CRANFIELD UNIVERSITY

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Cost-Reduction of Waste Processing through Manufacturing Knowledge

SCHOOL OF APPLIED SCIENCES

MSc by Research

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Abstract

The rapid transformation of the Waste Management sector has significantly altered the nature of the traditional waste processing business and the nature of competencies required to manage it. With the increase in volume of waste being processed, one element of the transformation of the waste sector, is the move from a craft-industry often with agricultural methods to a post-industrial sector processing high volumes of materials efficiently and effectively. Over the last two centuries the manufacturing sector has also moved from a craft industry to one that learnt how to use technology for material processing, and then learnt how to organise for efficient high-volume production. The application of the coherent techniques developed by various manufacturers (notably Toyota) has resulted in systematic removal of waste (over-production, waiting, transport etc) and cost in manufacturing. These methods are termed ‘lean manufacturing’.

This report describes a project which seeks to test the relevance and value of manufacturing knowledge to waste site operators, by bringing together the expertise and the manufacturing knowledge to waste operators. The industrial aim is to significantly reduce operating costs. It is important to define manufacturing knowledge as that knowledge that specifically relates to lean manufacturing and its implementation.

Firstly, the researcher presents an exhaustive and critical literature review of lean manufacturing. Then waste operators’ current practices in operations management are characterised and their existing access to manufacturing knowledge is described, based on interviews with several waste companies.

The utility of manufacturing knowledge, and any adjustments needed to suit waste operations will be described, focussing on prioritised areas for improvement and specific proposals for changing operations. The potential scale of these changes can be very important and advantageous when we consider that the Japanese car manufacturer, Toyota, used lean manufacturing to show the then world leading Ford how to reduce production costs by 30%.

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Chapter 1

Context of the project

1. Introduction

The origin of those companies involved in Waste Management brings a historically framed set of competences with it. The rapid transformation of the sector has significantly altered the nature of the traditional waste processing business and the nature of competencies required to manage it.

With the increase in volume of waste being processed, one element of the transformation of the waste sector, is the move from a craft-industry often with agricultural methods to a post-industrial sector processing high volumes of materials efficiently and effectively. Over the last two centuries the manufacturing sector has also moved from a craft industry to one that has learnt how to use technology for material processing, and then learnt how to organise for efficient high-volume production. In the latest revolution the mass-production paradigm has been replaced by that of 'lean production'. The application of the coherent techniques developed by various manufacturers (notably Toyota) has resulted in the systematic removal of waste (over-production, waiting, transport etc) and cost in manufacturing. The story of lean production is well documented, bringing a revolution in system effectiveness and efficiency by clearly identifying sources of waste and systematically removing them.

The waste sector is relatively immature at managing material flows, particularly within a facility. Traditional layout, often based on site history, is one cause. A focus on efficient use of a critical technological investment is another. This project suggests that lack of knowledge of what is possible is another contributor. Such knowledge has been slowly developing in the manufacturing sector, with the characterisation of the knowledge a relatively recent activity.

2. Project aim

This project seeks to test the relevance and value of manufacturing knowledge to waste site operators, by bringing together the experts and their knowledge of manufacturing to waste operators. It is important to define manufacturing knowledge as that knowledge that specifically relates to lean manufacturing and its implementation. The industrial aim is to significantly reduce operating costs.

3. Project deliverables

The deliverables set for this project were:

1. **A targeted, critical review** of the application of manufacturing techniques, and especially those of lean production, to waste operations. This would describe the waste operators' current practices in operations management and identify their existing level of manufacturing knowledge.

2. **An adjusted manufacturing knowledge for use in waste operations.** Based on the involvement of waste operators, some parts of manufacturing knowledge will be selected, and possibly adjusted. These are expected to focus on issues of site layout, of material handling and of scheduling, aiming to reduce overall operating cost.

3. **Case studies and results.** The research proposes to work closely with two waste companies (EnvironCom and Biffa). Each site will join in a joint analysis of its current operations using the manufacturing knowledge. The output will be prioritised areas for improvement and specific proposals for changing operations. The case companies will control the implementation of any proposed changes. The effect of the changes will be predicted and monitored.

4. **Communications**, initially via a report and Journal paper, e.g. CIWM Journal, summarising the work. Broader communication of the potential value of manufacturing techniques will be through write up in Sector magazines such as ENDS report, and the Waste2000 series conferences, emphasising case experiences rather than theory.

4. EnvironCom presentation

EnvironCom is “an innovative recycling company bringing high tech vision to the recycling industry. Its facility is fully licensed for the treatment of fridge & WEEE (Waste Electrical and Electronic Equipment). Its mission is to become the leading Pan European R3 provider, leveraging state-of-the-art reuse, recycling and re-marketing services and business information technology in asset management and asset management recovery. EnvironCom intends to be the leading full-service company for recovering and maximising value from the environmentally safe processing of excess, obsolete or end-of-life commercial, industrial and consumer electrical and electronic equipment. EnvironCom has invested in the latest state-of-the-art recycling technology for refrigerators, CRT’s, car bumpers and facia assemblies and has a vision of its current and future sites being used as total recycling centres, where several recycling technologies will be available to customers on demand covering the range of electrical and electronic products under the WEEE directive.” *(Source: EnvironCom, 2005)*

◊ *Facility is licensed for the treatment of:*

- all categories of WEEE considered
- refrigerators, freezers and cold rooms. Domestic and commercial processing and ODS destructions on site
- CRT (monitors and TV’s) which are recycled on site
- all processes managed through the application of wireless PDA data capture and control

◊ *Team*

The EnvironCom team has been drawn from a number of large blue chip companies within the electronics sector who together provide customers with a one stop shop and tailored solutions for all of their recycling problems that fall under the WEEE directive.
The team is composed of around 50 people from different disciplines like supply chain management, logistics management, environmental compliance management, health and safety, marketing, executive management, quality assurance, industrial engineering, process engineering, software, asset management and call centre management.

◊ *Services provided by EnvironCom include:*

- Collection of WEEE
- Treatment of WEEE
- Asset management of WEEE
- Assessment of product – Eco Design (EUP directive implications)
- Comprehensive software and reporting

◊ *Location*

Their initial recycling centre operates from a large site north of Peterborough (Grantham, UK). Its characteristics are as follow:

- Surface: 150K sq ft facility
- Fully licensed for WEEE and Fridge Freezer Recycling
- State of the Art Fridge Freezer Recycling Technology – CFCs handled on site (only site in UK)
- CRT machine and WEEE processing lines installed
- Comprehensive Logistics Network
- Wireless Network
- State of the art IT deployed

The second site is the Headquarters and asset recovery centre of the company in Glasgow (UK). Its characteristics are as follow:

- Surface: 16K sq ft facility
- Fully licensed for IT and Telecoms Recycling
- Secure Data Management to military standards
- Customer Defined Workflow
- Serial Number Tracking
- Comprehensive Logistics Network
- Wireless Network
- State of the art IT deployed – We3

5. Biffa presentation

BIFFA Waste Services is the UK's largest waste and end-of-life resource management company, providing collection, landfill and specific waste services to local authorities and industrial/commercial clients. BIFFA's logistics operation handles 6 million tonnes of domestic, industrial, and commercial solid waste streams, and their landfill division disposes of around 9 million tonnes of similar material each year. Their materials recovery and composting units recover and divert from landfill around one million tonnes per annum (in April 2005).

◊ *Services provided by BIFFA include:*

- Collection of all kinds of waste from light commercial to heavy or bulky types
- Cleaning/industrial services
- Special waste (integrated waste management, treatment technologies, waste water, packaged waste – hazpack, backtrack, Biffa environmental services, forecourt services, offshore services, clinical waste, Biffa environmental technology)
- Landfill services
- Local authority services
- Recycling services (cardboard, compost, fluorescent tubes, glass, office paper)
- Biffa, in collaboration with 2 other companies, has set up the Transform compliance system to offer activity based collection, treatment and processing services to meet the new UK regulations.

◊ *Location*

Biffa operates in around 120 sites throughout all UK. These sites are divided according to their services which are landfill, recycling, collection, municipal and special waste.

6. Methodology

6.1. General project methodology

In this project, the researcher will:

1. Evaluate the level of manufacturing knowledge of waste operators by conducting an exhaustive literature review of manufacturing techniques and compiling a manufacturing questionnaire to assess the knowledge level of waste operators.
2. Identify and adapt if needed, manufacturing knowledge to tackle selected waste operations problems, predicting their effectiveness.
3. Use the manufacturing knowledge in 2 case applications, working with the site operators, and their data, to identify improvements and proposed actions.
4. Predict the impact of the implementation of manufacturing knowledge at the case sites and analyse value of it.
5. Report the findings in a DEFRA research report, MSc thesis, Waste sector magazine and international journal.

6.2. Data collection methodology

There are different methods of collecting data and their use will depend on the type of problem that is faced. Quality and quantity are important factors that have to be taken into account in choosing the method. Before starting this process, the researcher has to decide which type of data is needed and the choice will depend on that decision.

On the one hand, qualitative methods aim to obtain a precise piece of information. For this purpose, direct contact with the people that know about the problem is needed, most commonly by interviews and site visits, etc. The qualitative methods have typically been used to collect data about the manufacturing knowledge of waste operators and as well for the site studies.

On the other hand, quantitative methods focus on acquiring a broad range of data from different sources. That is needed if the research requires opinions from different actors. The way in which this quantitative data is collected is by email, articles on the internet, etc. The quantitative methods will typically be used to get results for the literature review.

Sometimes, a mix of those different methods represents the right decision.

7. Potential risks of the project

The potential risks are mainly linked to the companies. The duration of the project is one year which, though it may seem long enough for this kind of project, is in fact very short if problems begin to arise. Indeed, the project is not only dependent on the researcher's motivation but as well, on the motivation and availability of her partners who are the companies and her supervisor. If all components do not come together at the same time, the researcher will have difficulty in carrying through his project.

8. Report structure

This report consists of 6 main sections which are:

◊ Section 1. Context of the project
◊ Section 2. Literature review
◊ Section 3. Questionnaire and its results
◊ Section 4. Cost reduction of waste processing at a BIFFA site

Chapter 2

Literature review

This chapter will outline the findings based on the literature review, carried out as part of this project through an exhaustive quantitative research in databases, and relevant books, journals, theses and websites. The thesis subject required a double research. The first one was in relation to Lean Manufacturing (and its implementation in "normal" companies). The second research was in relation to manufacturing knowledge of waste companies.

1. Introduction

1.1. History

For U.S Environmental Protection Agency (EPA), "Lean manufacturing is a business model and set of methods that helps eliminate waste (**Muda** in Japanese) while delivering quality products on time and at minimal cost with greater efficiency. It is the systematic elimination of muda from all aspects of an organization's operations, where muda is viewed as any use or loss of resources that does not lead directly to creating the product or service a customer wants when they want it."

It derives from the Toyota Production System, Henry Ford and other predecessors.

- Lean manufacturing goes back to Eli Whitney and the concept of interchangeable parts (1800). For the next 100 years manufacturers developed their system of engineering drawings, modern machine tools were perfected and large scale processes held the centre of attention. Frederick W. Taylor looked at individual workers and work methods. Consequently, Time Study and Standardized Work (*Strategos website*) were invented.

- Then, there was the Manufacturing Strategy of Henry Ford (1910) based on the labour force and the mass production (single, never changing product). Ford is considered by many to be the first practitioner of Lean Manufacturing. After the First World War (1920), customer demand began to change (annual model changes, multiple colours, and options). So, the Ford system began to break down but Henry Ford refused to change the system.

- Then, Japanese industrialists studied Ford production methods. In the 1940s, Vice President, Taichi Ohno, began working on the Toyota Production System (TPS). He recognized the central role of inventory and the importance of respect to employees. Toyota System Production was clearly the opposite of the Mass Production philosophy. Indeed, TPS involved a fundamental shift from conventional "batch and queue" mass production to product-aligned "one-piece flow" pull production. Whereas "batch and queue" involves large high volume production of standardized products with minimal product changeovers based on potential customer demand, a "one-piece flow" system rearranges production activities in a way that processing steps of different types of products are conducted in a continuous flow.

- *The Machine that Changed the World (Womack and al., 1990)* was the first book which high-lights Toyota production methods and which compares them to traditional mass production systems.

	Mass production	**Lean production**
Basis	Henry Ford	Toyota
People-designers	Narrowly skilled professionals	Teams of multi-skilled professionals at all levels in the organization
People-production	Unskilled or semi-skilled professionals	Teams of multi-skilled professionals at all levels in the organization
Equipment	Expensive, single-purpose machines	Semi automated systems which can produce large volumes with large product variety
Production methods	Produce high volumes of standardized products	Make products which the customer has ordered
Organizational philosophy	Hierarchical-management takes responsibility	Value streams using appropriate levels of empowerment-pushing responsibility further down the organization
Philosophy	Aim for 'good enough'	Aim for perfection

Table 1: Summary of the comparisons highlighted (Womack and al., 1990).

Lean Thinking: Banish Waste and Create Wealth in your Organisation (Womack and Jones, 1996), is equally a key book in lean history as it summarizes the lean principles and coins the term 'Lean Manufacturing'.

The lean concept is more than a simple production method. It is a management system rooted in key principles (continuous improvement, respect and involvement of employees), with key objectives (create only value for products, stable long-term growth), supported by methods and tools (Kaizen, Just-in-Time, 5S, standard work, cellular manufacturing, total productive maintenance, etc.).

3 levels of lean thinking *(Lean Thinking, Womack and Jones)* can be distinguished:

- Definition of the product's added value that is created by the company,
- Development of an original management system,
- Development of a characteristic production system.

1.2. Elimination of Muda

Lean manufacturing links performance (productivity, quality) to company flexibility, which must be able to continually improve its processes. Lean manufacturing looks for performance by continuous improvement and the continuous improvement by the elimination of muda. In the article *The Benefits of Lean Manufacturing (Melton, 2005)*, seven different kinds of muda are highlighted:

1. **Overproduction**: Product made for no specific customer (ahead of an order). Development of a product, a process or a manufacturing facility for no additional value.
2. **Waiting:** As people, equipments or products wait to be processed. It is not adding any value to the customer (stock-outs, lot processing delays, equipment downtime, and capacity bottlenecks).
3. **Unnecessary transport of materials**: Moving parts and products unnecessarily. While the product is in motion it is not being processed and therefore not adding value to the customer (transporting work-in-progress long distances, trucking to and from an off-site storage facility).
4. **Over-processing**: When a particular process step (performing unnecessary or incorrect processing) does not add value to the product.

5. **Inventories**: Storage of products, intermediates, raw materials, and so on, all cost money.
6. **Unnecessary movement by employees during their work**: The excessive movement of the people who operate the manufacturing facility is wasteful. While they are in motion they cannot support the processing of the product. Excessive movement of data, decisions and information.
7. **Production of defective parts**: Errors during the process-either requiring re-work or additional work (scrap, rework, replacement production, inspection).

1.3. Three levels of Lean Thinking

1.3.1. Product ADDED Value

The first principle and most important, is to **define the true VALUE** of the product according to customers. Generally, actions on a product are divided in three categories:

- actions "creating value" (represent 5% for most production operations)
- actions "no creating value but which are necessary today" (represent 35% for most production operations)
- "unnecessary" actions (represent 60% for most production operations)

The second principle is to **establish the VALUE STREAM of the product.** Tools useful to evaluate the added value of a product are *value stream mapping* and *process mapping (Lean Thinking, Womack and Jones). Value stream mapping* is a diagram showing the different steps, activities, material flows, communications that are involved with a process or transformation.

