from the Umberto library or eco-invent database

The three main specification methods which were used for this project were possibility 1, 3 and 4. That's why these possibilities are explained in more detail. The use of mathematical functions as described in point 2 was included in point 3 and 4 to edit the existing data in Excel. The pre-defined transition modules like 'Transport' or 'Metal Production' are used mainly for LCA of a product and were not applicable for this problem. In addition the eco-invent database was not available in the Umberto test version, it could be bought optionally to Umberto.

⁹⁵ Cf. ifu Hamburg (2010), pp. 8-1 – 8-80

Manual State of Inputs and Outputs of a Transition with Coefficients

With right click on a transition by choosing 'Edit Specification' the field for defining input/output relations opens. Here materials from the pre-defined material list can be dragged & dropped to the input or output side. Next the coefficients can be defined.

In the fictional example in Figure 53 the input coefficients for Nickel are 1 kg and for chemicals 0,4 kg. Output coefficient for master is 0,9 kg and waste is 0,5 kg. Now the transition is fully defined. Next the quantity of a certain material can be set. E.g. here the red marked arrow can be specified with the output 'Master 850 kg'. On basis of these 850 kg produced master the material flows of this simple process can be calculated.

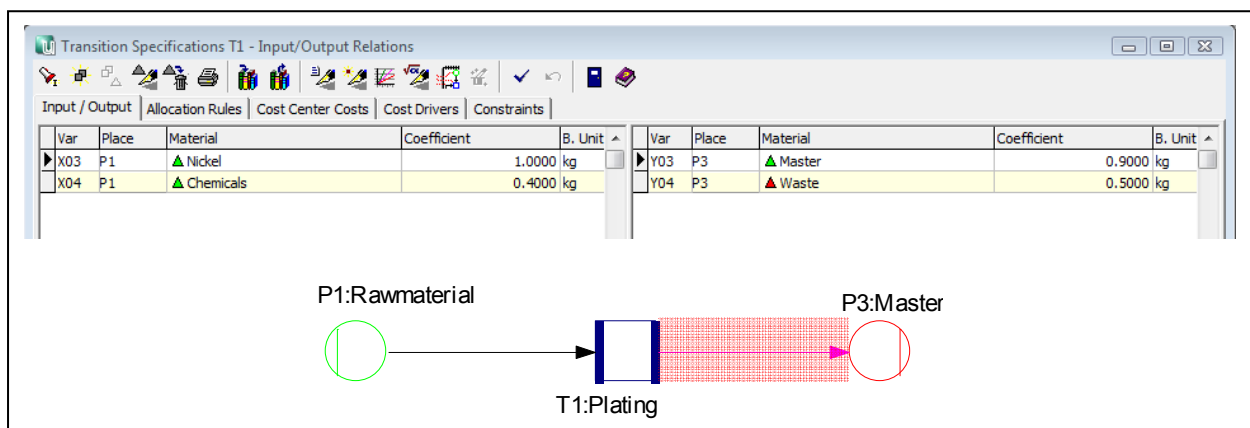


Figure 53: Transition Specification in Umberto

Transition Specification by Import Existing Data for Input/Output Relations

This possibility to specify a transition is almost the same than the first one. The difference is that the inputs and outputs don't have to be put in manually. With a special icon, which is shown in Figure 54, inputs and outputs for the transition can be imported for example from Excel files. The Excel file must contain of the columns material, quantity and unit for inputs and outputs. If the import material is not defined in the material list of the project, it has to have the unit kg (or kJ). After the data import the system can again be calculated by specifying an arrow of the process as described in the previous possibility.

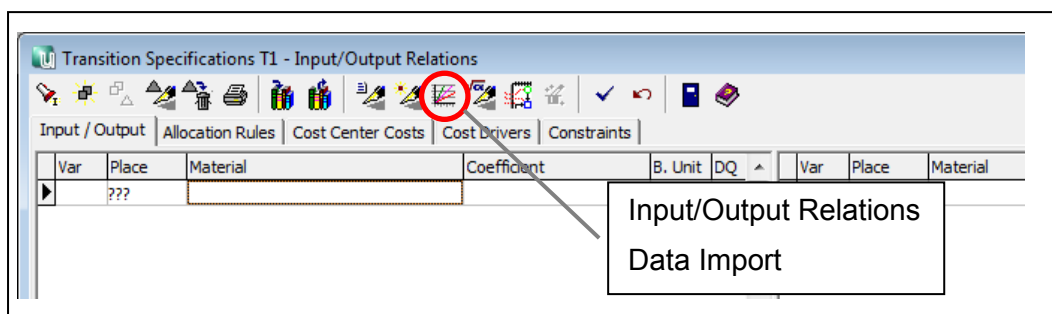


Figure 54: Data Import of Input/Output Relations

Import of Existing Data for Material Flows of Diverse Arrows

The third possibility which is discussed is the direct import of material quantities for input and output arrows of a transition. This procedure can be done with the 'Input Monitor'. With the Input Monitor data from existing files can be queried with SQL. Next the selected data can be allocated to the different arrows of a system.

The left part of Figure 55 shows the menu SQL from the window for editing multi materials import of the input monitor. Here SQL queries to imported data can be made. In this SQL query data to the columns 'ShortName', 'Material', 'Quantity' and 'Unit' from the field 'Mastering' of an Excel file is requested. Then the selected data can be allocated via its short name to the red marked arrows, which are displayed in the right side of Figure 55.

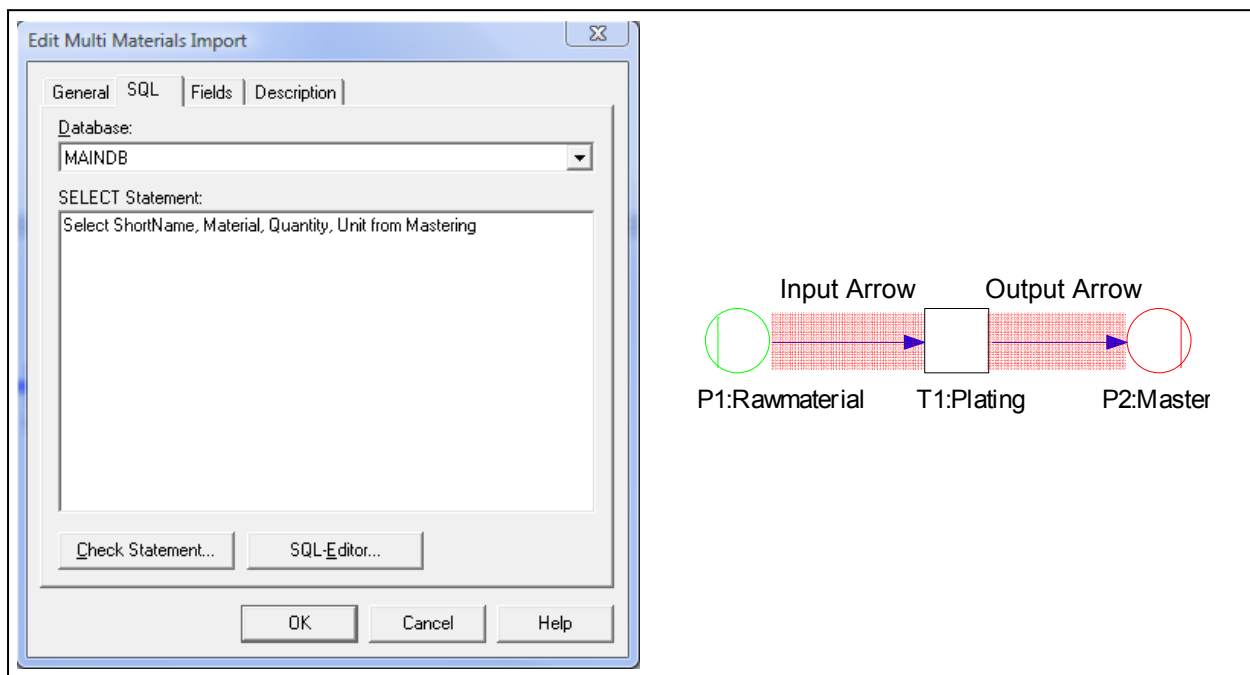


Figure 55: SQL Query and Allocation of Data with Input Monitor

For example you can give the input arrow by right click 'Edit Attributes' the short name 'Plating Input' and the output arrow 'Plating Output'. With the yellow lightning icon 'Set Input Vector' of the input monitor, all materials witch includes the short name 'Plating Input' will be allocated to the input arrow and all materials witch includes the short name 'Plating Output' will be allocated to the output arrow.