1.3.2. Development of original MANAGEMENT system: Kaizen

In the lean model, production methods are based on the principle of continuous improvement called **Kaizen** *(Lean Thinking, Womack and Jones)* in Japanese. The three main objectives of **Kaizen** are elimination of muda, productivity improvement and sustainable continual improvement. For EPA, "this philosophy implies that small, incremental changes routinely applied and sustained over a long period result in significant improvements". Kaizen is based on a suggestion scheme and planned improvement activities made by workers from multiple functions and levels in the organization. They work in teams with a team leader performing a coordinating role in addition to assembly tasks. The team uses techniques, such as *value stream mapping* and *the 5 whys*, to identify opportunities quickly to eliminate muda in a production area. To improve the multi-skilling practices of workers, they follow training and job rotation. This is particularly important because many are assembly workers who have responsibilities in contrast to mass production where responsibilities are given to specialists. This involvement of employees at all levels of the organization has been identified as a driver of improvements in lean manufacturing.

Human resource policies are as important as the technical system in the implementation of lean production. In contrast to mass production, worker commitment, skill, and motivation are critical to operational success. To ensure this, it is important to implement compensations linked to performance, high levels of training and skill development for both new and experienced workers, and efforts to reduce status barriers between managers and workers.

The ultimate goal of lean manufacturing is to get close to perfection. It means trying to completely eliminate all muda so that all activities along a value stream create value. The whole system is maintained in a permanent creative tension which demands concentration.

Kaizen is the overall lean framework of all process improvement methods.

1.3.3. Development of characteristics PRODUCTION system

In Lean Manufacturing, two basic principles of production system apply: **FLOW and PULL**. Indeed, it is important to **assure the FLOW of value stream** without break to fight against "batch and queue". In the **PULL system,** which is the opposite of the traditional push system used in mass production, production does not commit to a delivery until demand for its output is signalled by the consumer.

The first thing to ensure the production is based on flow and pull is to calculate the *Takt time*. It is used to synchronise the production rate with customer demand, and is obtained by dividing the available production time by the demand, a manufacturing system under takt time operates at the specific pace required to meet current demand.

Secondly, one of the important concepts in lean manufacturing is to ensure a flow and pull by using *Just-In-Time (JIT)*, the goal of which is to eliminate muda by cutting unnecessary inventory and removing delays in operations. This concept focuses on reducing inefficiency and unproductive time, and on continuously improving the processes and the quality of the products, based on a policy of employee involvement and inventory reduction. JIT is also regarded as an inventory control system. It is based on the principle that each process should be provided with the right part, in the right quantity, and at exactly the right point of time.

This concept itself is based on sets of tools such as *Heijunka*, *Kanban* and *SMED (Lean Thinking, Womack and Jones).*

- *Heijunka* (or load leveling) is a technique to determine appropriate quantities and types of products needed in a given day to meet customer orders. This prevents batching, thereby minimizing inventory and delays and avoiding making lots of a product one day and zero the next day.

- *Kanban* is a technique determining process production quantities, and in doing so, facilitates JIT production and ordering systems. It uses a small card attached to boxes of parts to signal that more parts are needed from the previous process step. Kanban is used to control work-in-progress (WIP), production, and inventory flow.

- *SMED* (Single Minute Exchange of Die) is a series of techniques to quickly convert a machine to produce a different product type. This tool achieves a quick response to changes in customer demand.

Moreover, to ensure a "one-piece flow" system, it is usually necessary to create a different layout, from the traditional “batch and queue” layout, which is called “*cellular manufacturing*” layout. It is a situation in which products proceed, one complete product at a time, through various operations without interruption, backflow, or scrap. Employees have a view of all the system; it is a challenge to keep the flow running smoothly.

Finally, all these techniques can not be efficient if working conditions are deficient and work is not rigorously standardized.

- *5S* is a technique consisting of five steps (Sort, Set in order, Shine, Standardize, and Sustain), that creates and maintains a clean, neat, and orderly workplace.

- The production team must be cross-skilled. For this, *SOPs (Standard Operation Procedures)* prevent problems in the operational process and make the workers learn new tasks more quickly. The aim is to establish guidelines to exactly define how work should be performed for each activity on the value stream, how long that activity should take, and how much inventory should be maintained to support that activity.

- The machines must be made 100% available and accurate through a series of techniques called *Total Productive Maintenance (TPM).*

- *Jidoka (or Automation)* is the transfer from "human intelligence to automated machinery so machines are able to detect the production of a single defective part and immediately stop themselves and signal for help", from *Lean Thinking (Womack et Jones,1996).* This enables operators to supervise many machines with no risk of producing vast amounts of defective pieces and to concentrate on other value-added works. This technique is closely linked to *poka-yoke* (mistake-proofing device), which is the application of procedures to make mistakes impossible. *Poka-yoke* focuses on prevention and detection.

Finally, *transparency* (or *visual control*) i.e. defined in *Lean Thinking (Womack et Jones, 1996)* as "the placement in plain view of all tools, parts, production activities, and indicators of production system performance" which reinforces standardized procedures and presents the status of the system.

1.4. Implementation of Lean concepts

Why does everybody want to implement lean? Generally, the driving force behind implementing lean is to boost company profits and competitiveness. These efforts have three primary objectives:

- Reduction of production resource requirements and costs,
- Improvement product quality,
- And customer satisfaction.

For Lean Enterprise Institute, the three principal components of a transformation to leanness are:

- Roadmap for a succession of change initiatives that transform operations in the company,
- Transformation of cross-functional infrastructure and processes,
- And cultural transformation.

Steps to implement the Lean concepts can be mapped as below:

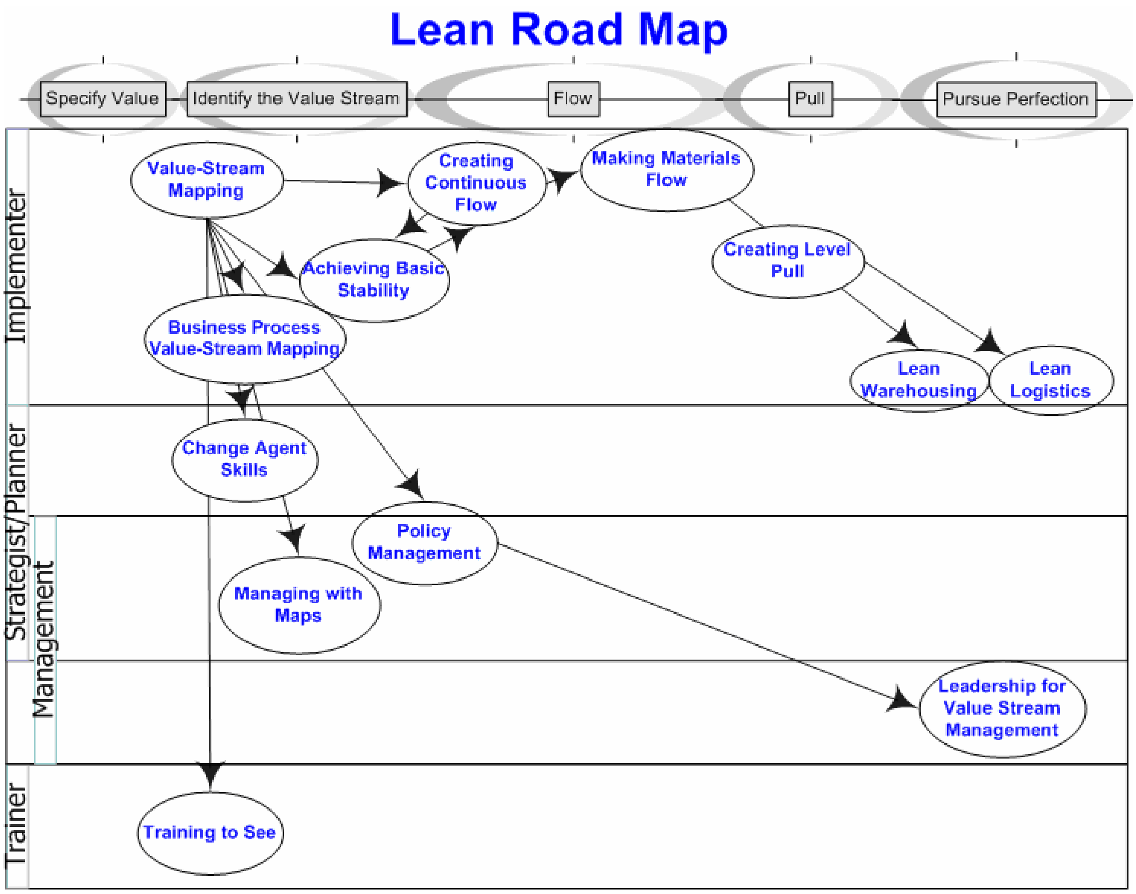

Figure 1: Concrete steps map to implement the Lean principles (Lean Enterprise Institute, 2005).

The five main steps in a lean transformation are in the sections along the top. On the left are the roles that people play in the transformation.

The framework for lean manufacturing implementation is:

- Make changes in accordance with lean principles and company strategy,
- Make the right changes at the right times,

- Evaluate the benefits of lean change initiatives, using performance measures (metrics…).

To convert to a lean company, it is not sufficient to apply lean tools but a real management system is required. For this, there exists a methodology called "Business Process Improvement" (BPI), which is designed to bring about different improvements in the administrative and support processes that support production processes.

From the book *Business Process Improvement (Harrington & James, 1991),* "the BPI efforts start by focusing on defining, understanding, and reducing cost, cycle time, and error rates.

The 3 major objectives:

- Making processes effective (producing the desired results),
- Making processes efficient (minimizing the resources used),
- Making processes adaptable (being able to adapt to changing customer and business needs)."

1.4.1. Five different steps of BPI *(from Business Process Improvement, Harrington & James, 1991)*

Phase 1: Organizing for improvement

Objective: to ensure success by building leadership, understanding and commitment.

The most important point is to build top level commitment and to demonstrate the involvement of top management. Thus, managers do not miss opportunities to deepen their understanding of lean manufacturing.

Activities:

1. Provide a project overview (chief goals, targets and benefits)
2. Provide a project vision and goals
3. Develop a schedule (logical sequence of events with important milestones)
4. Establish a communication plan (everybody has to be informed of the big picture of the implementation, thereby ensuring people are able to provide input and monitor the changes that are occurring)

5. Establish an executive improvement team. A cross-discipline team can “sell” the concept to their peers and ensure full commitment, communication and empowerment.
6. Appoint a lean change agent
7. Provide executive training on lean
8. Review business strategy and customer requirements
9. Select the critical processes
10. Appoint process owners
11. Select the process improvement team members

Phase 2: Understanding the process

Objective: to understand all the dimensions of the current business process.

Firstly, the current state of the company needs to be understood. For this, a well-known tool, v*alue stream mapping*, has to be used. The current state map is useful in revealing muda in the entire value stream and identifying the lean tools that best fit their environment (excessive inventory, large production lead-time). **It is the ideal starting point**. Secondly, once the muda are identified by the current state map, the first version of the future state map can be developed with the help of employees through structured questioning but also by, using a simulation designed to create the ideal future state map. Moreover, simulation provides a means for quantifying the potential gains of lean tools and it can facilitate the decision to implement lean manufacturing.

Activities:

1. Define the process scope and mission (to find out the impact they may have on one other)
2. Define process boundaries
3. Provide team training (use case studies to convince people that the changes will improve the current situation…)
4. Develop a process overview
5. Define customer and business measurements and expectations for the process. It is important that managers focus on the customers instead of focusing on the shareholders, as is usual in companies.
6. Flow diagram the process

7. Collect cost, time and value data
8. Perform process walkthroughs
9. Resolve differences
10. Update process documentation

Phase 3: Streamlining

Objective: to improve the efficiency, effectiveness and adaptability of the business process.

When the principles of lean manufacturing are understood, it is important to move and begin to implement quickly. The more the quick wins are demonstrated, the quicker people will want to do more. One important thing is to make sure they are visible. Therefore, quick results do not mean to focus only on short term goals. On the contrary, managers have to focus on long term without losing sight of short term goals.

Activities:

1. Provide a team training
2. Identify improvement opportunities (errors and rework, high cost, poor quality, long time delays, backlog)
3. Eliminate bureaucracy
4. Eliminate no-value-added activities
5. Simplify the process
6. Reduce process time
7. Error proof the process
8. Upgrade equipment
9. Standardize
10. Automate
11. Document the process
12. Select and train the employees

Phase 4: Measurements and controls

Objective: to control the process for continual improvement.

Metrics and measurements are important aspects of a lean change initiative; they show the progress made.

Activities:

1. Develop process measurements and targets
2. Establish a feedback system
3. Audit the process periodically
4. Establish a poor-quality cost system

The different indicators can relate to "**sales, production and inventory management"** (forecasting, production smoothing, Kanban, supermarket, visual pull signals, standard work-in-process…), **"total organizational buy-in"** (skills training, continuous improvement, team building…), **"total quality management"** (statistical process control, 5S…), "**lean manufacturing techniques"** (value stream mapping, takt-time, SMED…)**, "strategic level critical success factors"** (turnover growth, reduce costs…), **"key business measures"** (total cost reduction, total turnover…).

Phase 5: Continuous improvement

Objective: to implement a continuous improvement process.

Activities:

1. Qualify the process
2. Perform periodic qualification reviews
3. Define and eliminate process problems
4. Evaluate the change impact on the business and on customers
5. Benchmark the process
6. Provide advanced team training

1.4.2. Cultural transformation: a barrier to lean manufacturing?

It would appear that the main barrier to lean manufacturing is the resistance to change. Indeed, because of the implementation of lean, employees have to move from an environment that usually tackled problems by "fire-fighting" to an environment of disciplined sustainability. Moreover, lean, by its nature, and the elimination of muda of motion and transportation, will result in the operators potentially becoming bored with more concentrated, monotonous work and productivity suffering as a result. This can be overcome by rotating operators between processes in the factory; thereby benefiting the operators and therefore the company.

Moreover, it is important to provide continuous training to employees because they are on hand when the crisis situations arise. Workers should take part in the decisions and be encouraged to reflect and to suggest production system improvements.

2. Lean Manufacturing in waste sector

Currently, a lot of waste is produced which can not be completely eliminated. So, it is necessary to put in place waste management systems which are the most sustainable possible. Four levels of sustainability in waste management can be distinguished:

- The first level of sustainability of waste management and the friendliest for our environment is to reduce the production of waste to the minimum consistent with economic sustainability.
- The second level is re-use. Objects are put back into use. They are not part of the waste stream.
- The third level of sustainability of waste management is waste recovery including materials *recycling, composting* and recovery of *energy from waste*.
- The last and the least attractive option for our environment is waste disposal. To make it as sustainable as possible, waste disposal has to be carried out to high standards.

2.1. Waste recovery systems

Waste recovery is a term used to cover all processes by which waste is converted into a usable form or energy. This includes recycling, composting and incineration.

The project case studies are recovery companies specialized in *recycling* and *composting*. Further details about both are listed below.

2.2. Waste Recycling

Recycling (DEFRA and ADEME website) is any method waste processing which results in the production of a usable raw material or product. Recycling has different advantages such as:

- Extension of product life and maximization of the value extracted from raw materials.
- Energy savings because the recycling of secondary materials generally uses less energy than extracting and processing raw materials.
- Disposal reduction.
- Consumer participation through better public awareness and understanding of environmental issues.