This possibility seems to be a little laborious, but after the system is set up once, material flow analysis for a system to different periods can be made quickly. Because a rapid periodic carrying out of MFA is a basic requirement, the import of data with the input monitor is the best solution for automated material flow analysis at Sony DADC.

Details to this method will be presented in Chapter 5.4 and further information can be found in 'Umberto Fortgeschrittenen Schulung Lektion 3'.

5.4 Interfaces and Data Import

To get results, the built material flow network has to be filled with data and then the system has to be calculated. As shown in Chapter 5.3, beside the manual input of data you have the possibility to import data in Umberto.

The database system at Sony DADC consists of the database management system Oracle with its many specific databases like Avalon, the BDE system (factory data capture system) or in a special database for the mastering department. In Avalon data to receiving or consumption of material is stored. In the other databases data to produced goods of several machines is available.

To get reports of the data, queries of the databases can be made. A software which is used for queries at Sony DADC is Business Objects (BO).

So with BO you have the possibility to make specific queries of material quantities for respective processes. The queried data has to be exported to Excel and afterwards imported in Umberto. So for importing data in Umberto as described, BO and Excel is a prerequisite. Figure 56 and 57 show the basic importing process and details to an example of how to import data from BO to Umberto.

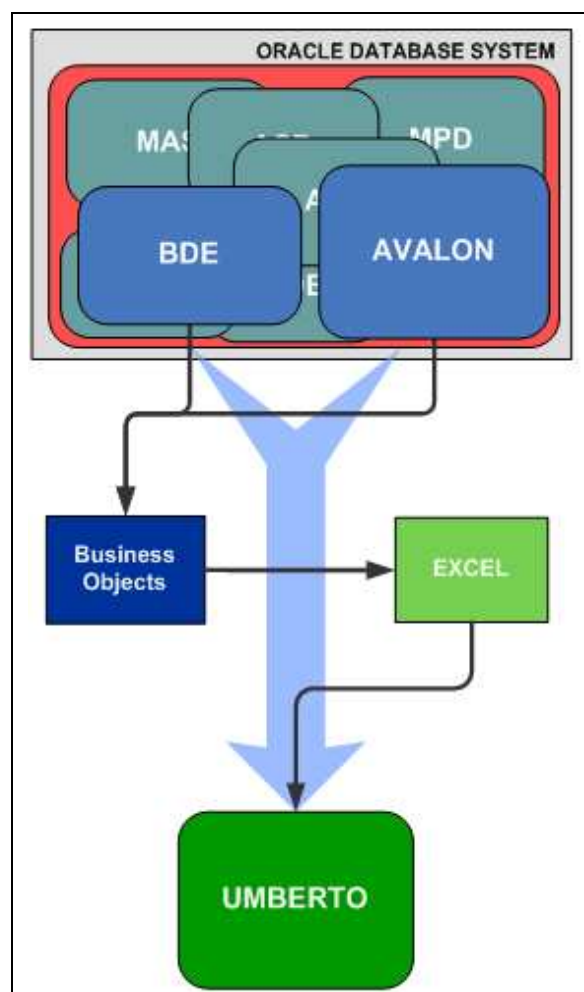


Figure 56: Basic Structure for Data Import in Umberto

Details for Import of Data from Business Objects to Umberto

Data import concept for raw materials in mastering, replication and printing.

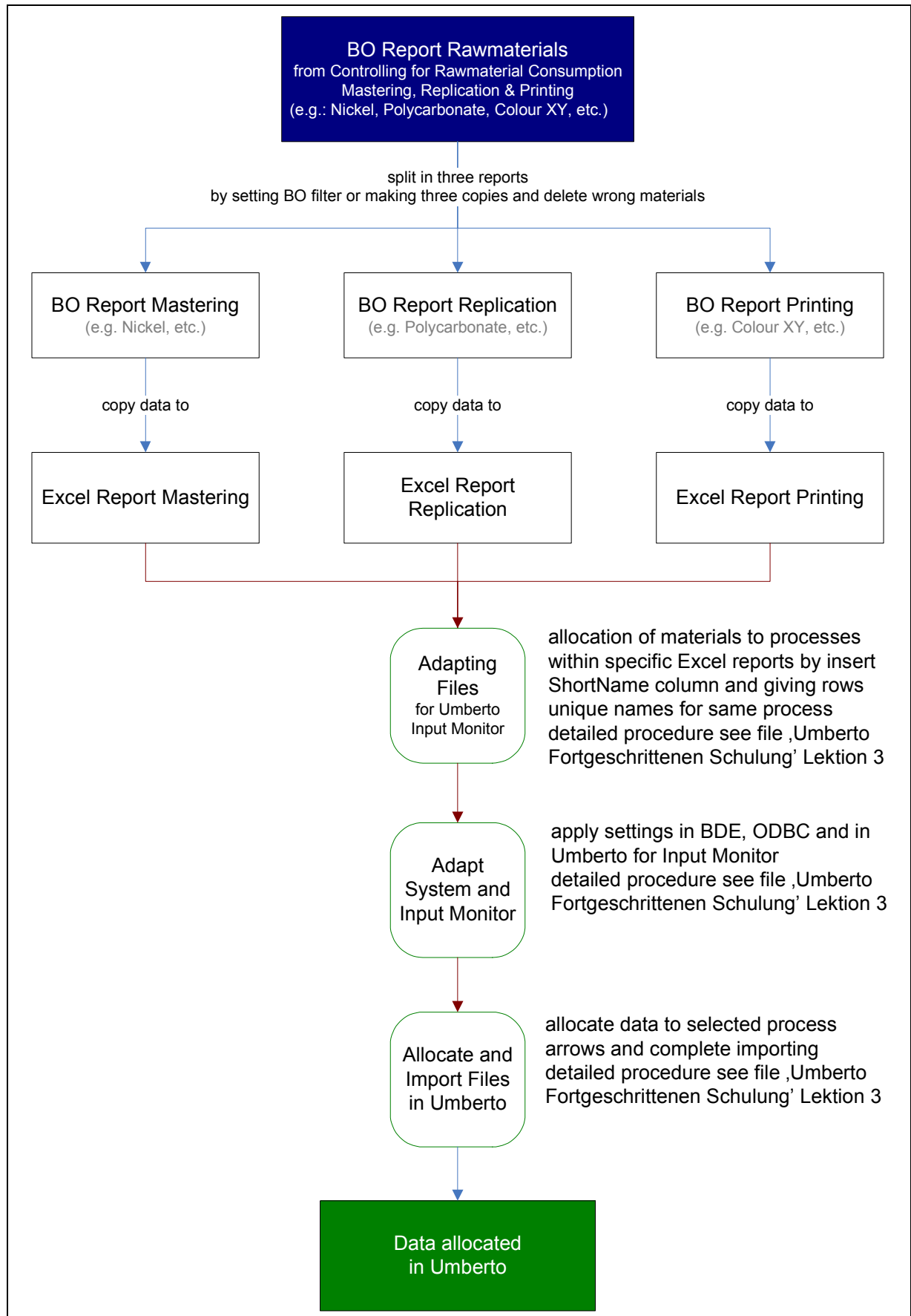


Figure 57: How to Import Data in Umberto

The first step of the example of Figure 57 is to split the main controlling BO report to BO department reports by setting a filter or copying the report and adapt the queries for each department. After you have run the queries for a selected period the data from BO has to be copied to an Excel file. The ready adapted Excel file can look like the following Tables 8 and 9 for CD Replication.