Moreover, European directives are continually bringing into force strict controls aimed at minimising waste, and the most common requirement has been to recycle waste.

Sorting operations are at the heart of any waste recycling stream. They are positioned between the collect and treatment operations. The principle of sorting is to transform a mixed waste flow into several waste parts which are recycled and become usable materials.

Waste sorting is composed of manual sorting and also of, automatic sorting (e.g.: magnetic sorting for ferrous metals). Automatic and manual sorting are not opposed. On the contrary, they are complementary in sorting operations.

- Manual sorting is often a prior step to treatment operations (e.g.: disassembling for WEEE).
- Automatic sorting has several aspects including:
    - Replacing of humans. Machines using the same criteria (visual criteria such as form, colour).
    - Doing what humans are unable to do. Machines using specific criteria (visual criteria such as form, colour).
    - Assisting humans in detection. Machines using specific criteria (visual criteria such as form, colour), point out to, operators the detected object (by light beam).

- Assisting humans in handling. Operators detect objects and machines take them off the flow.
- Mechanical sorting is a kind of automatic sorting; it is composed of mechanical operations using the materials' physical characteristics.

The trend is to develop automatic sorting techniques which are more and more varied and high-performing. Currently, WEEE sorting automation is almost non-existent except for shredded products.

2.2.1. Waste arisings and legislation

333 million tonnes of waste were produced in UK in 2002/03. As can be seen from the following table, waste from mining and quarrying represents 30 per cent of total. These are not covered by the EU Waste Framework Directive.

Therefore, controlled waste including demolition and construction, industrial, commercial and household waste are subjected to the EU Waste Directive. Household waste represents 9 per cent of the total produced.

Waste from agriculture and sewage sludge represents less than 1 per cent of the total.

Source	%
Demolition and construction	32
Mining and quarrying	29
Industrial	14
Commercial	11
Household	9
Dredged spoils	5
Agriculture	< 1
Sewage sludge	< 1

Table 2: Estimated total annual waste arising by sector (Source: DEFRA, ODPM, Environment Agency, Water UK, 2005).

Currently, most waste is sent to landfill site. Therefore, 45 per cent of industrial and commercial waste is recycled or composted along with 17% of household waste. Under the EU landfill directive, UK must dramatically reduce the amount of biodegradable municipal waste.

The UK policy is based on several texts including:

- Waste Strategy 2000: national waste strategy for England
- Waste Not Want Not: Cabinet Office's Strategy Unit review of UK waste policy (December 2002)
- Waste Strategy Review: National waste strategy for England
- Review of environmental and health effects of waste management: research reports published May and December 2004
- UK Government response to the European Commission’s Communication: "Towards a thematic strategy on the prevention and recycling of waste"
- Waste and Resources Action Programme: developing markets for recycled materials

The UK legislation and directives are based on several texts including:

- EU Waste Framework
- Electrical and electronic equipment (including WEEE and ROHS directives)
- Waste Oil Directive
- Hazardous Waste
- Packaging, Packaging Waste and the Packaging Waste Regulations
- Landfill directive
- End-of-life vehicles (ELVs)
- Batteries Directive
- Biowaste
- Waste Incineration
- Environmental Protection Act 1990
- Environment Act 1995
- Public participation
- Information on the Waste and Emissions Trading Act 2003
- The Producer Responsibility Obligations (Packaging Waste) Regulations 1997
- The Finance Act and Landfill Tax Regulations 1996
- Waste Minimisation Act 1998

2.2.2. Household waste: arisings

25,4 million tonnes of household waste were produced in UK in 2003/04. For recycling and composting of household waste, the target (set in Waste Strategy 2000) is 25 per cent in 2005/6. Currently, 18 per cent of household waste is collected for recycling and composting. The following table breaks down household waste recycling and composting by material. It shows that composting represents 30 per cent of total arisings.

Materials	%
Compost	30
Paper and cardboard	28
Co-mingled (paper, can, plastics…)	18
Glass	13
Scrap/White goods	10

Table 3: Household waste recycling by material (Source: DEFRA, 2003/4).

2.2.3. Waste electrical and electronic equipment

2.2.3.1. Domestic WEEE arisings and legislation

Currently, many domestic and commercial appliances contain electronic parts. This is partly due to the high rate of technological change in this sector. Consequently, waste electrical and electronic equipment has been identified as producing one of the fastest growing waste streams in the EU, with estimates of 16 kg per person in UK *(Toner, 2002)*. The UK produces about 939,000 tonnes each year of domestic equipment that represents 93 million items of equipment *(ICER, 2003).* It constitutes 4% of municipal waste, increasing by 16% to 28% every five years (3 times as fast as the growth of average municipal waste) and is predicted to reach 12 million tonnes by 2010 in the UK *(Toner, 2002)*.

In the face of this amount of products and finally obviously of waste, the European Waste Electrical and Electronic Equipment (WEEE) Directive was drafted and became

European law in February 2003. It sets collection, recycling and recovery targets for all types of electrical products. The restriction on Hazardous Substances Directive, which accompanies the WEEE Directive, bans the use of heavy metals and brominated fire retardants in the manufacture of electrical and electronic equipment. The Directives must be implemented in European Member states by August 2004. Collection, treatment and financing systems for WEEE must be in place by September 2005 and the first collection and treatment targets are to be attained by December 2006.

The following list shows the arisings of domestic WEEE in the UK in 2003. The different categories of WEEE were defined according to the classification of WEEE in the WEEE directive:

Categories of domestic WEEE	Tonnage discarded ('000 tonnes)		Units discarded (millions)	
Large household appliances	644	69%	14	16%
Small household appliances	80	8%	30	31%
IT/telecoms equipment	68	7%	21	23%
Consumer equipment	120	13%	12	13%
Tools	23	2%	5	5%
Toys, leisure & sports equipment	2	< 1%	2	2%
Lighting	2	< 1%	9	10%
Monitoring & control equipment	< 1	< 1%	< 1	< 1%
Total domestic WEEE	939	100%	93	100%

Table 4: Arisings of domestic WEEE in the UK in 2003 (Source: ICER, 2005).

The main component of electronic equipment waste is large household appliances (70% by weight are washing machines, fridges/freezers and cookers), which make up 69% of the total weight.

The WEEE directive imposes on the Members States the requirement to recycle 50-75% of waste electrical and electronic equipment by 2006 and to recover value from between 70-80% of waste electrical and electronic equipment by 2006. Currently, the only types of domestic WEEE being recycled on a large scale are in the large household appliance category (refrigeration equipment, large white goods and microwave ovens).

Refrigeration equipment is required to be separately collected for recycling because of the ODS Regulation which came into force in January 2002. Other types of large household appliances are recycled because they have a positive scrap metal value. For these reasons it is estimated that nearly all waste large household appliances already enter a recycling process.

2.2.3.2. Characteristics of WEEE

There are more and more waste electric and electronic products and they need to be recycled because all materials going into these products are potential resources (metals, plastics…). One of the major problems of WEEE is that they consist of an important number of components which are heterogeneous and complex in terms of shapes, sizes, materials etc. So, among all these different kinds of WEEE, valuable materials and hazardous substances have to be identified and quantified to ensure an environmental friendly and cost effective recycling system.

a. Hazardous substances and components

Generally, WEEE contain hazardous components. Because they are unfriendly for our environment, they need to be removed by separate treatment. Examples of hazardous materials and components were listed in the following table:

Materials and components	Description
Batteries	Heavy metals such as lead, mercury and cadmium are present in batteries
Cathode ray tubes (CRTs)	Lead in the cone glass and fluorescent coating over the inside if panel glass
Mercury containing components (e.g. switches)	Mercury is used in thermostats, sensors, relays and switches (e.g on printed boards and in measuring equipment and discharge lamps); it is also used in medical equipment, data transmission, telecommunication, and mobile phones
Asbestos waste	Asbestos waste has to be treated selectively
Toner cartridges, liquid and pasty, as well as color toner	Toner and toner cartridges have to be removed from any separately collected WEEE
Printed circuits boards	In printed circuit boards, cadmium occurs in certain components, such as SMD chip resistors, infrared detectors and semiconductors
Polychlorinated biphenyl (PCB) containing capacitors	PCB-containing capacitors have to be removed for safe destruction
Liquid crystal displays (LCDs)	LCDs of a surface greater them 100cm^2 have to be removed from WEEE
Plastics containing halogenated flame retardants	During incineration/combustion of the plastics halogenated flame retardants can produce toxic components
Equipment containing CRC HCFC or HFCs	CFCs present in the foam and the refrigerating circuit must be properly extracted and destroyed or recycled
Gas discharge lamps	Mercury has to be removed

Table 5: Major hazardous components in WEEE (Cui,Forssberg, 2003).

b. Materials composition

Domestic WEEE (excluding large household appliances) is composed of the following materials:

Materials	% weight
Metals	49
Plastics	33
Cathode-ray tube	12
Bois	5
Others	1

Table 6: Average materials composition of household WEEE (Source: ADEME, 2005).

Categories of domestic WEEE	Ferrous metals	Non ferrous metals	Glass	Plastics	Others
Large household appliances	61%	7%	3%	9%	21%
Small household appliances	19%	1%	0%	48%	32%
IT	43%	0%	4%	30%	20%
Telecoms equipment	13%	7%	0%	74%	6%
Consumer equipment	11%	2%	35%	31%	22%
Lighting	2%	2%	89%	3%	3%

Table 7: Average materials composition of household WEEE (Source: ECOTIC, 2005).

2.2.3.3. Costs of treating and recycling domestic WEEE

The costs of treatment and recycling are affected by a number of factors such as:

- where treatment facilities are located
- the degree of sorting required
- the amount of manual labour required to dismantle equipment
- how much processing is required before the resulting material streams can be recycled
- the material composition of equipment entering a treatment facility
- the market value of the resulting material streams
- technology required to add value, e.g. to plastics streams

The costs of treatment and recycling will vary considerably for different groups of equipment as shown in the following tables:

WEEE groupings for separate collection	Estimated costs
Refrigeration equipment	£5 per unit
LHA excl. refrigeration, heating & air treatment	+/- depending on treatment required
Equipment containing CRTs	Average £7 per unit
Lighting	30 – 40 pence per unit
All other WEEE	£100 - £200 per tonne

Table 8: Estimated unit costs of treating and recycling domestic WEEE (Source: ICER, 2005).

WEEE groupings for separate collection	Units/tonnage requiring treatment/recycling	Estimated costs £million
Refrigeration equipment	2,652,400	13,3
LHA excl. refrigeration, heating & air treatment		+/- depending on treatment required
Equipment containing CRTs	4,101,000	28,7
Lighting	1,800,000	0,5 - 0,7
All other WEEE	205,000 tonnes	20,5 – 41,0
Total excl LHA		63,0 - 83,7

Table 9: Estimated total costs of treating and recycling domestic WEEE (Source: ICER, 2005).

NB: The estimates of tables 4 and 5, exclude the costs of transporting equipment between a designated collection facility and a treatment operator.

2.2.3.4. WEEE recycling methods

3 main steps in WEEE recycling can be distinguished:

- Pre-treatment: step which requires a dismantling of hazardous components;
- Treatment: processes used to recover and separate desirable materials;
- Refining: in this step, recovered materials are refined and become again raw materials.

Currently, there are four methods to treat the products:

- Disassembly (dismantling) to:
  - the reuse of components
  - the dismantling of hazardous components
  - recover valuable components and high grade materials (printed circuit boards, cables, plastics…);
- Mechanical recycling: mechanical/physical processes are used to recover desirable materials;
- Incineration and refining to recover metals;
- Chemical recycling for the precious metals (gold, silver) of circuits' board.

Currently, WEEE sorting automation is almost non-existent except for shredded products (white goods: freezers, washing machines…) and the disassembly of brown goods (e.g. TVs, computers…) is still very costly. So, it would be very important to develop a mechanical recycling process for this kind of product which though they do not metal, contain much plastic.

a. Disassembly

One of the most important stages in product life is the product recovery (or end-of-life) which can be remanufacturing, re-use or recycling. Recycling often requires disassembly, notably for the WEEE. Disassembly may be defined as a method for separating a product into different parts. It is the opposite of assembly.

The following figure shows the current disassembly process which is used in a WEEE recycling plant:

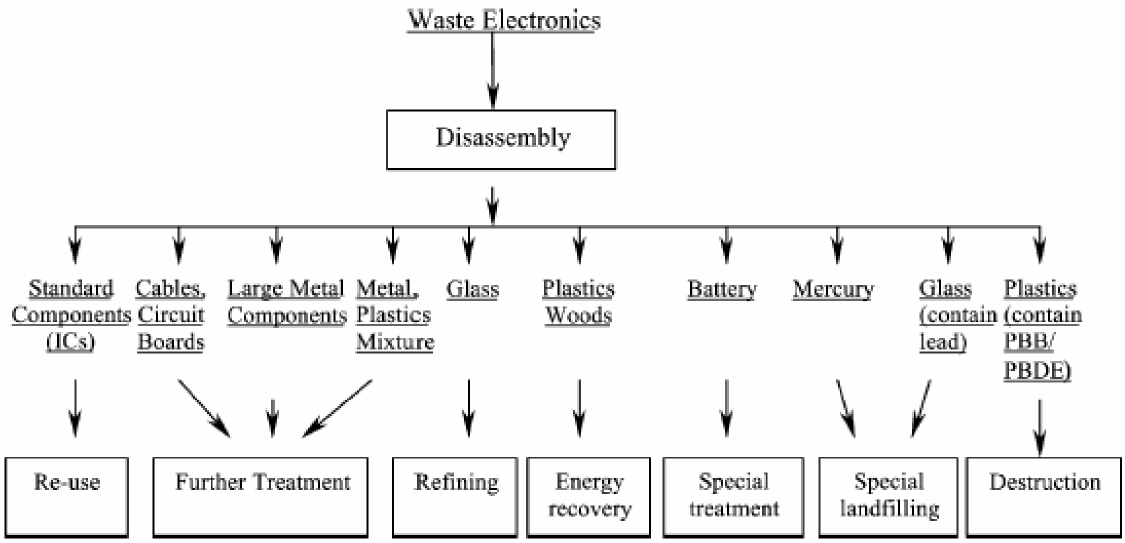

Figure 2: Recycling process developed by Ragn-Sells Elektronikåtervinning AB.

Disassembly and assembly differ in many points and the approaches to solve problems are very different.

These following differences between assembly and disassembly can be distinguished:

- **Demand sources**

In assembly, all components tend to converge to a single demand source (final product) whereas in disassembly, parts move from the product state to their original sources (components). In the disassembly case, each component item constitutes a potential source of demand which is challenging to manage because they are too numerous. So, they are combined to share the same procurement source.
The convergence principle in assembly is opposed to the divergence principle in disassembly.

- **Market dynamic**

Another difference which differentiates Manufacturing and De-manufacturing is their respective position in the market. Indeed, while Manufacturing follows the pull system, De-manufacturing has to involve simultaneously a service company and a seller of components and materials. In de-manufacturing, it is hard to predict the market demand for disassembled components and materials. The result is a major difference between manufacturing and de-manufacturing in planning and controlling the "processing".

Indeed, in disassembly, it is not necessary to decide which products are needed and when, as in manufacturing, but simply which types of discarded products are to be disassembled. The demand for products stemming from disassembly is practically unplanned. The function of levelling processing in de-manufacturing is not aimed at meeting customer deadlines but only at ensuring high utilization and low storage costs.

- **Product variety**

In de-manufacturing, a difficult problem is managing the enormous variety of products to be disassembled, as well as the uncertainty as to their quantity and properties. The variety results from a broad range of products which come from different manufacturers. The fluctuating number of products for disassembly results from the place of use as well as alternative disposal technologies.

- **Operation times**

In de-manufacturing, the variation of operation times is much greater than in production, and the establishment of standard times is difficult to put in place because of uncertainties regarding the variety of products. Consequently, it is difficult to create workplans.

- **Capacity requirements**

The capacity requirements are highly variable. This variety of discarded products involves small lot sizes and a greater variety of necessary disassembly processes and machinery.

- **Disassembly cost**

The disassembly with the optimum cost is the one which maintains profitability and at the same time minimizes the damage to the environment. Even though complete disassembly is beneficial for the environment, its cost is too high. So, it is important to find a balance between the resources invested in the disassembly process and the return realised from it.

- **Disassembly efficiency**

Disassembly planning is determined by which discarded products are to be disassembled. This depends on the technological possibilities, market prices and service requirements of the customer. A typical scenario of a disassembly system is:

- In the disassembly facility, various types of products are sorted into families of products based on the percentages of common components.
- Each family of products is disassembled in a separate cell.
- All parts of interest are disconnected and then, recovered or recycled.

- **Storage/Utilization/Delivery**

There is a continual conflict between the interests of the customer and those of the company. The customer (before treatment) wants short delivery times with an appropriate price and quality. On the other hand, the company aims at a high utilization and low inventories in order to minimize the amount of capital tied up. Due to the low value of discarded products, the amount of capital tied up in recycling does not play an important role. However, due to the high volumes of discarded products and disassembled components and materials, storage costs can be important. As de-manufacturing is at the moment not performed on demand, the market objective of short delivery times is at present of lower importance. Instead, low disposal costs for customers (after treatment), and a high quality and delivery performance for disassembled components and materials are decisive market requirements.

The objective of a high utilization of the equipment is equally important in manufacturing and de-manufacturing.

The highlighted differences can be summarized in the next table:

	System characteristics	Manufacturing	De-manufacturing
MARKET	Demand sources	Converge to Single	Diverge to Multiple
	Market position	Seller	Seller & Service Company
	Market demand	Predictable	Hard to predict
	Demand	Dependent	Low
	Delivery time	Short	No importance
	Delivery Performance	High	High
	Disposal Cost	-	Low
	Price	Appropriate	Low/Unpredictable
	Quality	Appropriate	High
COMPANY	Machine utilization	High	High
	Value of products/ intermediates/raw materials or discarded products	High	Low
	Inventories	Low	No importance
	Storage cost	Low	Low
	Products variety	Normal	Enormous
	Operation times	Predictable	Hard to predict

Table 10: Comparison of manufacturing and de-manufacturing.

Disassembly plays a key role in de-manufacturing. Due to the low added value in disassembly, if the disassembly company wants high profitability, it is necessary to ensure a high utilization of resources. It seems obvious there is a need to develop new techniques and methodologies to specifically address disassembly process planning. Therefore, applicability of traditional production planning and scheduling methods to product recovery systems is very limited due to the previously highlighted differences.

b. Mechanical processing: separation and reduction techniques

WEEE recycling equipment and technologies include compactors, shredders, grinders, chippers, granulators, magnetic drum separator, overband separator and cryogrinding.

2.3. Waste Composting

Waste composting is the production of a granular material containing valuable plant nutrients thanks to the aerobic processing of biologically degradable organic wastes. When compost is added to soil, it results in improved soil structure and enriches the nutrient content of the soil.

2.3.1. Arisings and composting legislation

29 million tonnes of household waste are produced in UK each year. From the Environment Agency, 60% of these 29 million tonnes were biodegradable in 1995 (or 17.4 million tonnes).

So, there is significant potential for producing more compost in UK. Indeed, it would be possible to reduce the quantity of household waste by half if households composted their own kitchen vegetable and garden waste.

2.4. Problems and Opportunities

Peter Jones, Director of Development and External Relations at BIFFA, said:" To meet the UK's needs the waste management industry is fast progressing from a low-tech fairly inexpensive industry to high-tech big business…". Obviously, it can be imagined that this important change of company nature is going to have different consequences for the Waste and Secondary Resources Sector. To identify opportunities and problems for the Waste Sector organisations in the coming 5 years, a survey was made by the Chartered Institution of Wastes Management of 315 companies, of which 71 organisations responded. For these companies, the 3 most important opportunities are new legislation, the full compliance and changes to existing laws and the application of more recycling.

Chapter 3

Questionnaire and its results

In the previous chapter, it has been noted that the literature on manufacturing knowledge in waste companies is almost nonexistent. One of the project objectives was to evaluate the level of manufacturing knowledge of waste companies. To reach this objective, a questionnaire was used.

1. Questionnaire design

In order to get maximum information from the interviewed waste companies about their manufacturing knowledge, an exhaustive questionnaire was compiled (See Appendix A) investigating 11 key areas including:

1. Market
2. Materials
3. Flow & Layout & Handling & Logistics
4. Maintenance
5. Setups & WIP (Work-In-Progress)
6. Quality
7. Scheduling & Control
8. Strategy
9. Management Team Approach
10. Detection of 7 Muda
11. Lean Manufacturing

- Areas 1 and 2 are factual questions present in any questionnaire for companies. The first area, market area, investigates turnover, profits, regulations which influence the company, customers before treatment (who? how many? frequency delivery?), customers after treatment (who? how many? frequency delivery?), suppliers (what is supplied?).

The second area, materials area, concerns waste (or input materials) and products (or output materials). It explores the nature of waste, the quantity of input waste, the different kinds of waste contained in input and the different kinds of products contained in output.

- Areas from 3 to 9 were compiled in relation to the literature review of lean manufacturing. Lean manufacturing is the systematic elimination of muda from all aspects of an organization's operations and product operations which do not add value for the customer. Consequently, different operations were identified in relation to flow & layout & handling & logistics (area 3), maintenance (area 4), setups & WIP (area 5), quality (area 6), scheduling & control (area 7), strategy (area 8) and management team approach (area 9).

- Area 3, flow & layout & handling & logistics area, investigates the portion of total space which is used for storage and material handling, the portion of the plant space which is organized by function or process type, the characteristics of material handling (load, distance, flow pattern) and the rate of overall housekeeping and appearance of the plant. In relation to logistics, the objective was to discover if the company has changed its transport arrangements to improve performance.

- The maintenance (area 4) questions ask if the company has got equipment records and data, if it follows a defined preventive maintenance schedule, if equipment breakdowns after limit or interrupt production, what the overall average availability of plant equipment is.

- Area 5, setups and work-in-progress area, explores the equipment characteristics (expensive/cheap, automated/manual, single/multiple purpose), the number of machines, which one causes bottlenecks, what the average overall setup time for major equipment is, what the lead time is, what the added value time is.

- In relation to quality (area 6), it was aimed to learn if the company has a quality monitoring system, if it uses a statistical process control, how much the amount of scrap from process (failed operations) is.

- The scheduling and control (area 7) questions attempt to discover what portion of work-in-progress flows directly from one operation to the next without intermediate storage, what portion of work-in-progress is under Kanban or similar control, what the on-time delivery performance is, how the company manages variation in throughput volumes (by scheduling inputs, scheduling machines, scheduling labour, keeping enough raw materials available to fill any delivery gaps), if there is a variation in your process times.

- The strategy questions (area 8), concerns the key business drivers and which factors influence the company is success.

- The management team approach (area 9) questions concern the extent to which managers and workers are measured and judged on setup performance/output/input/finance/other strategy, if the company changes its methods to improve labour efficiency, what the typical skills level of people in production is, what kind of organizational philosophy is in the company, what kind of organization is in the company (directive/bureaucratic/consultative/participative), how workers on the factory floor are remunerated (individual incentive/weekly wage/work group incentive/salary/annual bonus), to what extent people have job security, what the annual personnel turnover is, what percentage of personnel have received at least 8h of teambuilding training, what percentage of personnel are active members of formal work teams, quality teams or problem-solving teams.

- Area 10, the detection of 7 muda area, asks questions about the seven different kinds of muda in order to highlight them. They include questions about overproduction (extent of warehouse space, development and production organization imbalance …), waiting (large amount of work in progress…), transport (movement of pallets of intermediate products…), inventory (large buffer stocks…), overprocessing (in-process controls which never show a failure…), and motion (large teams of operators moving…), and defects (missed or late orders, excessive overtime…).
- Finally, in area 11, the company has to answer some questions making use of a "lean manufacturing" presentation. This last area is used to conclude the questionnaire and to

investigate what are the key concepts that might interest the company, what are the main things the company remembers, if they think there is any value to a waste business in using lean techniques, where the greatest opportunity to improve is and what operational problems the company thinks that waste businesses currently experience.

2. Assessment and maps

After interviewing 8 companies, the questionnaires results were used to assess the 11 key areas for each company and then, having gathered all data, a map was drawn of the manufacturing knowledge state of waste companies. (See Appendix B)

2.1. Companies assessment

To compare the questionnaires results, it has been decided to assign a mark (0, 1, 2, 3, 4) out of 4 for each answer. For instance, taking into account the question "What portion of total space is used for storage and material handling (%)?", according to the answered percentage, a mark was assigned (answered percentage: 0-15% = 4; 16-30% = 3; 31-45% = 2; 46-70% = 1; 71 – 100% = 0). Another example, taking into account the question "How would you rate overall housekeeping and appearance of the plant?", according to the answer, a mark was assigned (messy & filthy = 0; occasional mess & some dirt = 2; neat & tidy = 4).

For the assessment, only the answers from areas 3 to 10 were taken into account. Indeed, areas 1, 2 and 11 have not got information which can be marked. After marking each areas question, a total was calculated for each area and for each company.

Example: for area 3, there are 6 questions which are marked out of 4. So, each company can get 24 points as maximum for this area. The same thing was done for the other areas.

8 companies were marked but only three companies were taken into consideration, they represent the different kind of wastes:

- company C1: the *composting plant* of DONARBON;
- company C2: the *WEEE company*, ENVIRONCOM;
- company C3: the *general waste company*: SHANKS.

In the following table, the different areas' points for each company can be seen. These points represent their current ability in each area. It has been noted that only areas 3 to 9 have been taken into account.

Maximum points total by area | Points by area and by company. | % by area and by company.

AREA	Number of questions	Total points	Area Points C1	Area % C1	Area Points C2	Area % C2	Area Points C3	Area % C3	Area Points C4	Area % C4
3.Flow & Layout & Handling & Logistics (6)	6	24	9	38%	8	33%	11	46%	15	63%
4. Maintenance (4)	4	16	8	50%	10	63%	8	50%	13	81%
5. Setups & WIP (2)	2	8	0	0%	1	13%	1	13%	4	50%
6. Quality (3)	3	12	6	50%	6	50%	5	42%	5	42%
7. Scheduling & control (3)	3	12	8	67%	5	42%	8	67%	8	67%
9. Management (9)	10	36	9	25%	9	25%	24	67%	20	56%
Total points (for 6 areas)	28	108	40		39		57		65	

Table 11: Current ability by area for each company.

To assess area 10, the answers have also been assigned a mark between 0 and 4. Therefore in this case, 0 represents a very good score and 4 a poor score, an area to improve.

Maximum points total by area | Points by area and by company. | % by area and by company.

Muda	Total points	Area Points C1	Area % C1	Area Points C2	Area % C2	Area Points C3	Area % C3	Area Points C4	Area % C4
Overproduction	4	0	0%	0	0%	1	25%	2	50%
Waiting	4	4	100%	0	0%	4	100%	4	100%
Transport	4	4	100%	2	50%	4	100%	4	100%
Inventory	4	0	0%	0	0%	0	0%	4	100%
Overprocessing	4	1	25%	3	75%	4	100%	4	100%
Motion	4	4	100%	0	0%	2	50%	2	50%
Defects	4	3	75%	0	0%	2	50%	0	0%

Table 12: Areas to improve for each company.

2.2. Companies maps

After having gathered all the data in both tables, these data needed to be depicted by two graphs. Both graphs allow the different problems for each company to be identified quickly.

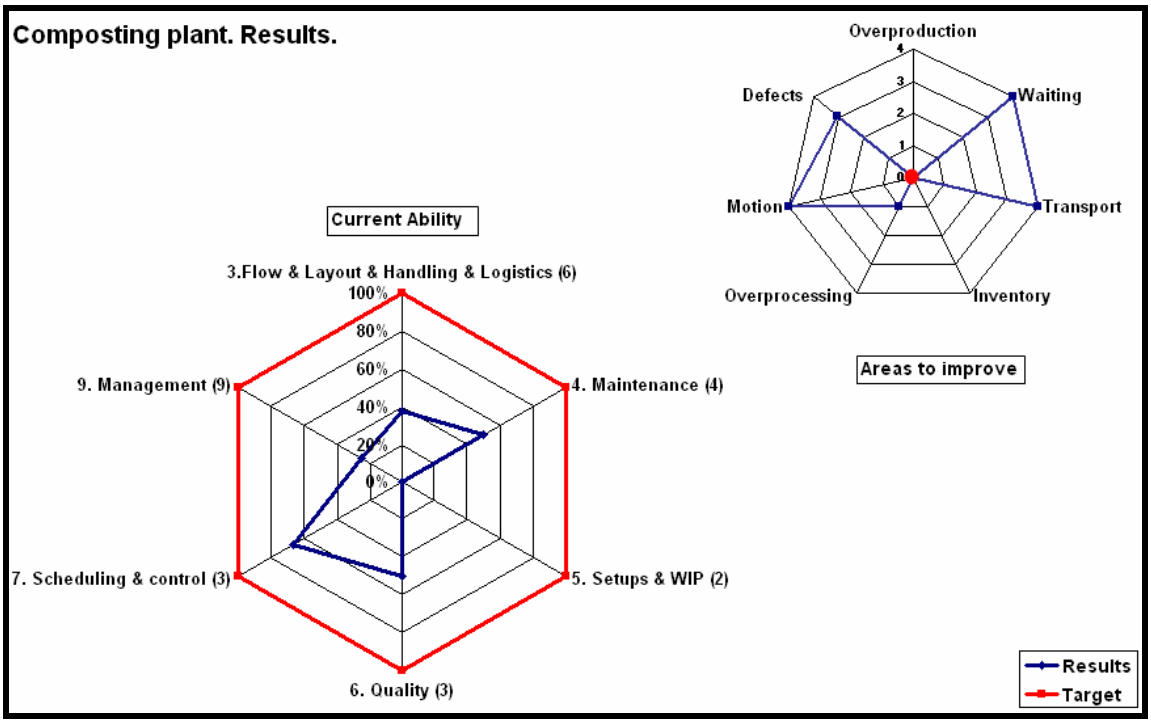

Figure 3: Graphs representing the current ability of each company (key areas 3 to 9) and areas to improve for each company (key area 10).

3. Review of manufacturing system of a composting plant

3.1. INPUT wastes: treated products and processing capacities

Donarbon is licensed for the treatment of biodegradable wastes including:

- green/garden waste
- catering waste
- commercial growers waste
- paper and cardboard

Donarbon treat wastes which come from councils and small independent businesses (e.g. landscapers).

3.2. Treatment processes

After having been collected from people’s homes and recycling centres, organic wastes can be treated in a composting facility. There are two different kinds of composting plant, one which treats wastes containing food and the other without food in it.