Input Table

Shortname	Material	Quantity	Unit	Source
Rawmaterial	Polycarbonate Shot CD	101144	k units	BO Report Rep
Stamper	Stamper	17194	units	BO Report Mas
Rawmaterial	Aluminum	991,7	kg	BO Report Rep
Rawmaterial	Protective Ink 1	9205,0	kg	BO Report Rep
Rawmaterial	Protective Ink 2	1389,4	kg	BO Report Rep
Rawmaterial	Colours	190,4	kg	BO Report Rep

Table 8: Excel Report CD Replication Inputs

Output Table

Shortname	Material	Quantity	Unit	Source
Output	CD Printing Ready	97355,3	k units	BO Report Replication Yield
Recycling	PC Waste clear*	30242,1	kg	= 0,299 [g/unit] x Polycarbonate Shot [k units]
Waste	PC Waste clear	21818,8	kg	BO Report Replication Yield
Waste	Stamper	636,1	kg	BO Report Mas
Waste	Aluminum	875,4	kg	= 0,00899 [g/unit] x Disc Printing Ready [k units]
Waste	PC Waste	34448,4	kg	BO Report Replication Yield

Table 9: Excel Report CD Replication Outputs

The grey source column quotes where the data comes from or optional how it has to be calculated. As can be seen in Figure 58 and 59, the brown short name column quotes to which arrow the data will be imported

To import the data in Umberto the fields which should be imported must be given a unique name in Excel. This could be done by marking the required fields, then under the Excel menu 'Insert' a name for the fields can be defined. So in this case it would be respectively input for the input data and output for the output data. In the next picture you can see in the top left corner that the blue marked fields are named 'Output' because shortname, material, quantity and unit have to be imported in Umberto later on.

	F	G	H	I	
5	Shortname	Material	Quantity	Unit	Source
6	Output	CD Printing Ready	97355,3	k units	BO R
7	Recycling	PC Waste clear*	30242,1	kg	= 0,29
8	Waste	PC Waste clear	21818,8	kg	BO R
9	Waste	Stamper	636,1	kg	BO R
10	Waste	Aluminum	875,4	kg	= 0,00
11	Waste	PC Waste	34448,4	kg	BO R

Figure 58: Excel Report CD Replication Outputs

A number of stampers will also be stored and therefore not be classified as waste. This fact is not considered in the example.

After applying the settings in BDE and ODPC (see Umberto Fortgeschrittenen Schulung Lektion 3) the arrows in Umberto have to be specified with the same short names like in the Excel sheet. So in our case with right click on arrow under 'Edit Attributes' the short names for CD replication would be named as following:

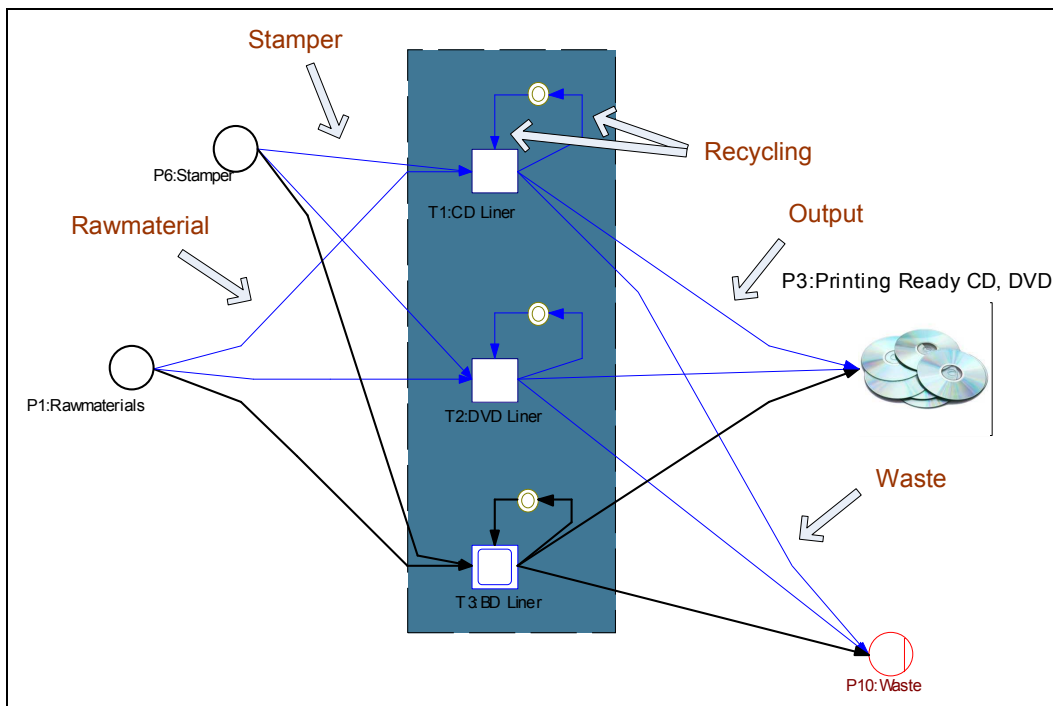


Figure 59: Allocation of Import Data for CD Replication

Finally the data can be imported with the 'Set Input Vector' icon of the Input Monitor and then the system can be calculated.

As has been previously mentioned, this whole procedure only has to be performed once. Afterwards the data can be copied to the created Excel sheet and updated in the network in Umberto to get the new material flow of a selected period.

So after setting up this system the possibility to get the material flows within an acceptable time frame is given. Depending on to which frequent data from the databases is updated or available, material flows can be analysed even down to one single day.

Ways of Importing without Business Objects

There are also other ways to import data to Umberto. The step from database to BO and from BO to Excel can be avoided by programming Excel queries via macros for the databases. So in that case with Excel needed data could be directly report and so BO could be left out. This can be made by support of the IT department or replication engineer specialists.

A third way is that ifu Hamburg programs an interface especially for Sony DADC, which is absolutely feasible. But here an additional cost of about 100.000€ will rise, hence this method was not considered closer in the project.

5.5 Output Results

If all processes are modelled and specified and all data is imported and assigned, the network system can be calculated via 'Calculation - Network - Current Period'.

If the calculation was successfully, several possibilities are available to report, visualize and evaluate the results.

5.5.1 Sankey Diagram

One opportunity for visualization, like was described in Chapter 3.7.3, is to display the results as Sankey Diagram. Therefore colours have to be defined for the different materials under network attributes and Sankey Diagram properties. Then with the displayed icon in Figure 60 the Sankey Diagram can be showed.

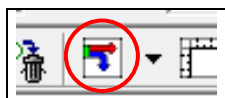


Figure 60: 'Show Sankey Diagram' Icon

In the appendix in Figure 73 an overview of the Sankey Diagrams of the modelled material flow network in Umberto is shown. Starting from the Sony DADC Anif network, all material mass flows down to the subprocesses are displayed.

Sankey Diagram Production in Umberto

In Figure 61 the Sankey Diagram for the production is presented in more detail. The water consumption in the material flows was only considered in the mastering department. The water flow is displayed in light blue, the Nickel waste water is grey and the acid/base waste water is maroon. Other basic colours of the diagram are yellow for the raw material flow of polycarbonate, the ready packed CDs are red, the DVDs are green and the BDs are blue.