3.2.1. In Vessel composting

All waste containing food has to be treated within 24 hours. Their storage is impossible because of the regulations of Environmental Agency. It is treated in an In-Vessel composting plant. It is an enclosed facility where oxygen and temperature levels are monitored and managed to ensure that the waste is sanitised and odours are contained.

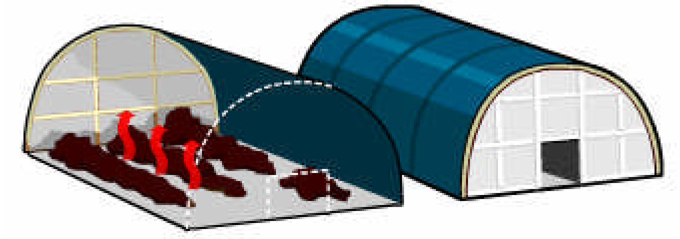

Figure 4: In Vessel composting plant (Sita, 2005).

After being shredded, water is added to the organic waste and they are mixed. The mixture goes directly into first barrier composting where a temperature of 60°C must be maintained for two consecutive days. Then, the mixture goes into a second barrier composting to achieve again at a temperature of 60°C for 2 consecutive days. After that, the waste is formed into windrows (toblerone shaped heaps) for maturation. They are turned every week for 6 to 10 weeks. The end-result is compost.

3.2.2. Open windrow composting

All other waste which does not contain food is treated in an Open Windrow composting plant. This consists of a series of open-air windrows.

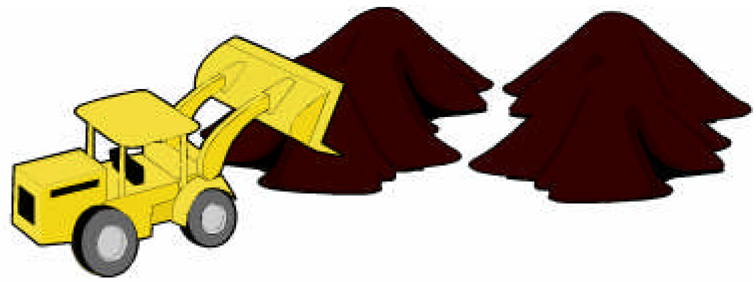

Figure 5: Open windrow composting plant (Sita, 2005).

First, the input waste is checked for quality. Then, it is shredded and formed into windrows. They are turned every week for 14 weeks. The end-result is compost.

3.3. OUTPUT wastes

Once all the waste is treated and processed and the compost is ready, it can be sent for use in landscaping, garden centres and agriculture.

3.4. Manufacturing problems

- **Overprocessing and lead time**

The treatment duration to get compost is regulated. In total, the organic waste has to stay 4 days in two different barriers. This means, composting plants have to be very well organized and have to plan and optimize the use of their barriers to be sure they are always filled . Even though this is well understood it is not always done. It would be very interesting to study how the organic waste is managed from the moment it enters the facility to the moment it leaves. If the organic waste is not processed as soon as there is an empty barrier, it means it needs to be stored, which increases material handling so there is an added cost.

- **Skills of workers**

Currently, composting plants employ unskilled workers. Only the managers are skilled.

- **Highlighting of 7 muda**

The first step in the lean manufacturing process is the detection of the 7 muda (overproduction, waiting, transport, inventory, overprocessing, motion, defects). The questionnaire included, for each of theses muda some examples of their consequences (e.g. if a company needs to extend its warehouse space and uses it, it means there is an overproduction waste). So, it has been tried to find some examples of the consequences of each kind of muda that would lead identifying some muda.

For the composting plant, 4 muda were detected: waiting (large amount of work in progress...), transport (movement of pallets of intermediate products…), motion (large teams of operators moving...), and defects (missed or late orders, excessive overtime…).

- **Results of the questionnaire**

In part 3 of this report, the way to assess the manufacturing knowledge of the different companies was described. It has been decided to use 2 graphs to highlight the waste companies' problems. If a composting plant like Donarbon is considered, it was very quick to conclude by referring to the following graphs:

- its current ability in each area (flow & layout & handling & logistics, maintenance, setups & WIP, quality, scheduling & control, management),
- the different muda present in this company.

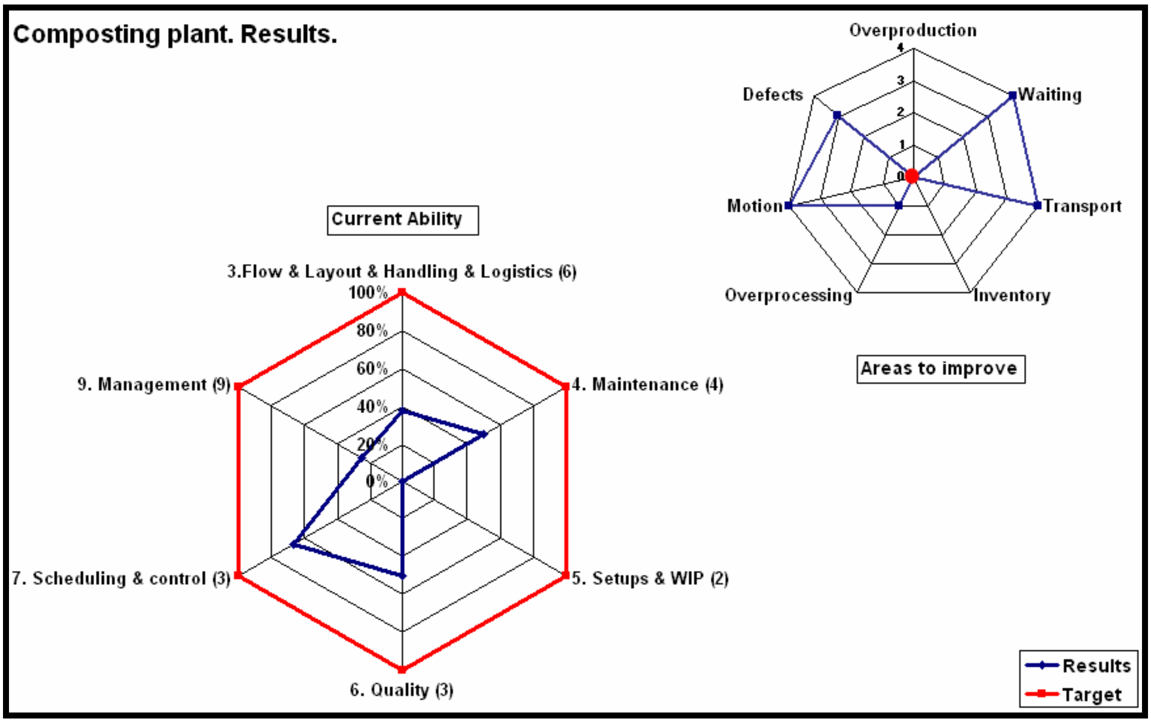

Figure 6: Graphs representing the current ability of a composting plant (questionnaire key areas 3 to 9) and areas to improve for a composting plant (questionnaire key area 10).

For an explanation of factors which cause a bad score (<50%) for each area, it was necessary to look in detail at the answers. It was concluded that this plant has to make efforts to improve:

- area 3: particularly in material handling and general house keeping. They should also decrease the percentage of space organized by function;

- area 5: the equipment is too expensive and the setup time for major equipment too long;

- area 6: they could put in place a statistical process control;

- area 9, particularly in the judgement of staff, they should change their methods to improve labour efficiency, change their structure of their organization, increase the percentage of personnel receiving teambuilding training and who participate in work teams, decrease the annual personnel turnover.

In relation to area 10, they have to decrease or even better eliminate 4 important muda waiting, transport, motion and defects.

4. Review of manufacturing system of a recycling plant in WEEE

4.1. INPUT wastes: treated products and processing capacities

EnvironCom is licensed for the treatment of all categories of WEEE including:

- Large household appliances (refrigerators, freezers…)
- Small household appliances (vacuum cleaners, toasters, fryers…)
- IT & telecommunications equipment (PC, laptop, printers, telephones…)
- Consumer equipment (radio sets, video cameras…)
- Lighting equipment (lights for fluorescent lamps…)
- Electrical and electronic tools (drills, saws, sewing machines)
- Toys, leisure and sports equipment (racing car sets…)
- Monitoring and control instruments (smoke detector, heating regulators…)
- Automatic dispensers (for hot drinks, for solid products…)

EnvironCom is able to treat a maximum of:

- 400,000 domestic refrigerators per year
- 50,000 commercial refrigerators per year
- 500,000 CRT’s / TV’s per year
- 100,000 IT
- 170,000 tonnes per year with a capacity of 25 tonnes per hour for WEEE processing

85% of treated products by EnvironCom come from other waste management companies and 15% from local authorities. EnvironCom works with approximately one hundred companies. Fifty of them represent 80% of EnvironCom is business.

4.2. Treatment processes

At the end of its life, electrical and electronic equipment has to be treated with processes which are able to recover all the valuable components and manage potential dangers. EnvironCom treats and processes four different kinds of WEEE: fridges, commercial fridges, TV's and monitors, big and small WEEE. They are processed in different lines.

4.2.1. Fridges

4.2.1.1. Step 1: Pre-treatment

Before any treatment, the first of all operations is the pre-treatment. Because of the WEEE and RoHS directives and the ODS (Ozone Depleting Substances) regulation, EnvironCom has to remove from all these products plastics with Brominated Flame Retardants, circuit boards (> 10 Sq cm), LCD's (> 100 Sq cm), capacitors (PCB), ceramic fibres, CRT, batteries, external cables, CFC, HCFC and HFC. The dismantling step is generally manual. As well, the operators have to remove all hardened hinges, foodstuffs, glass, mercury switches and capacitor. They have to loosen compressors, extract and contain refrigerants and oils.

4.2.1.2. Step 2: Treatment

After the pre-treatment, fridges are placed onto the feed conveyor and then, sent to an automated 3-stage shredding machine. Fractions are progressively reduced in stages to small pieces of fragmented scrap material. Following shredding, a magnetic separator enables the recovery of all ferrous materials. Non ferrous metals and other materials continue through Eddie Current separator. It separates non ferrous metals (e.g.: aluminium, copper, brass…) from a mix of foam, plastic and other materials.

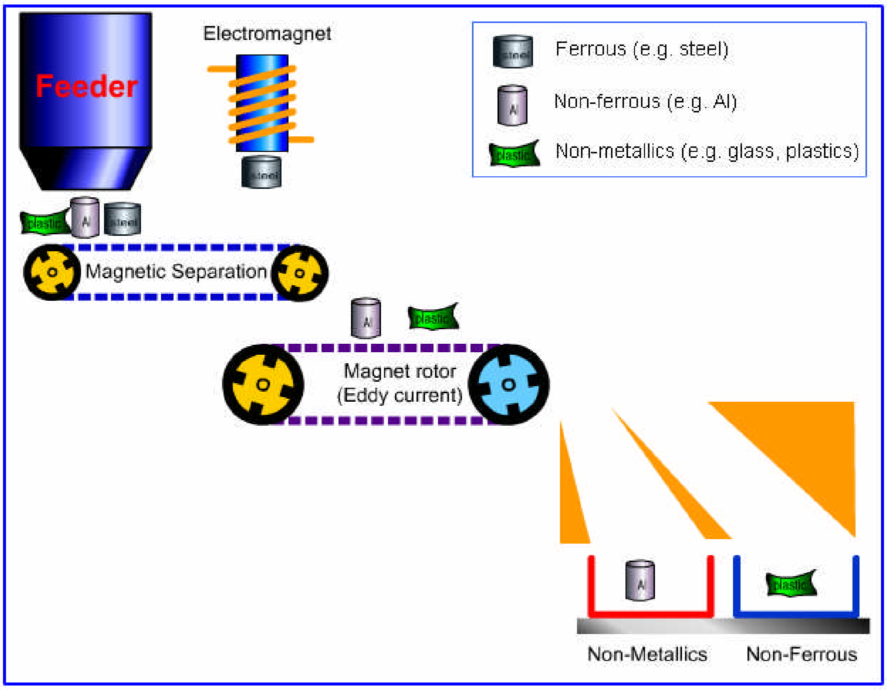

Figure 7: Magnet and Eddy current separation.

Then, an air separator enables plastics to be sorted from foam. Finally, the foam goes through a granulator which reduces it to a powder. This powder is compacted and transformed into foam briquettes.

During all the processes in treating fridges, a vacuum continually extracts all CFC pollutants.

4.2.1.3. Step 3: CFC destruction

CFC's from refrigerant and foam are extracted and collected. They pass into a catalytic abatement system; they are heated to 400 degrees centigrade and are dosed with caustic soda. The outputs after processing are carbon dioxide and saline solution. Furthermore, PH is monitored.

4.2.2. TV's and monitors

4.2.2.1. Step 1: Dismantling

Firstly, TV's and monitors are unloaded and sorted. After manual dismantling which involves sorting plastics, circuits' boards, yoke, cables, band, gun etc, operators prepare the CRT (Cathode-Ray Tube) for splitting.

4.2.2.2. Step 2: Glass splitting

The tube is split by means of a hot wire process. The CRT is placed in the Hot Wire machine. It is then lowered into the system and a wire is automatically positioned around the panel glass of the CRT. The wire is then heated by passing an electrical current through it. Following the heating cycle, the wire is removed and a fine spray of cold water is targeted at the heated area on the CRT. This causes the glass to fracture and splits panel glass from funnel glass.

4.2.3. All other WEEE

4.2.3.1. Step 1: Pre-shredding treatment

The mandatory dismantling of certain elements (Brominated Flame Retardants, circuit boards (> 10 Sq cm), LCD's (> 100 Sq cm), capacitors (PCB), ceramic fibres, CRT, batteries, external cables, CFC, HCFC and HFC) is the same for all other WEEE as for fridges.

In addition, there is an optional dismantling for recycling components of high value. These are recovered to facilitate resale, secondary de-manufacturing or value-added recycling. The dismantling step is manual.

4.2.3.2. Step 2: Shredding with the hammer mill

Firstly, WEEE are loaded on to 2 different conveyors belts according to their size, on one the big WEEE (washing machines, dish washers, dryers, cookers…) and on the other the small WEEE. All these WEEE are sent to the hammer mill (fragmentor) which shreds them into small scrap material pieces. Following shredding, a magnetic separator is used to recover all ferrous materials. Non ferrous metals and other materials continue through Eddie Current separator. It separates non ferrous metals (e.g.: aluminium, copper, brass…) from a mix of plastics, glass and other materials. This mix is mainly composed of plastics which can be recycled. However, if the plastics bin is too contaminated by other materials, it is sent to landfill.

4.3. OUTPUT fractions

Once all wastes are treated and processed. EnvironCom gets different materials, which can be recycled, like steel, tin aluminium, stain steel, mix steel/copper, aluminium, copper radiators, plastics, landfill, brackets, cables, motors, plugs, briquetted foam, drained compressors, clear glass, CRT front glass, CRT funnel glass, de-gassed compressor oil, scrubber liquor, CRT/leaded glass, printed circuit boars and fluorescent tubes. Good appliances can be resold.
These materials are mainly bought by six companies.

4.4. Manufacturing problems

- **Maintenance problem in fridges plant**

In December, further to a breakdown, a fire occurred on the fridges' line. This line started up again in May. This breakdown was responsible for significant amounts of inventories of fridges. Inventories are expensive and there are other associated costs such as space, tracking and insurance. Companies adopt different levels of maintenance. In all cases, there is an apparent cost and a true cost which varies with the level of maintenance. The five possible stages of maintenance can be observed below.
In the first level of maintenance, there is no action until equipment fails. So, the apparent cost is very low while the true cost is very high.
For the next stages, the higher the level of maintenance, the lower the true cost, though apparent cost does not vary so much.
On the second level of maintenance involves a regular service (oil and grease).
The third level of maintenance includes inspection and preventive repairs.
The fourth level of maintenance includes equipment re-engineering.