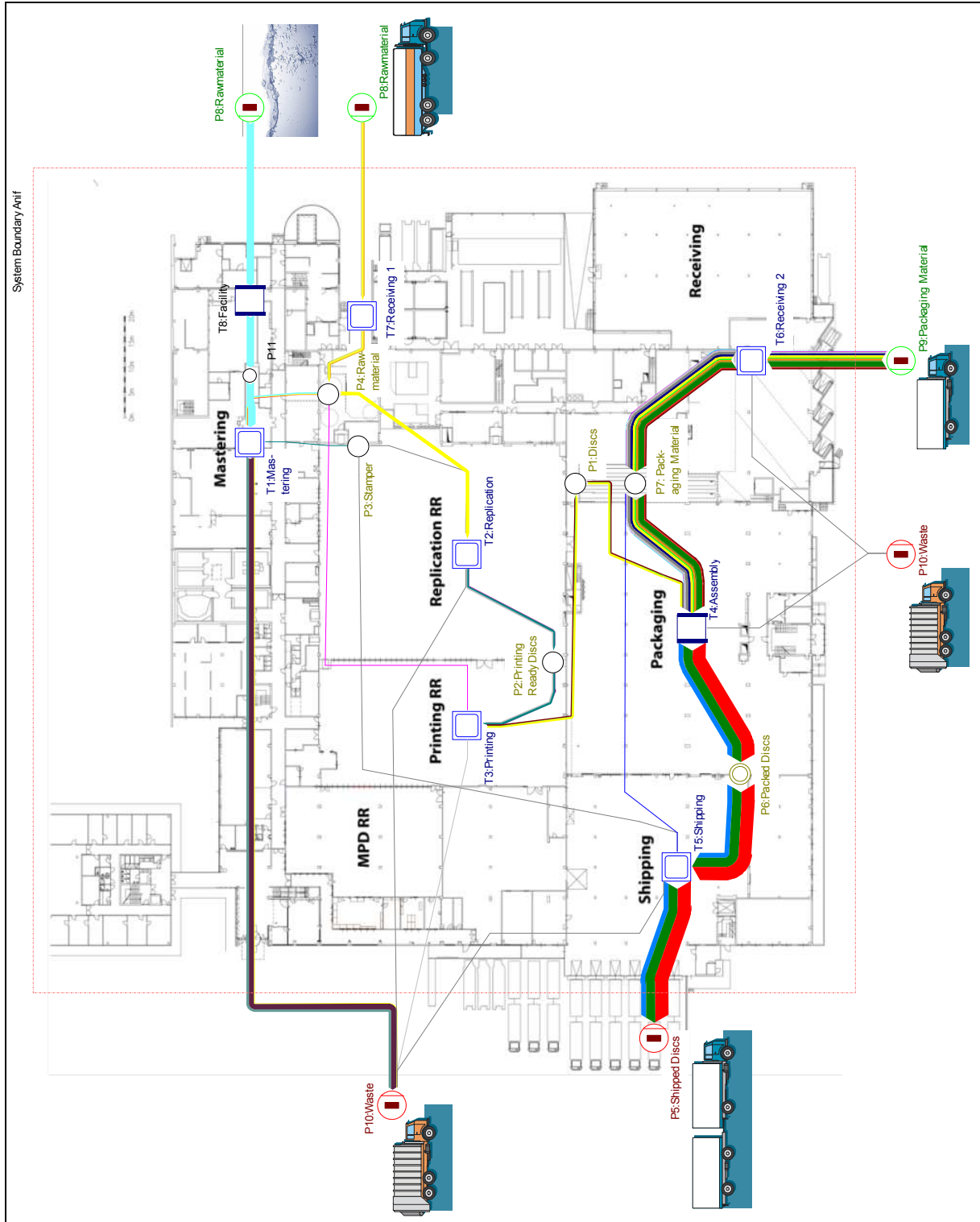


Figure 61: Sankey Diagram Production in Umberto

Sankey Diagram Replication in Umberto

The Sankey Diagram for the replication department is pictured in Figure 62. Again the polycarbonate raw material is yellow. The other raw materials make less than 1% of the total raw material mass flow, that's why they are difficult to see. The purple flow shows the CD mass flow, red is for DVD and the two blue colours are for BD SL and BD DL. The waste flow is grey and green and the closed loop recycled polycarbonate is dark blue.

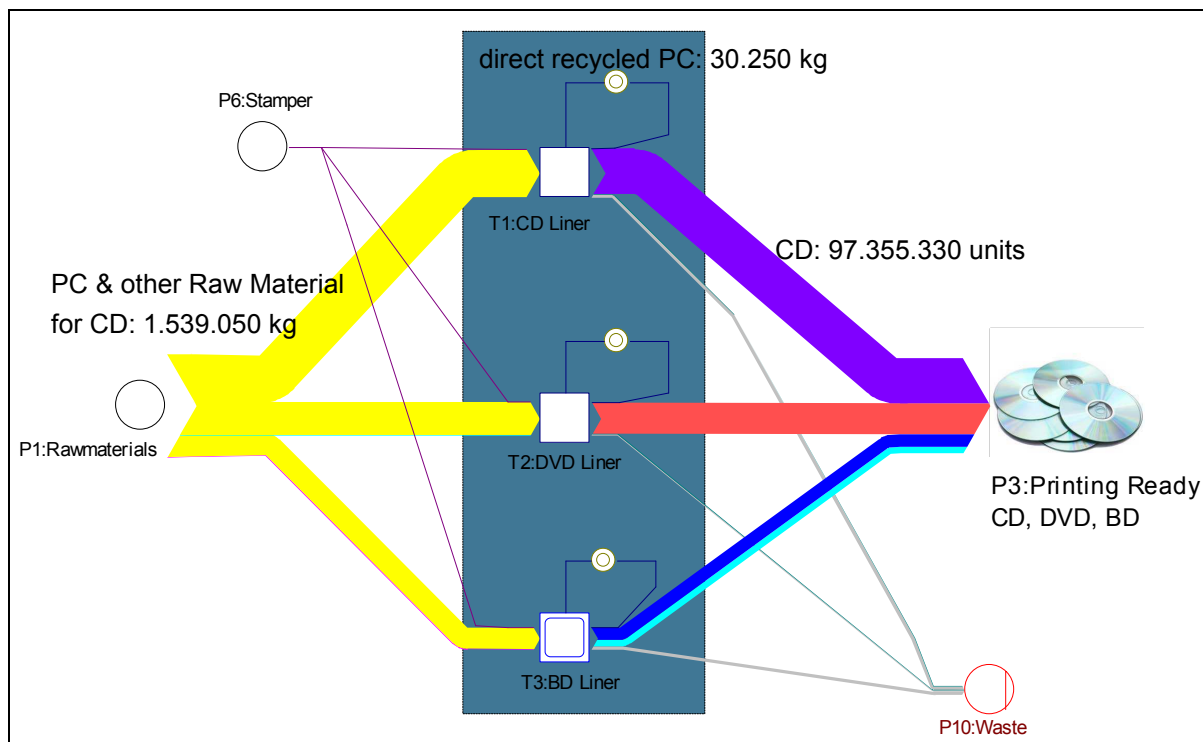


Figure 62: Sankey Diagram Replication in Umberto

5.5.2 Input/Output Balance

To get the I/O balance, 'Balance - Preview - Default Boundaries' have to be selected. Now the I/O balances can be displayed in different ways. For example material flows of single transitions, material flows of the total system, etc.

Therefore the balance can be sorted by materials, transitions-materials, places-materials or in other selections. So if 'sorted by materials' is chosen, the summarized material flow of the total selected system will be displayed. By choosing 'transition - materials', the material flow of a transition will be displayed.

In the balances in Figure 63 and Figure 64 can be clearly seen, which materials were used in which quantities for the different manufacturing processes. By defining properties for materials it can be shown which hazardous materials were used, where they were processed and if they have to be special disposed. Also can be seen where the waste did incur along the manufacturing processes. It can be reported how efficiently the different processes are and how efficiently the materials are processed. By giving transparency you can illustrate where is potential for material savings. It also can be displayed which and where chemicals do discharge into the waste water.

Input:			Output:		
Item	Quantity	Unit	Item	Quantity	Unit
<input type="checkbox"/> T1 CD Liner			<input type="checkbox"/> T1 CD Liner		
▲ Aluminum Target	991.6831	kg	▲ Aluminum	875.3685	kg
▲ new SD55	1389.4395	kg	▲ CD Printing Ready	97355.3330	k units
▲ PC Waste clear*	30242.0700	kg	▲ Ni Stamper 37g	2210.1180	kg
▲ Polycarbonate Shot CD	101144.0429	k units	▲ PC Waste clear	21818.8300	kg
▲ Protective Ink SD2407	9205.0367	kg	▲ PC Waste clear*	30242.0700	kg
▲ PS Black	87.4603	kg	▲ Polycarbonate Coated	113819.3753	kg
▲ Resin Protective	9205.0367	kg	<input type="checkbox"/> T2 DVD Liner		

Figure 63: I/O Balance Sorted by 'Transitions – Materials'

Input:			Output:		
Item	Quantity	Unit	Item	Quantity	Unit
↳ A1 Rawmaterial [P1 to T1]			↳ A3 Output [T1 to P3]		
▲ Aluminum Target	991.6831	kg	▲ CD Printing Ready	97355.3330	k units
▲ new SD55	1389.4395	kg	↳ A4 Waste [T1 to P10]		
▲ Polycarbonate Shot CD	101144.0429	k units	▲ Aluminum	875.3685	kg
▲ Protective Ink SD2407	9205.0367	kg	▲ Ni Stamper 37g	2210.1180	kg
▲ PS Black	87.4603	kg	▲ PC Waste clear	21818.8300	kg
▲ Resin Protective	9205.0367	kg	▲ Polycarbonate Coated	113819.3753	kg
▲ Target Aluminum	116.3147	kg	↳ A5 Recycling2 [T2 to P4]		

Figure 64: I/O Balance Sorted by 'Arrows – Materials'

Which materials are included in which quantities in an end product and which waste incurred for producing the end product can be answered by defining the material flow network with input/output relations as shown in Chapter 5.3.1. Afterwards the system can be calculated on basis of one output unit.