The fifth level of maintenance requires predictive maintenance schedule.

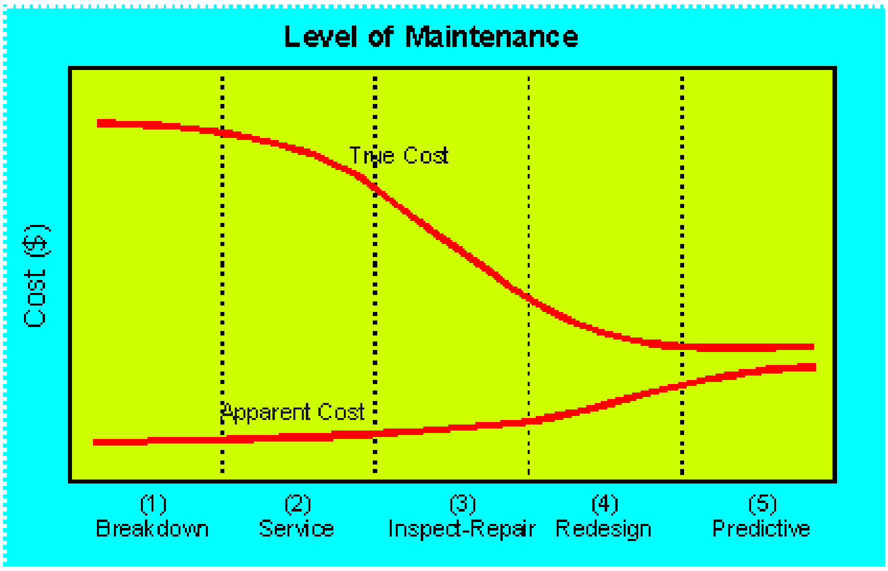

Figure 8: The true cost of maintenance (Strategosinc, 2005).

Most maintenance operations still operate on the principle of “if it is not broken, don’t fix it”, to resist this breakdown theory of maintenance, EnvironCom put in place a defined preventive maintenance schedule. In spite of this, there are still equipment breakdowns in EnvironCom which often limit or interrupt production. Consequently, they developed a database to list all causes of breakdowns.

- **Storage and material handling**

Interviewing EnvironCom, it has been realized that the portion of total space used for storage and material handling is 85%. Only 15% is dedicated to processing. This was an important consequence of the December fire. In the next six months, the EnvironCom technical manager hopes to reach 30% of total space used for storage and material handling and 70% for processing. Indeed, he is conscious of the actual amount of materials which represents a lot of money. So, he wants to limit it.

- **Lead time and added value time**

The lead time was compared with the added value time. The waste’s lead time is the time for a waste to go from the in-gate to the out-of-gate. The product’s added value time is the time during which the waste is processed, the time for which the customer is paying. In EnvironCom, at the moment, the lead time for all WEEE is from 2 to 10 days. Whereas the product's added value time is ten minutes for a fridge and five minutes for a TV. In the lean manufacturing theory, the gap between both times should not exist. In reality, there is always a difference. But in the EnvironCom case, this gap should be improved. Moreover, the technical executive stated that 50% of the lead time is strictly material handling, loading, unloading.

- **Skills of workers**

One of the drivers for waste companies is to make their team multi-skilled. Unfortunately, currently they employ mainly unskilled workers.

- **Tidiness and cleanliness**

Despite a very strong political will to keep their premises clean and tidy, in reality this depends on the different managers of waste companies. There is significant pressure from local authorities which assess the cleanliness of waste companies.

- **Highlighting of 7 muda**

As for composting plants, the WEEE companies were asked the same questions about the 7 muda. 2 muda were detected: transport (movement of pallets of intermediate products…) and overprocessing (in-process controls which never show a failure).

- **Results of the questionnaire**

As for the composting plant, the WEEE plant has been assessed for:

- its current ability in each area (flow & layout & handling & logistics, maintenance, setups & WIP, quality, scheduling & control, management),
- the different muda present in this company.

For an explanation of the factors which cause a bad score (<50%) for each area, it was necessary to look in detail at the answers. It has been concluded that this plant has to make efforts to improve:

- area 3: particularly the material handling, and general house keeping. They should also decrease the percentage of space organized by function and the percentage of space dedicated to storage and material handling;

- area 5: the equipment is too expensive and the setup time for major equipment too long;
- area 6: they could put in place a statistical process control;
- area 7, they could improve the percentage of products which are on time;
- area 9: particularly in the judgement of staff, they could change their methods to improve labour efficiency, change the structure of organization, increase the skills level of people, the compensation of workers, the percentage of personnel receiving teambuilding training and who participate in work teams.

In relation to area 10, they should decrease or even better eliminate 2 muda which are transport and overprocessing.

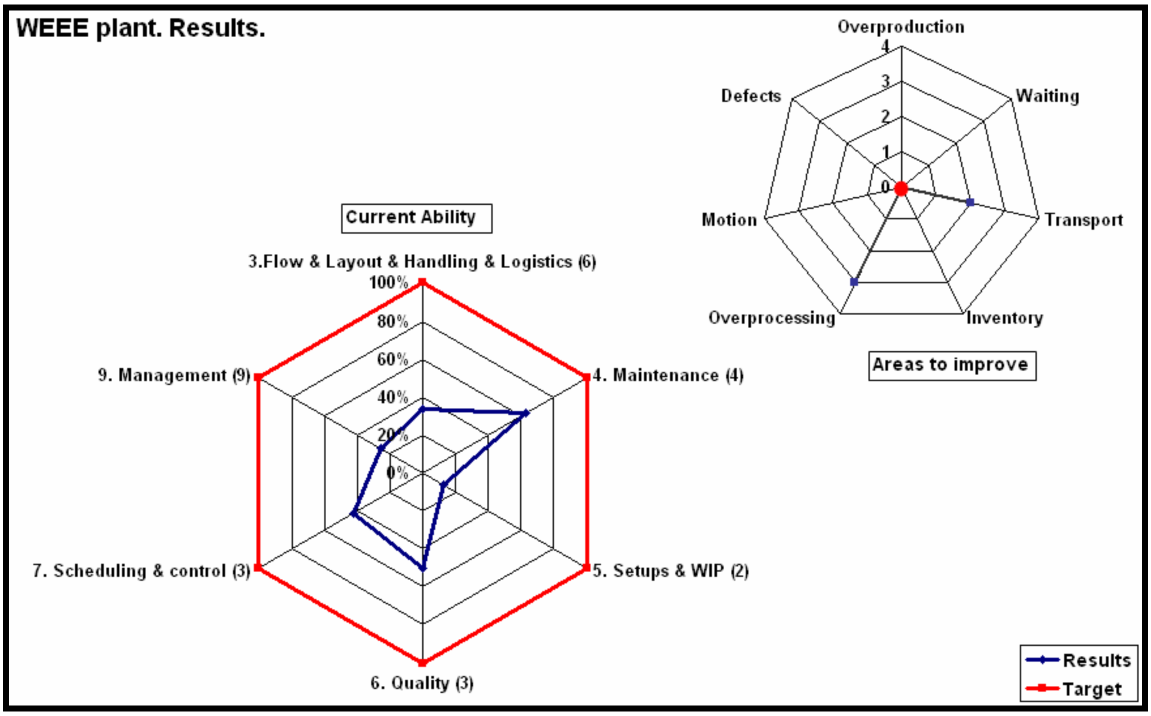

Figure 9: Graphs representing the current ability of a WEEE plant (questionnaire key areas 3 to 9) and areas to improve for a WEEE plant (questionnaire key area 10).

5. Review of manufacturing system of a virtual general waste company

In United Kingdom, six big national and international waste management companies share the waste market between them:

- *BIFFA Waste services*
- *Shanks Group plc*
- *Viridor Waste Management*
- *Cleanaway Ltd*
- *Sita, Suez Environment*
- *Onyx, Veolia Environment*
- *Waste Recycling Group (WRG)*

These companies try to provide different services in order to compete. Some of them are more specialized in collection, others in landfill, energy recovery or recycling. But overall, all these companies provide collection, recovery, recycling, disposal and energy recovery services to local authorities, industry and commercial clients.

5.1. INPUT wastes: treated products and processing capacities

The six big companies are licensed for the recycling of wastes including:

- construction/demolition
- newspapers
- commercial/industrial recycling
- composting
- fluorescent tube & lamp
- household
- sometimes WEEE, hazardous wastes, specifical wastes etc.

According to each company, 30-50% of products treated by these companies come from local authorities (household wastes) and 50-70% from other waste companies. In general, they have got long term contracts with local authorities that assure them of a certain financial stability.

5.2. Treatment processes

Currently, waste have to be treated with processes by means of are able to recover all valuable components. The last step for residuals wastes after treatment which can not be recycled anymore is disposal.

5.2.1. Household waste

5.2.1.1. Step 1: Sorting

Option 1: Generally, recyclable materials (newspapers, magazines, cardboard, other paper, drink cans, food cans, glass bottles, glass jars, plastic bottles, plastic carrier bags, and plastic containers) and non recyclable materials are sorted before arriving at the recycling plant. Wastes for recycling can be collected from people's homes (kerbside), from recycling sites, and from businesses. Then, when recyclable materials arrive at the recycling site, they have to be treated by category of material (glass, plastic, ferrous materials, non ferrous materials etc.).
Option 2: Waste is not sorted before arriving at the site. So, they have to be sorted at the site.

5.2.1.2. Step 2: Treatment and baling

The treatment of household wastes does not require a lot of machines. There is a machine to load waste onto the conveyors (3 or 4 conveyors in a medium site). All wastes are separated (plastics, ferrous and non ferrous metals, paper, and cardboard). To separate non ferrous metals (e.g. aluminium cans) and ferrous metals, magnets are used. Then, all separated wastes are crushed and compressed to form bales, and transported to recycling facilities.

5.2.2. Other wastes

Among the other wastes are construction/demolition, fluorescent tubes and lamps, commercial/industrial wastes. These kinds of products require specific processes.

5.3. OUTPUT wastes

Once all wastes are treated and processed, a household waste plant gets different materials, which can be recycled, such as plastics, wood, 2 types of paper, compost, cardboard, aluminium, steel, 2 types of glass, landfill. These materials are mainly bought by processors (e.g. aluminium recycling facility).

5.4. Manufacturing problems

- **Bottlenecks and failed operations**

Interviewing household waste recycling plants, different bottlenecks appear in their sites. The first one is the loading of input materials. The second one is the baling of output materials. Furthermore, during processing, there is a small amount of waste which can not be processed and which goes directly to landfill. As well, there is waste which could be processed but is not because of failed operations (e.g. balers).

- **Storage and material handling**

Interviewing household waste recycling plants, it has been realized that the portion of total space used for storage and material handling is 70/80%. Only 20/30% is dedicated to processing.

- **Lead time and added value time**

The lead time was compared with the added value time like for the WEEE recycling plant. In certain household waste recycling plants, the lead time for output waste is from 2 to 15 days, whereas the waste’s added value time is 30/40 minutes. This gap comes from two main things. Firstly, recycling plants wait for the best prices to sell their output wastes. Secondly, recycling plants are not sure of being supplied sufficient input waste.

- **Skills of workers**

One of the drivers for waste companies is to make their team multi-skilled. Currently waste recycling plants have 70% of workers who are unskilled and only 30% of the team are multi skilled.

- **Tidiness and cleanliness**

Despite a very strong political will to keep the premises clean and tidy, in reality it depends on the different managers of waste companies. There is strong pressure from local authorities who assess the cleanliness of waste companies.

- **Highlighting of the 7 muda**

As for the composting plant, the household waste recycling companies were asked the same questions about the 7 muda. 6 muda were detected: overproduction (extent of warehouse space, development and production organization imbalance …), waiting (large amount of work in progress…), transport (movement of pallets of intermediate products…), overprocessing (in-process controls which never show a failure…), motion (large teams of operators moving…), and defects (missed or late orders, excessive overtime…).

- **Results of the questionnaire**

As for the composting plant, the general waste plant has been assessed for:

- its current ability in each area (flow & layout & handling & logistics, maintenance, setups & WIP, quality, scheduling & control, management),
- the different muda present in this company.

For an explanation of factors which cause a bad score (<50%) for each area, it was necessary to look in detail at the answers. It has been concluded that this plant has to make efforts to improve:

- area 5: the equipment is too expensive and the setup time for major equipment too long;
- area 6: they could put in place a statistical process control;

In relation to area 10, they have to decrease or even better eliminate 5 muda, namely waiting, transport, overprocessing, motion and defects.

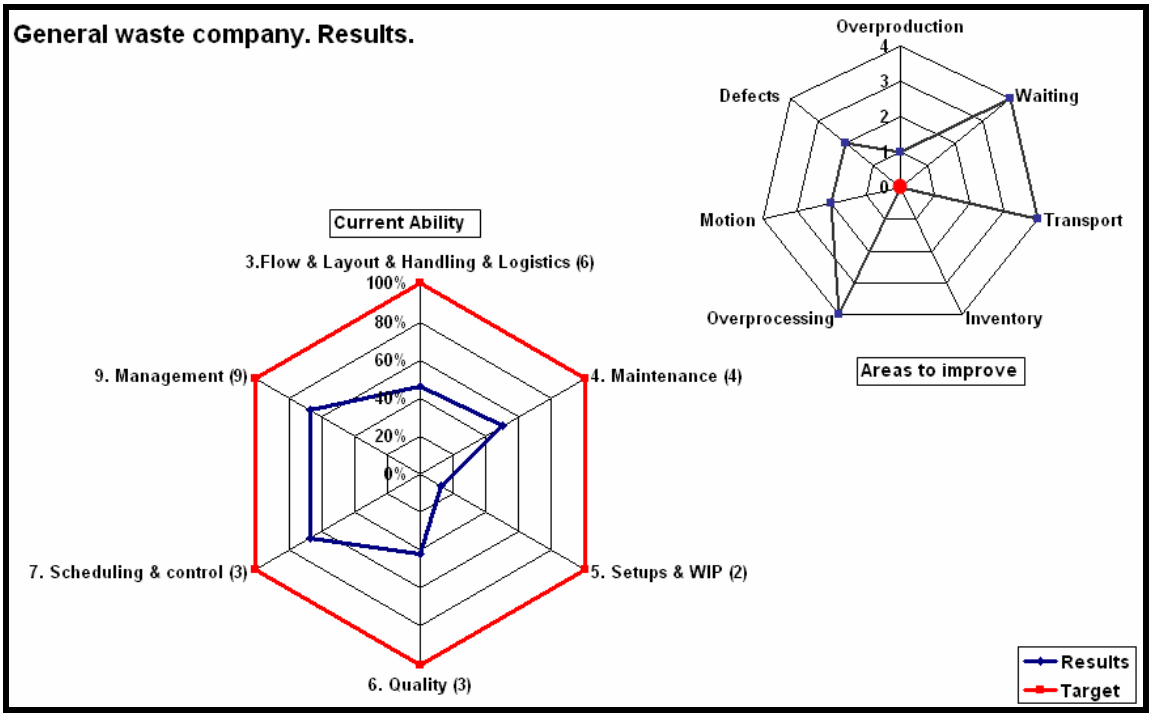

Figure 10: Graphs representing the current ability of a general waste company (questionnaire key areas 3 to 9) and areas to improve for a general waste company (questionnaire key area 10).