5.5.3 Comparing of Input/Output Balances

The balances can be saved, exported to Excel as report or compared with balances of other periods or alternative scenarios. With 'Balance - Select' two or more saved balances of different periods can be compared with each other. As described in Chapter 4.6 by comparing I/O balances of different periods information to how the production efficiency develops and how the process efficiency increases or decreases compared to

earlier periods can be given. Also a 'standard period balance' can be defined and afterwards compared with actual balances to see where production problems are, where is potential for improvement or where targets have been reached.

The results of the comparisons can be displayed also graphically in different charts.

5.5.4 Further Insightful Applicability

Further very useful information can be given if also energy flows and cost flows are investigated. Which processes consume the most energy, which are the most cost-intensive processes, where are the most cost-intensive materials processed or where is potential for cost savings, are just examples for questions which then could be answered.

To evaluate the environmental performance, indicators can be defined like it is explained in Chapter 3.8.2.4. In this way transparency to global warming, human toxicity, odour, acidification or eutrophication caused by the company can be given.

How to use performance Indicators (e.g. product carbon footprint, CML-method) is especially presented in Umberto training courses.

5.6 Possible Strategies for Global Integration of Umberto

In this Chapter it's discussed how Umberto should be applied at other Sony DADC locations.

Based on the previously described principles, an automated software-supported MFA at the different Sony DADC sites can be carried out. At the beginning of the MFA of a plant, the production processes have to be investigated to determine the material flows and to locate available data, like it was explained in Chapter 4. Therefore about twelve weeks of work for one person have to be scheduled. With the gathered information, the plant can be modelled in Umberto afterwards.

The used database systems within Sony DADC vary from location to location. Therefore how to gather data from the databases have to be coordinated on site with the database specialists.

Material Flow Network of Sony DADC in Umberto

As shown in Chapter 5.2.2 the peak level of the material flow network in Umberto symbols the whole company Sony DADC. The whole company can be structured in two different ways.

One way to get a clear and neat structure is to arrange the different locations of Sony DADC as separate projects as can be seen in Figure 65. If a project is chosen, for example Sony DADC Anif, the start window or user interface will open.

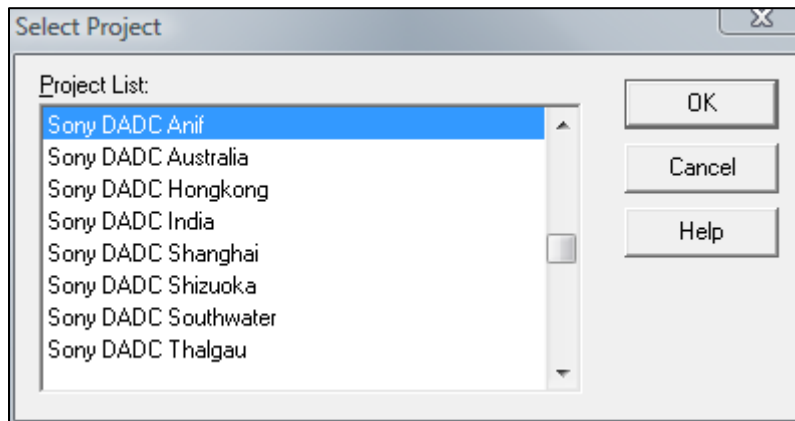


Figure 65: Project Mask from Umberto

Second possibility is to create an overall net for Sony DADC, like displayed in Figure 66, where all plants are subordinated. Advantage of an overall net is that you can balance and compare the whole company or areas of the company. You can for example compare the different I/O balances of similar processes and answer the questions which processes are more efficient than in other plants, where is potential to improve the processes or where are significant efficiency differences. Disadvantage is because of the size of the project it is getting more complex and difficult to maintain the system.

So for the beginning it may be better to structure the system as recommended first with separate projects for each site. To create a system like described in possibility two can then anyway be made afterwards.

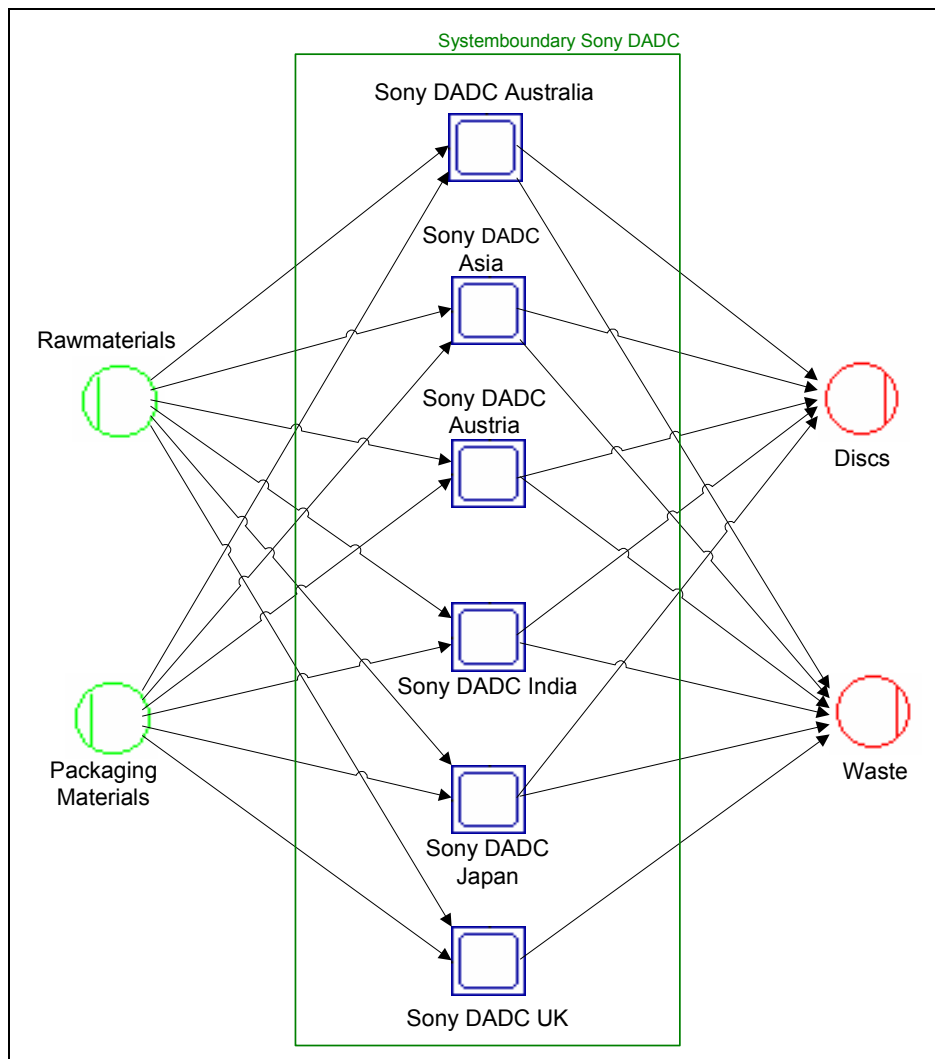


Figure 66: Possible Overall Material Flow Network of Sony DADC in Umberto

5.7 Main Issues for Material Flow Analysis with Umberto

If a user is familiar with Umberto, for modelling the material flow network of Sony DADC Anif one week is needed. For specify the whole system, adapting BO reports and Excel files, setting input monitor, about five more weeks are necessary.

So with a recommended introduction stage of two weeks, about two months of work for one person are needed to get the first results of the material flow analysis of the whole system after the installation of Umberto.

For adapting the BO reports, the help of a specialist for two weeks is suggested.

For system maintenance and MFA once in a month, one to two days per month are needed.

For the beginning one or two licences are recommended, but it depends on how many persons would like to work at the same time with Umberto.

The two available versions of Umberto are Umberto *5consult* and Umberto *5business*. In the consult version it is possible to store subnets in the Umberto library for reusing and to administrate the library, which can not be done in the business version.

For Umberto *5consult* the 1st licence is 9.900€, the 2nd-4th licence costs 5.900€ each. The first Umberto *5business* licence costs 6.600€, 2.900€ have to be paid for the licences two to four. So two licences for Umberto *5consult* are 15.800€ and two licences for Umberto *5business* are 9.500€. That's why it's recommended to work at the beginning with the business version, if it is necessary to use the additional features later one, it's any time possible to upgrade to the consult version. For getting important update and support from ifu Hamburg, 2% of the list price per month and licence has to be paid.

Finally, to exploit the whole features of Umberto it's recommended to attend the workshops and training courses for beginners and advanced users, which are organized from ifu Hamburg and take place in Munich and Hamburg regularly. In the courses will be, inter alia, thorough presented how to use environmental performance indicators.

6 Conclusion and Outlook

Savings of resources by conserving materials and to produce less waste and environmental loadings are tasks which will be significantly facilitated by implementing the developed concept for automated MFA. With this adopted and applied MFA system, potentials for resource conservation and environmental protection will be revealed in a capable way. The implementation of this concept would additionally help to improve resource management, environmental management, and waste management at Sony DADC further.

Conclusion to the Results of Material Flow Analysis

The MFA thoroughly investigated the processes of the discs production departments of Sony DADC Austria in Anif. The MFA showed that very useful information is given in regard to the processed materials. It was clearly balanced which materials were used in which processes for manufacturing the discs and which waste and waste water therefore was produced in fiscal year 2009. For visualization Sankey Diagrams and charts clarify the results. The gathered information is used to find potentials for improvements. In this way possibilities are revealed to process resources more efficient and for avoidance of waste and waste water. That is why the MFA supplies important information to resource management, environmental management, and waste management decisions.

Conclusion to the Developed Concept

Based on the carried out MFA, the concept for a global approach was developed. By implementing the MFA concept, which was extensively explained in Chapter 5, an efficient tool for controlling, evaluating and improving of the processes is created. To construct the MFA system the software Umberto of ifu Hamburg has to be used. The processes of the discs production have to be modelled in networks and sub networks, specified and connected with the Sony DADC databases. The system will be able to analyse the material flows periodically. The results will be reported with different input/output balances and visualized with Sankey Diagrams and charts.

By balancing the monthly data of material consumptions, the transparency of the production processes will be decisively increased. The visualization possibilities of Umberto will help to display the different flows clearly. In this way the MFA system will help to reveal weak spots and make decisions on a well founded basis. Periods can be easily analysed and compared and the efficiency of the processes can be reviewed.

Data for reporting for REACH or GRIDS can be easily taken over from the automated MFA. The MFA will be a big support for the use of the EMS elements 'plan', 'do', 'check', and 'act'. Thus, the ISO objective continuous improvement of the processes is facilitated. Decision about the choice of waste management scenarios and about management of resources should be based on the MFA.

The set up of the MFA system at Sony DADC Anif will take about eight weeks for one person, so after two months the first results of the automated MFA can be expected. Hence, after three months the first periodically comparisons can be made.

Outlook for an Expansion to a Global Material Flow Analysis Network

In the first step the system should be used for the process analysis at Sony DADC Austria in Anif. If the contribution of the MFA-concept to more efficiency can be realised, it can be adapted to the Sony DADC manufacturing site in Thalgau.

Finally, the system can be expanded to a global MFA network, which includes different production sites of Sony DADC in Japan, America, Pan-Asia and other sites. This would lead to additional key performance indicators, which can be compared between the different locations on a global scale. Thus, possibilities for process efficiency maximization can be revealed and coordinated.

Outlook to Further Available Features of the Developed Concept

To increase the overall transparency of the processes also energy flows should be considered and the features cost account and environmental performance indicator of Umberto should be utilized. This will facilitate an improvement of the energy efficiency in the production, show potentials for cost savings and environmental performance increase.

By using Umberto current scenarios can be optimized and future scenarios can be simulated. Afterwards the scenarios can be compared and expected results can be checked. MFA can be furthermore used as a support tool in designing of new products and in the selection of new or alternative materials. By doing so, the MFA becomes a standard tool for the design of products and processes and will improve the decisions by engineers or designers. For a full utilization of the features in Umberto, users should participate in the training courses of ifu Hamburg.

Summarized, many advantages to a suitable expenditure can be expected after implementing the developed MFA concept. That's why it's absolutely highly recommended to put this concept into practice.