6. Results and conclusions

As it has been commonly reported in the literature review, lean manufacturing knowledge in waste companies is almost non-existent. One of the project objectives was to evaluate existing manufacturing knowledge of waste companies. To achieve this objective, a questionnaire was used. These questionnaires and interviews have been very helpful for many reasons:

- Firstly, several waste companies were studied which enabled the researcher to understand their various processes, their organization, their problems, and their manufacturing knowledge.

- Secondly, it has been realized that it was very important to sort wastes into categories. The ways to process compost, WEEE and household waste are very different. So, the problems which result from them are also very various. In addition, solutions to resolve them are different.

- Thirdly, it is believed that the researcher has identified the most likely areas of concern for the waste companies, and is now able to focus her efforts on manufacturing knowledge and tools that tackle these areas of concern.

- Fourthly, agreements were reached with two waste companies to work with: a WEEE company, EnvironCom and a paper processing facility, a Biffa site.

- Finally, it has been tried to implement some manufacturing knowledge to these plants and to analyse the results of these implementations. But, working with companies which are interested in the project and in the results, means as well to answer to their needs. So, both companies have to be distinguished and it is necessary to talk about the two different projects. The Biffa project was focused on analysing their manufacturing practices and improving them to reduce their processing costs. The EnvironCom project was however focused on applying manufacturing knowledge to determine the operations strategy for a new recycling plant in order to maximise its effectiveness and the value of material streams coming out of the machine. Both projects were aimed at increasing company profits. At the Biffa site, costs had to be reduced in order to increase the profits whereas at EnvironCom, revenue had to be increased in order to increase the profits.

• *Biffa project.* After having identified the different manufacturing problems (see part 6.4) dealing with loading input waste and storing output products at the Biffa Avonmouth site, the researcher worked on their different zones (secure zone, zones 2 and 3). The topic was the application of manufacturing knowledge to determine the different improvements possible for handling and logistics. The different inputs, outputs, the machines, their capacity, the reality, the different movements of operators and their work way had to be studied carefully. The researcher wanted to know the possible cost reduction of the waste processing resulting from her improvement suggestions.

• *EnvironCom project.* The first step with EnvironCom was to identify their different manufacturing problems (see part 4.4). At the same time, important technical problems occurred which cause significant financial problems. The company manager who was at the beginning very motivated by the project “Implementation of manufacturing knowledge to reduce the cost of waste processing” ceased to be so after the occurrence of the technical problems. His concerns changed and our project too. Indeed the company manager preferred working on the profitability of this new line which is a big financial challenge to improving his existing lines by reducing their processing costs. Although the improvements and cost reductions of the existing lines are also important, it was not his priority at the time of the project. The EnvironCom manager will surely make do so later; his background of 30 years in manufacturing will definitely help and move him in this direction. All of this explains that the researcher decided with her partner to work not on the actual recycling plants but on a new recycling plant dealing with small and big WEEE. This project focused on the development of a model in order to assess the profitability of a shredding machine involved in a WEEE recycling process. The model takes into account the incomes and expenses derived from the whole process. It also calculates the material outputs of the machine and the benefit coming from the processing of a chosen set of WEEE. Some experiments are carried out with this model in order to estimate the correct recycling strategy and an analysis of the main findings is shown. The different solutions to recover materials in this site are easy. The first one is the shredding with a mandatory pre-treatment step. The second one is a dismantling with different levels which aims to recover the maximum valuable materials before shredding but this dismantle step cost money and it is not mandatory. So, the project aims to know which strategy was relevant in terms of costs and benefits. In relation to part 2.2.3 of the literature review, all questions in relation to the disassembly costs are very important for the sector dealing with WEEE. Indeed, WEEE sorting automation is almost non-existent and the manual disassembly is still very costly. For this reason, it is important to develop tools allowing companies to find the best strategy and the best economical balance between the different levels of disassembly. The disassembly whose cost is optimized is the one which keeps profitability and at the same time minimizes the damage to the environment.

For both projects, the researcher worked closely with the companies, with their data in order to get the best results possible. The researcher hopes her suggestions will allow a very significant cost reduction at the Biffa site and a significant increase in profits at EnvironCom. Due to the delays, the researcher could not be take charge of both projects. So, for the EnvironCom project, Xabier Landeta Callejo, an MSc student in "Design for Sustainability" was in charge. Both researchers were supervised by Stephen Evans.

Chapter 4

Cost reduction of waste processing at a BIFFA site

Thanks to Peter Jones, the director of external relations at BIFFA, a BIFFA site at which to work, was arranged. This site was *Avonmouth materials recycling facility.* This site is mainly a paper and cardboard processing facility. In addition, it processes metal cans and it is used as a storage area for glass.

1. Study methodology of the Biffa site

1.1. Definition of the Biffa project

After having visited the site, the researcher decided with the manager that she was going to work on problems of handling and logistics, especially the problems linked with the input waste loading and the bales storage. It was decided with the company to work on the problems of different zones (zones 1, 2, 3 and 6). In order to solve problems, it is necessary to collect data that can show their origins and describe the situation where they are being produced. It is crucial that the causes of the problem are understood in order to overcome them. The topic was applying manufacturing knowledge to determine the different improvements possible for handling and logistics and their associated processing cost reductions.

To have a better knowledge of the site, the data it was intended to gather were as follows:

- Machine capacities and their features
- Machine operational costs
- Productivity
- Income from receiving waste
- Selling prices of output materials
- Operators' costs (wages)
- Different steps required to complete a product process
- Time and distance for these steps.

All this information would enable the researcher to have a precise understanding of the machines and the recycling business. That would enhance the reliability of the study. The next point will explain the process followed to collect the necessary information.

1.2. Data collection

As the research was focused on obtaining quality data, the steps that comprised the data collection were as follows:

• The **first meeting with the project partner**, Biffa, was held at the end of June 2006 in Bristol (England), in one of the Biffa paper recycling facility. A tour around the site was conducted to enable the researcher to have an overall view of the activity of the company. Then, the researcher and her partner had a conversation about the objectives of the project. That also helped to get to know some of the employees of the company, who were very helpful throughout the project.

• The researcher went **twice to visit the Bristol site**. The first visit aimed to study the different inputs and outputs, their quantities, their sale and purchase prices, the capacity of the machines and the machine and operators' costs. For the second visit, the researcher stayed 3 days in the company with the operators. This visit aimed to collect actual performance data and to study and observe zones, their operators and machines, the productivity, the different steps required to complete product processes, the time and distance required by the operators to do these different steps. The characteristics of the machines and their features were explained by the staff in charge of them. Other information related to the recycling business was collected by means of conversations with the staff and observation of the current processes. This approach was adopted as it was the best way of getting to know the recycling processes in which the operators and machines were going to be involved. The activities that were being run by the company and their current situation were explained to the researcher.

• The company provided the researcher with valuable information in order to study their zones. These data were transferred during the **visits to Bristol and via email**. The latter method was employed as it was the quickest way of obtaining the information and a direct contact was not necessary. Operators were crucial in this study not only for the data collection but for solutions too.

All these sources of information helped to gain a great understanding of the problem.

The information gathered was then used to calculate the processing costs and to improve them. Figure 11 shows the process that followed to obtain the suggestions that will help the company in its improvement and cost reductions.

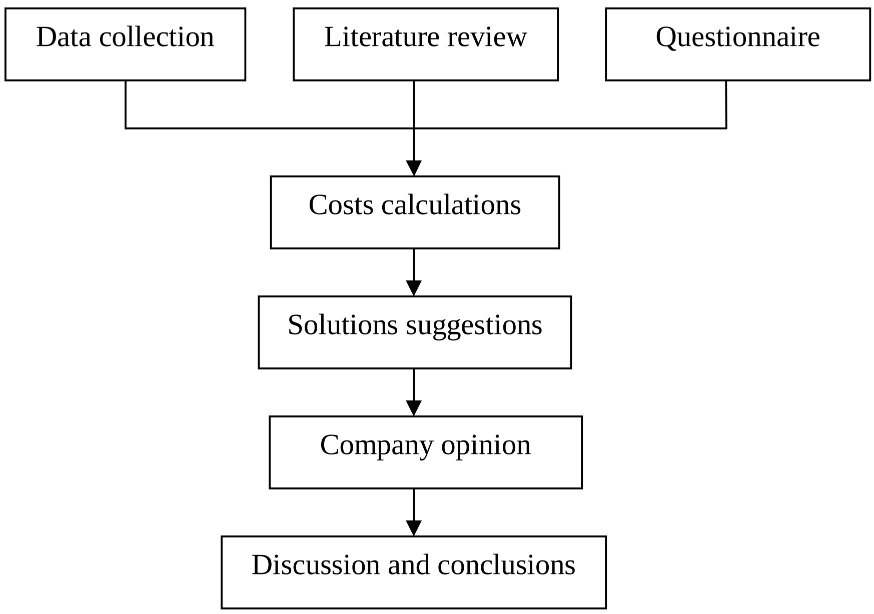

Figure 11: Project methodology

In the following chapters, the description of the site, the costs calculations for the different zones, solutions suggestions and the final conclusions will be explored.

2. Description of the BIFFA site

2.1. The different zones

The Avonmouth materials recycling facility is divided into zones (See Appendix C).

The restricted areas:

- Zone 1: Secure area.
- Zone 2: De-pallet, sort line and reel saw
- Zone 3: Bulk load tipping
- Zone 4: Bale store and loading
- Zone 5: External bale store and loading
- Zone 6: Glass and can tipping

The other areas:

- Zone 7: LGV parking	Collection
- Zone 8: FEL and trade waste containers	Collection
- Zone 9: Bulk carriers and skips	Collection
- Zone 10: Workshop and vehicle waiting area	Workshop
- Zone 11:Workshop parking and vehicle wash	Workshop
- Zone 12: Weighbridge, offices and car park	General

- Zone 1 is dedicated to processing confidential papers. This area is closed because of the papers confidentiality. Two operators work in this zone. There is one shredder and one baler. Because of the confidentiality of zone, photos were prohibited.

- Zone 2 is dedicated to the sort line. In the following picture, the sort line enables the sorting of different kinds of paper. The first bin is dedicated to plastic bags, the second one to mixed papers, the third bin to tear white shavings, the fourth bin to mixed, the fifth bin to white heavy letter and the last one the sixth to office pack. There is one operator working in this area. The conveyor belt located at the end of the sort line goes directly through to the baler of zones 2 and 3.

Figure 12: Sort line (on the left) and conveyor belt A of zone 2 going through to the baler (on the right).

- Zone 3 is dedicated to bulk load tipping. There is one operator loading papers, plastics or cardboards on to the conveyor belt which goes directly through to the baler of zones 2 and 3.

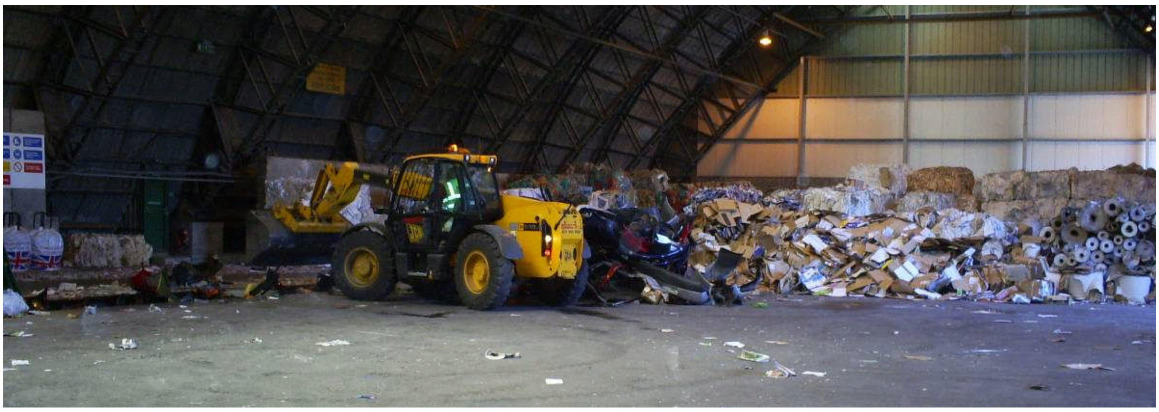

Figure 13: Operator loading papers, plastics or cardboards onto conveyor belt B (zone 3).

Figure 14: Conveyor belt B of zone 3 going through to the baler and bales coming out of the baler.

- The bales coming out of the baler are stored in zones 4 and 5. One operator is in charge of the storage task and loading the empty trucks with these bales which are sent to paper mills.

Figure 15: Operator storing bales coming out of the baler (zones 2 and 3).

Figure 16: Operator storing bales coming out of the baler (zone 5).

The different bales are stored inside (zone 4) and outside (zone 5). The bales that go outside are these of cardboard, mixed papers, news and magazines, wrappers and cans. The bales that go inside are these of office pack, over issue magazines, best white, white heavy letter, kraft sacks, light letter, unprinted white news and plastic.

- Zone 6 is dedicated to the storage of glass and cans.

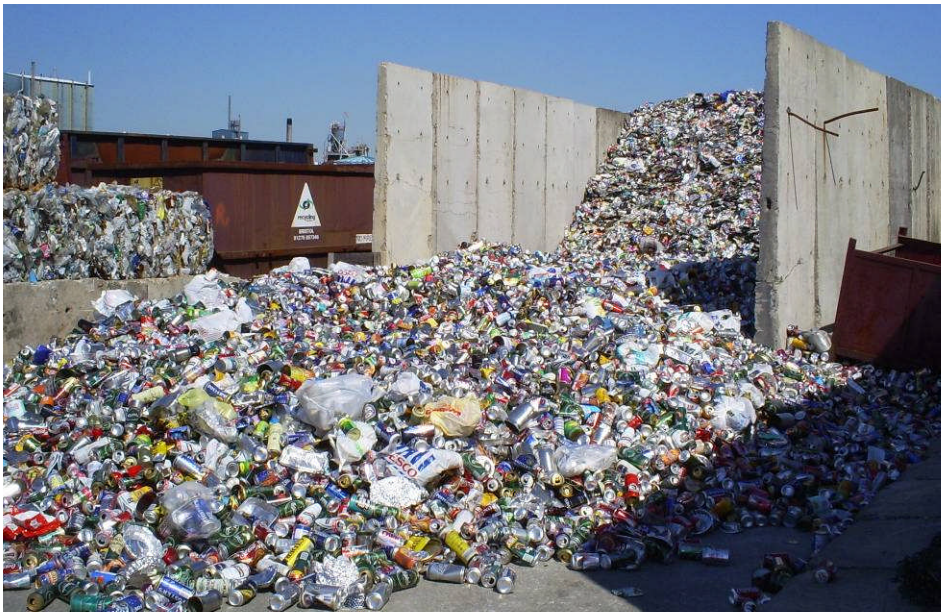

Figure 17: Storage area of cans (zone 6).

Biffa supplies its customers with clearly marked containers to enable them to separate glass bottles from other waste. Glass is collected from pubs, clubs and restaurants etc. All colours are collected mixed together.