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11 List of Abbreviations

A/B= Acid and Base

BD = Blu-ray Disc

BD DL = Blu-ray Disc with Dual-Layer

BD SL = Blu-ray Disc with Single-Layer

BDE database= Betriebsdatenerfassung, Factory Data Capture

BDE = Borland Database Engine

BO = Business Objects

CD = Compact Disc

CD-R = Compact Disc-Recordable

CML = Centrum voor Milieukunde Leiden

CMR = cancerogen, mutagen, reprotoxisch

DI Water = Deionised Water

DVD = Digital Versatile Disc

DVD-R = Digital Versatile Disc-Recordable

EMF = Extended Windows Meta File

EMS = Environmental Management System

EU = European Union

FY = Fiscal Year

FY09 = Fiscal Year 2009

g = Gram

GaBi = Ganzheitliche Bilanzierung, Software from PE International

I/O Balance = Input/Output Balance

ISO = International Organization for Standardization

k units = Thousand Units

kg = Kilogram

kJ = Kilojoule

LCA = Life Cycle Assessment

MFA = Material Flow Analysis

ODBC = Open Database Connectivity

PC = Polycarbonate

PCs = Personal Computers

PLM = Product Lifecycle Management

PVC = Polyvinyl Chloride

Qty = Quantity

REACH = Registration, Evaluation, Authorisation and Restriction of Chemicals

SFA = Substance Flow Analysis

Sony DADC = Sony Digital Audio Disc Corporation

SQL = Structured Query Language

STAN = Stoffflussanalyse, free software from TU Wien

t = Tons

TU Graz = University of Technology Graz

TU Wien = University of Technology Wien

UK = United Kingdom

UMD = Universal Media Disc

WMF = Windows Meta File

WW = Waste Water

Appendix

Schedule Diploma Thesis

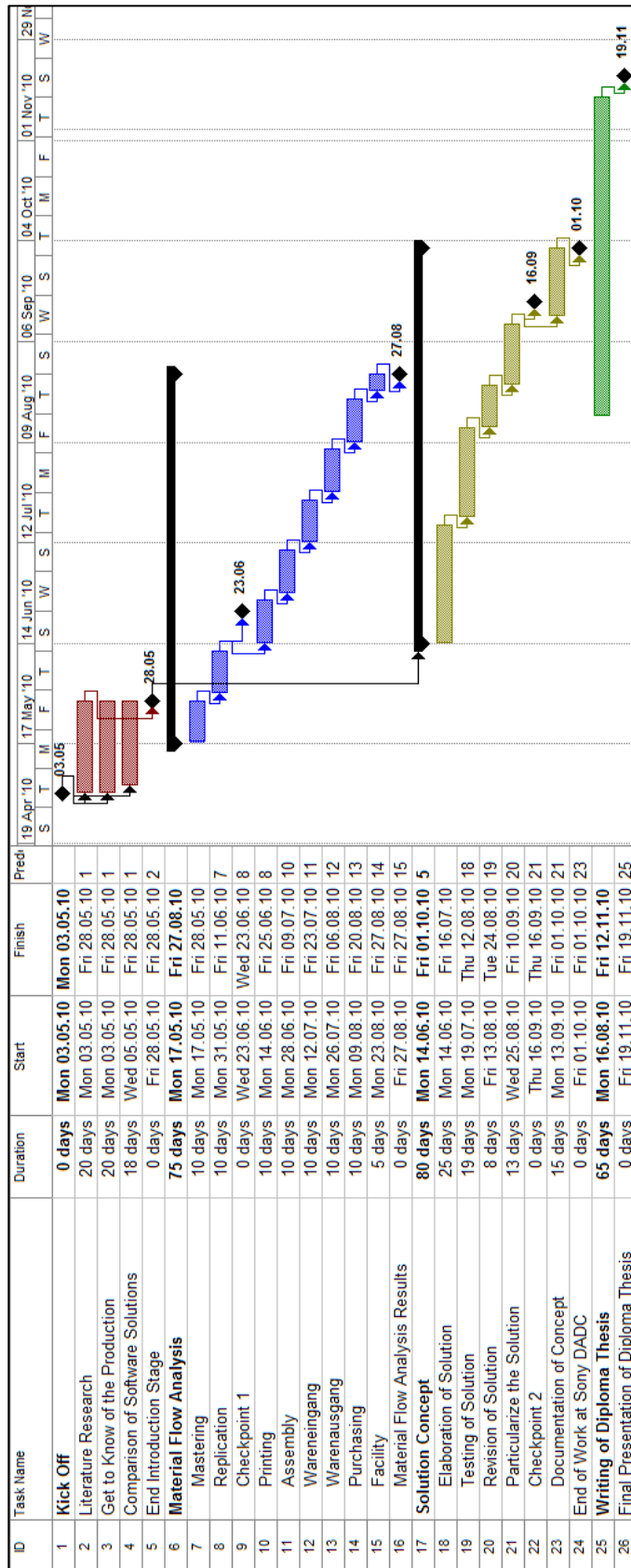


Figure 67: Detailed Schedule of Diploma Thesis

Screenshots to STAN and GaBi

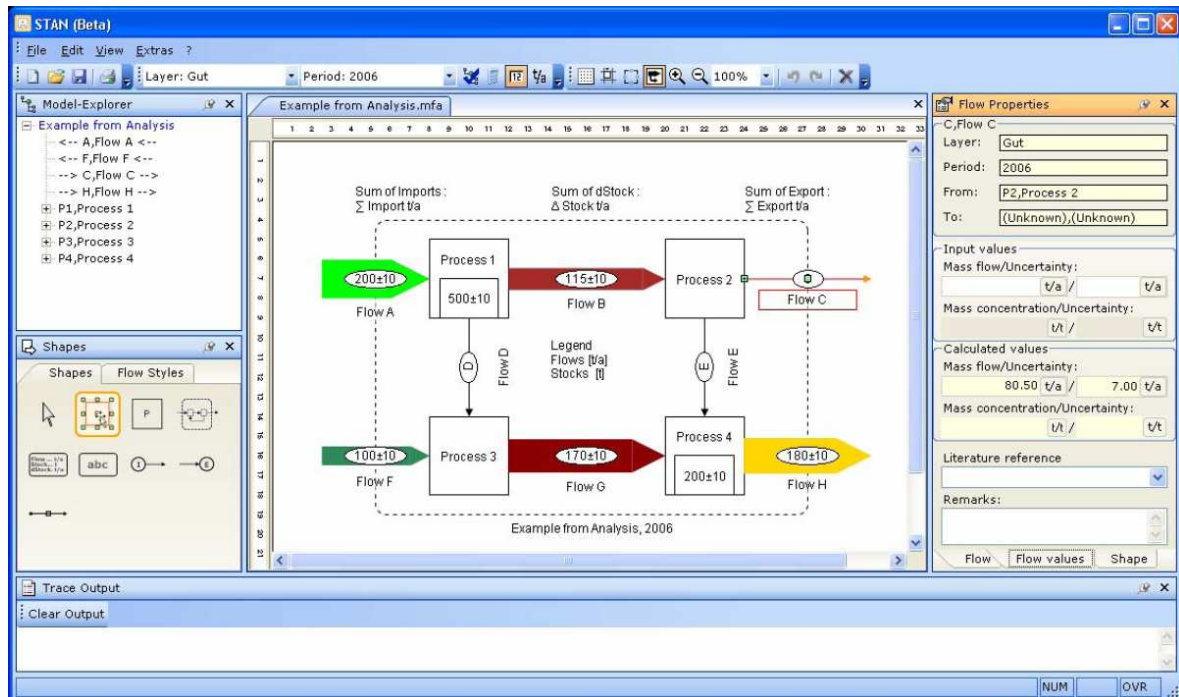


Figure 68: User Interface of STAN⁹⁶

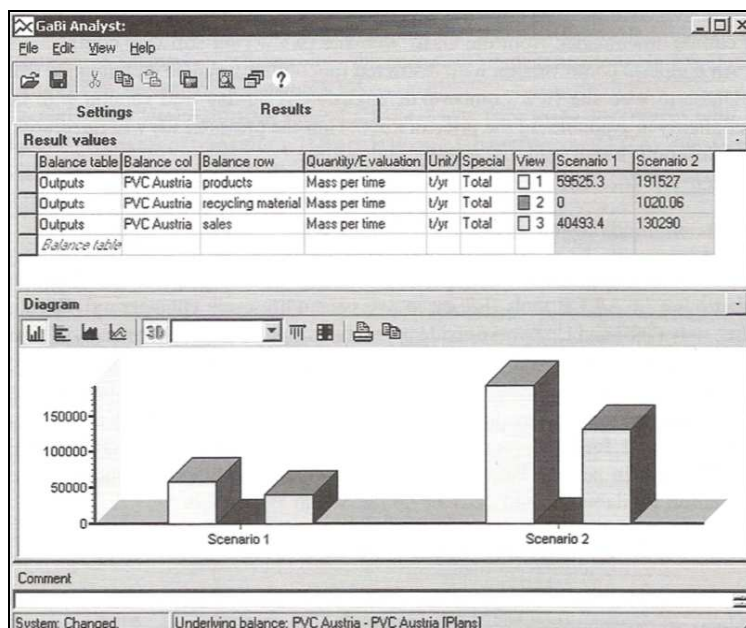


Figure 69: Comparison of Scenarios in GaBi⁹⁷

⁹⁶ Cencic (2010), p. 5

⁹⁷ Brunner and Rechberger (2004), p.131

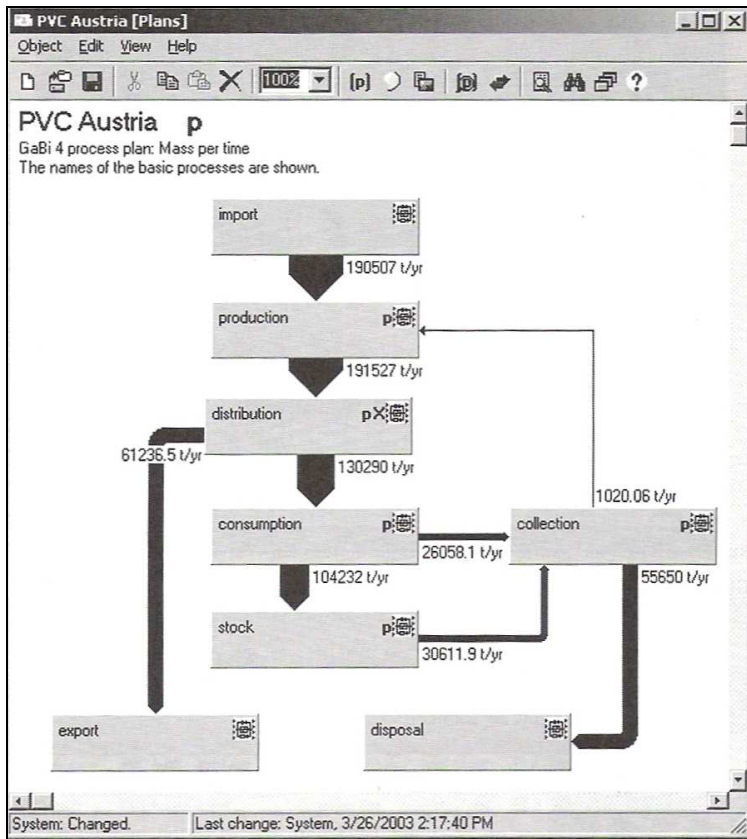


Figure 70: System with Sankey Diagram in GaBi⁹⁸

⁹⁸ Brunner and Rechberger (2004), p.129

Results Material Flow Analysis of Mastering Department

As described in Chapter 4.4, based on the I/O balance various Sankey Diagrams can be created. As further example the DI water consumption of CD/DVD mastering is worked out. Figure 71 gives an overview to the waste water output of CD/DVD mastering. The consumption of DI water and chemicals is resulting in Aluminium waste water, acid and base waste water and Nickel waste water.

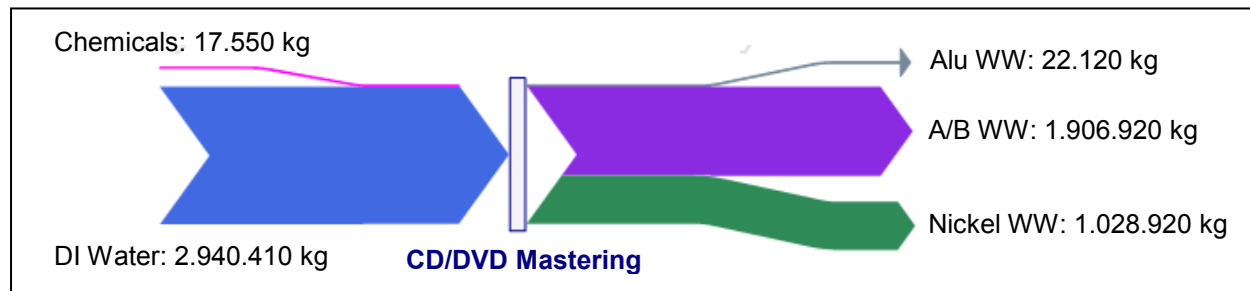


Figure 71: Sankey Diagram CD/DVD Mastering Waste Water Overview

The waste water output can be considered in more detail. More than 1000 m³ DI water was needed for the plating and finishing processes and more than 600 m³ DI water was needed for the glass recycling processes in FY 2009. Especially these three main mastering processes have potential for DI water savings, which gives of course at once potentials for savings in the output of waste water and in chemicals consumption as well. That's why these processes will be investigated closer by the mastering department, primarily the different metal parts washing processes, to exploit this available potential.

Results Material Flow Analysis of Printing Department

The colours are processed efficient in screen print and offset print. But as shown in Figure 72, diverse printing problems lead to a waste of about 2,7% of printed CDs in screen printing and 2,7% in offset printing as well. This is an acceptable number, but there is still room for improvement.

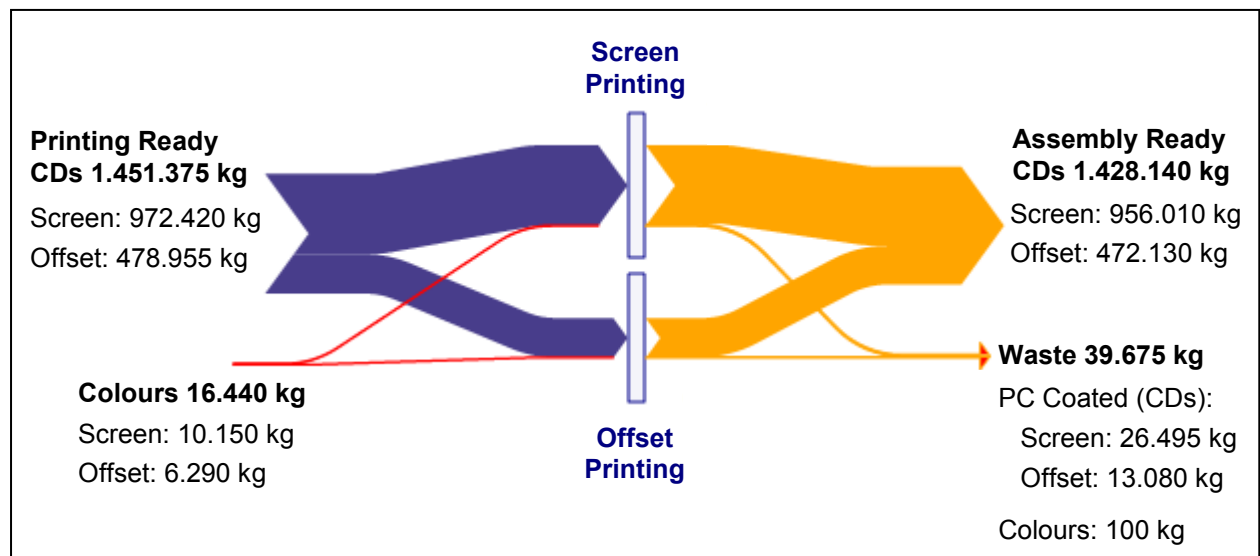


Figure 72: Sankey Diagram CD Printing

The produced waste in offset printing of Blu-ray discs especially of BD DL is above average. This resulted in a polycarbonate waste, which corresponds to more than 6% of printed BD DL had to be disposed. So here clearly improvement potential is offered. For example the DVD offset printing rate is stated with less than 1% loss, which is an excellent rate of course, but this value shows what can be reached. Reason for the gap in the rates is that the different discs contains of different materials. This is why BDs are more sensitive to pollutants which emerge from the offset printing process.

Measures can be the use of alternative lacquers in the replication process of the BDs or an increase of the cleanliness within the offset printing machines.

Sankey Diagrams of the Modelled Material Flow Network in Umberto

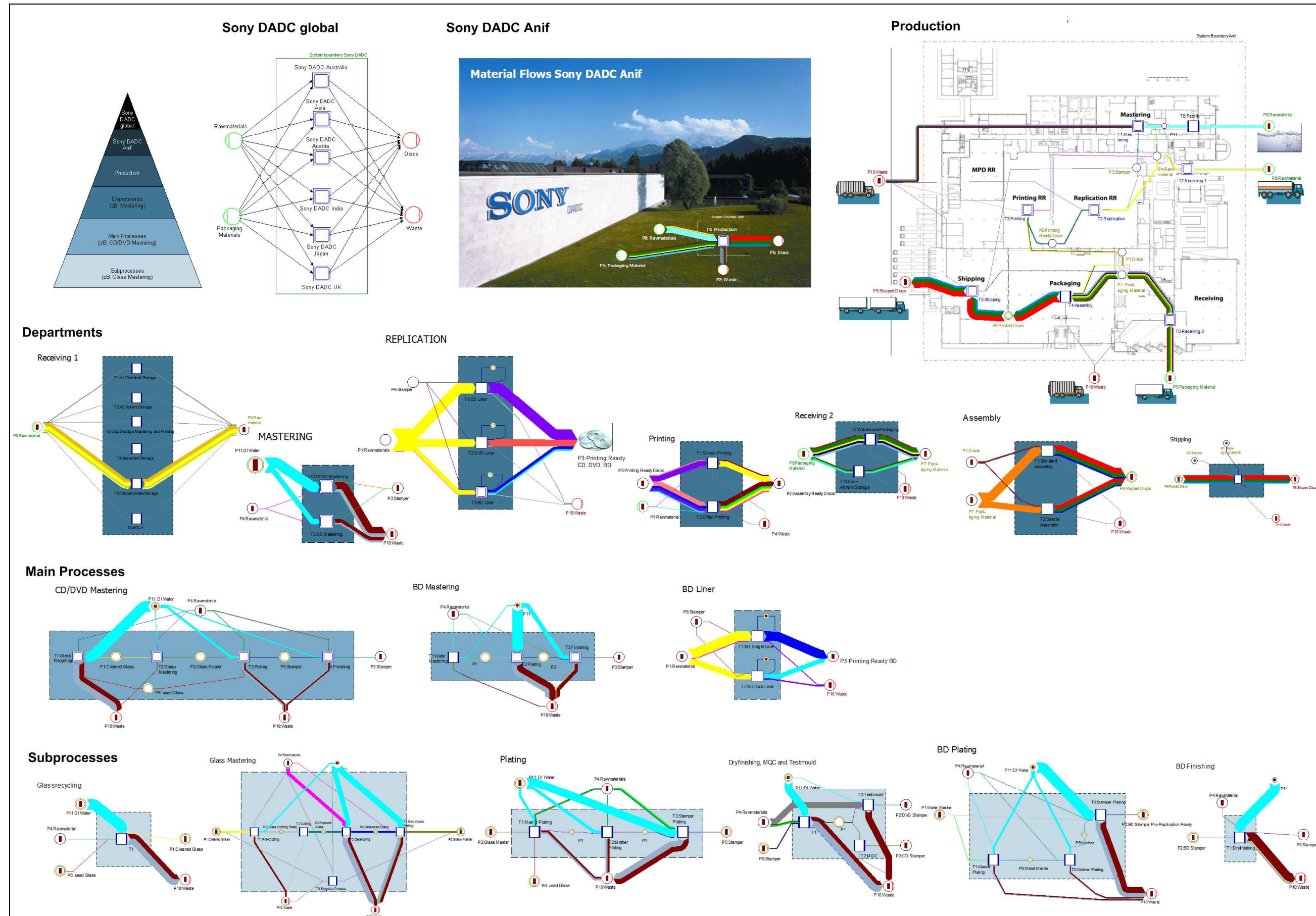


Figure 73: Sankey Diagrams of Sony DADC Anif in Umberto