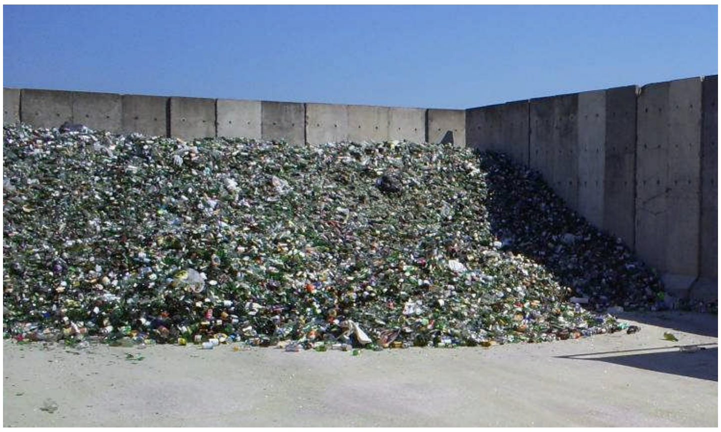

Figure 18: Storage area of mixed glass (zone 6).

- Zones from 7 to 12 are not directly linked to the study. It would not have been relevant to give more details about them.

2.2. Inputs and outputs

Each zone of the Avonmouth BIFFA site is in charge of processing one or several kinds of inputs. The inputs and outputs quantities and prices are quite stable during the year. Consequently, it has been decided to study the inputs and outputs between mid-June and mid-July (See Appendix D). This appendix contains the quantities, prices of sell and purchase of inputs and outputs. Thanks to it, it has been concluded that:

- Zone 1 which is exclusively in charge of processing confidential papers represents only 2% of the total site quantity but 18% in value.
- Zones 2&3 which are in charge of processing paper, cardboard, plastics and cans represent 77% of the total site quantity and 70% in value.
- Zone 6 which is in charge of storing glass represents 21% of the total quantity but only 12% in value. For this BIFFA site, it is a bonus.

There are two different businesses in this company, one which is relies on the quality (zone 1, benefit of £385/tonne) and one which is based on the quantity (zones 2&3, benefit of £47/tonne). Both are important for different reasons (quality and quantity) and have to be studied very carefully to try to reduce their respective processing costs.

2.3. Site operational costs

Different data about costs were collected; they are going to be used for different calculations in the following sections. These costs refer to:

- wages for 7 operators : £5500 per week or £785.7 per week per operator or £157.14 per day per operator or around **£15 per hour per operator**
- electricity: £500 per week (assumption: **6p/kWh**)
- baling wire: £300 per week
- maintenance: £1000 per week
- equipment rental: £800 per week
- depreciation: £1200 per week
- total site: £9300 per week

3. Previously

In the Avonmouth Biffa site, the researcher could easily identify the same manufacturing problems as those seen in part 6.4. However, all problems can not be fixed in one study. So, the researcher and the site manager decided to focus on applying manufacturing knowledge to determine the different improvements possible for handling and logistics and their associated processing cost reductions.

But even if this site has some manufacturing problems, it is very important to highlight the fact that as opposed to most waste companies which are composed of unskilled people, the operators' team at this facility is multi-skilled. One operator is able to do the work of the 6 other operators. This force to have a multi-skilled team could enable to resist to the common barrier to lean manufacturing implementation: the cultural transformation (See part 1.4.2). Having a multi-skilled team is a significant advantage and the site manager should make good use of this to begin to change his site organization. Furthermore, as seen in the literature review, a multi-skilled team in a company is a good base to develop kaizen (See part 1.3.2). In the next parts, we will study the different zones to see which kinds of improvement could be suggested. These improvement suggestions were done with the help of operators.

4. Study of the current zone 1

Zone 1 is closed and requires that the gates are always locked because of the paper confidentiality of the papers. A detailed map of zone 1 can be found in Appendix E.

Zone 1 resources are composed of:

- **two operators** for safety
- shredder and baler processing capacity : **4 tonnes per hour** or 7.3 bales per hour (550 kg/bale)
- average input confidential waste : **12 tonnes per week**
- average output bales of light letter and office pack : **25 tonnes or 45 bales per 2 weeks**

The daily work schedule:

- **working hours: 10h30**
  6h → 10h, 10h15 → 13h, 13h30 → 15h, 15h15 → 17h30
- **break periods: 1h**
  10h → 10h15, 13h → 13h30, 15h → 15h15

The daily operations are:

- preventive maintenance/check/clean time = 1h15. Even if there is a preventive maintenance session conducted every morning, it is not sufficient to prevent all the breakdowns. Certain breakdowns are unpredictable as also is their scale. If a major break down occurs in the shredder, it can sometimes be down for two or three days. But little problems maybe only last for one hour.
- start-up time = 5 min
- stop time = 20 min
- number of stops and start-up per day = 4 (which corresponds to the 3 operators breaks and the end of day)
- **total start-up time = 20 min**
- **total stop time = 1h20**
- **machine running time = 8h35** = 11h30 (day time) – 1h15 (maintenance) – 20 min (start-up time) – 1h20 (stop time)

The case study is based on:

- a quantity of around **12 tonnes** of secure paper to treat which is the average quantity **per week**
- input delivery method for this particular case study: 3 trucks
- number of pallets per truck: 12 pallets
  (340 kg per pallet – 20 kg per pallet = 320 kg paper/pallet)
- **total number of pallets: 36 pallets**

4.1. Goal of this case study

The theoretical time results are easy to calculate but it does not often correspond to reality because of the various muda and as well, because of the lost time for unnecessary tasks and those which are necessary but do not add value to the product. However, even if the theoretical and practical results do not correspond, they can be very close once muda have been eliminated. Our goal in this study is to reduce significantly the existing gap between both by means principally of a manufacturing knowledge.

4.2. Theoretical results

The processing time for 11.5 tonnes of confidential paper (= 36 pallets) and for 4 pallets (= 1 hour of work) were calculated.

- shredder and baler processing capacity : **4 tonnes per hour**
- processing time per 11.5 tonnes (or **36 pallets**) = 11,5/4 = **2h52 min**
  = 172 min
- processing time per **4 pallets** = 172/9 = **19 min**
- number of boxes per pallet: 32 boxes
- processing time per **box** = 19/128 = **9sec**

Conclusion: operators should treat:
- 3 trucks in 2h52min
- 4 pallets in 19 min
- 1 box in 9 sec

These results could seem utopian but even if there are not reached; it is possible to get close to them.

4.3. Practical results and detection of muda

4.3.1. Practical results

Firstly, zone 1 and its operators (patterns, motions, tasks, time needed for each task) and machines (capacity, productivity, break-ups) were observed and studied very carefully in order to detect the useless tasks and movements which take time and compare them with the theoretical results. Different measurements (time, quantity, distance…) were taken for one hour of work in zone 1 in other terms four treated and stored pallets. The machine locations are illustrated in appendix E.

Step 1: Unloading from the truck to the input storage space. ONE OPERATOR

- ✓ **Distance** between the truck and the input storage space = 18m x 2 = **36m**
- ✓ Necessary **time to unload a truck** containing 12 pallets = **10 min**

Step 2: Treatment of 2 pallets

- ✓ *Task A. Bringing the two pallets next to the shredder. ONE OPERATOR*
  - **Number of pallets** = **2**
  - **Number of boxes** = 32 x 2 = **64**
  - **Distance** to bring one pallet next to the shredder = 15 x 2 = **30m**
  - **Time** to bring 2 pallets = **2 min**

✓ *Task B. Loading the paper into the shredder. TWO OPERATORS.*

- Sub-tasks:

Average time = 5s per box or ≈ 5min per 2 pallets
- remove paper clips or staples
- emptying the paper of cardboard box into the shredder

Average time = 14s per box or ≈ 15min per 2 pallets
- pushing the button to switch the shredder on
- unfolding cardboard box and walking to the cage
- putting unfolded cardboard in a cage
- going back to the pallet
- taking another cardboard box

- **Average total time** to deal with 2 pallets or 64 boxes = **20 min**

✓ *Task B bis. Processing the paper. SHREDDER & BALER.*

- 2 pallets = 2 x 320 = 640 kg of paper
- Time to process 2 pallets = 20 min
- **Result ≈ 1.5 bales** (550 kg/bale)

✓ *Task C. Going to empty the full cage of cardboard. ONE OPERATOR.*

- **Distance** = 120*2 = **240m**
- **Time = 8 min**

Step 3: Treatment of 2 pallets

As before, the same results were found:

✓ *Task A. Bringing the two pallets near the shredder. ONE OPERATOR*

- **Number of pallets** = **2**
- **Distance** to bring one pallet near the shredder = 15 x 2 = **30m**
- **Time** to bring 2 pallets = **2 min**

✓ *Task B. Loading the paper into the shredder. TWO OPERATORS.*

- **Average total time** to deal with 2 pallets or 64 boxes = **20 min**

✓ *Task B bis. Processing the paper. SHREDDER & BALER.*

- Time to process 2 pallets = 20 min
- **Result ≈ 1.5 bales** (550 kg/bale)

✓ *Task C. Going to empty the full cage of cardboard. ONE OPERATOR.*

- **Distance** = 120*2 = **240m**
- **Time = 8 min**

Step 4: Unloading from the baler and storing 2 paper bales. ONE OPERATOR

✓ **Distance** between the baler and the output storage space = 18m x 2 = **340m**

✓ Necessary **time to go and store 2 bales** = **10 min**

The total of all these times is 1h20min. But observing the operators at work and taking into account that there are tasks carried out by two operators and others by only one, it can be said that two operators need around 1h to complete the four steps as detailed above.

Conclusion: operators need:
- Around 1h to deal with 4 pallets and get 3 bales stored
Conclusion: machines need:
- Around 40 min to process 4 pallets

4.3.2. Detection of muda

As has been noticed in part 1.3.1 of the literature review, the different actions on a product are divided into three categories according to whether they create value, do not create value but are necessary or are unnecessary. The different tasks present in our case study were sorted as follows:

- actions “creating value” = processing the paper
- actions “not creating value but which are necessary today” = unloading from the truck to the storage space, bringing the two pallets near the shredder, removing cardboard, emptying the paper of the cardboard box into the

shredder, pushing the button to switch the shredder on, removing paper clips or staples, unloading and storing 2 paper bales

- "unnecessary" actions = unfolding cardboard box and walking to the cage, putting unfolded cardboard in a cage, going back to the pallet, taking another cardboard box, going to empty the full cage of cardboard.

Conclusion: the muda are clearly:

- muda of motion

- muda of transport

4.4. Cost appraisal for zone 1

Using the date from part 2.3, the costs for zone 1 have been calculated:

- **wages for 2 operators : £15 per hour per operator**
- shredder consumption (kWh):
  - start-up power = Amps 130 x Volts 420 = 93 kW
  - one start-up consumption (duration: 5 min) = 93 x (5/60) = 7.75 kWh
  - **one start-up electricity cost** = 7.75 x 0.06 **= £0.46/start-up**
  - running power = Amps 30 x Volts 420 = 12.6 kW
  - running consumption for 1h = 12.6 x 1 = 12.6 kWh
  - **running machine electricity cost** = 12.6 x 0.06 = **£0.75 per hour**

4.5. Causes of the muda

4.5.1. Added value time ≈ processing time

The theoretical and real times to process 4 pallets of paper have already been calculated. Both times enable us to calculate the usage rate of the machines.

Ru (machines) *= theoretical time/real time= 19/40 =* ***47%***

Though this occupation usage is very low, it would be very utopian to think that it could be improved to 100% but it should be possible to improve it significantly. The major problem is not the machine but the input flow which is too slow. It might be thought that the problem is one of the numbers of operators but is not, the problem is that they are wasting time doing other tasks than loading the shredder. Indeed, the most important task and the one which creates value is emptying the paper from the cardboard box into the shredder (or loading). So, operators should focus on this one to reach the maximum capacity of the shredder. As seen before, there are several tasks which do not create value. They have to be, if not eliminated, at least significantly reduced. The tasks in question are:

- actions “not creating value but which are necessary today” = unloading from the truck to the storage space, bringing the two pallets next to the shredder, removing cardboard, emptying the paper from the cardboard box into the shredder, pushing the button to switch the shredder on, removing paper clips or staples, unloading and storing 2 paper bales
- actions “unnecessary” = unfolding cardboard box and walking to the cage, putting unfolded cardboard in a cage, going back to the pallet, taking another cardboard box, going to empty the full cage of cardboard.

4.5.2. Suggestions for improving the added value time or the loading speed

The **theoretical time** to process **4 pallets is 19 minutes**. This should correspond with the input flow time or loading paper into the shredder time which is the added value time. The rest of time represents lost money. Currently, the **actual processing time is around 40 minutes**. It has been noticed that around 10 minutes are dedicated to the task of “loading paper into the shredder” and 30 minutes to the tasks of dealing with the “cardboard and pushing the button”. So, if the 30 minutes dedicated to these tasks could be eliminated, the theoretical processing time of 19 minutes could easily be reached and it would be the machine which would become the bottleneck and not the operators.

4.5.2.1. Description of solutions 1 & 2

The following two solutions were identified with the operators of zone 1:

- ***Solution 1***: Automatically shredding instead of having an operator pushing the button to activate the shredder.

- ***Solution 2***: Emptying a 40 m^3 BIFFA container at the end of the day instead of emptying a 2/3m^3 cage 18 times travelling 240m (there and back) each time. Solution requires a BIFFA container and optionally a jack which would compress the input cardboard. This compressed cardboard would go to a 40 m^3 BIFFA container through a window which would be in front of the jack. This container should be sufficient for the packaging in cardboard of 12t of confidential paper and would only be brought to the zone 3 baler and processed at the end of the day.

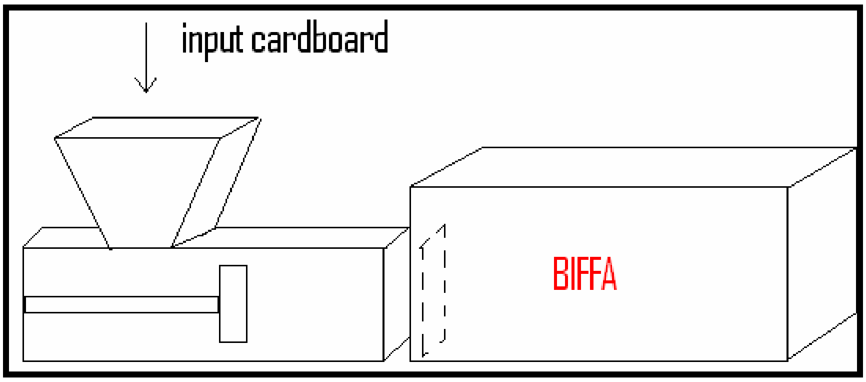

Figure 19: Scheme of solution 2.

4.5.2.2. Solutions feasibility

- ***Solution 1***: The automation is very easy to do; all the other machines of the company are automated.

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- ***Solution 2***: It will be checked whether there would be enough space for the container.

- Its dimensions would be *2.60m (height) x 2.50m (width) x 6.30m (length)*. So, the container surface on the ground would be $2.50m \times 6.3m = 16.4m^2$.
- The length of the wall (the wall between the storage space and the shredding area) is 6m and the width between the wall and the edge of the shredder is 6m. The available surface inside the building would be $6m \times 6m = 36m^2$.
- So, the container would fit. There are two possibilities as to where the container could be positioned as depicted in appendix E:

  - The first option would be inside the building. It would be positioned along the wall. The inconvenience would be to move the container in and out. There would not be enough space to manoeuvre.

  - The second option is to make a hole of 2.50m (width) in the wall and to make the container fit perpendicularly to the wall. The section with the window will be inside and the rest outside.

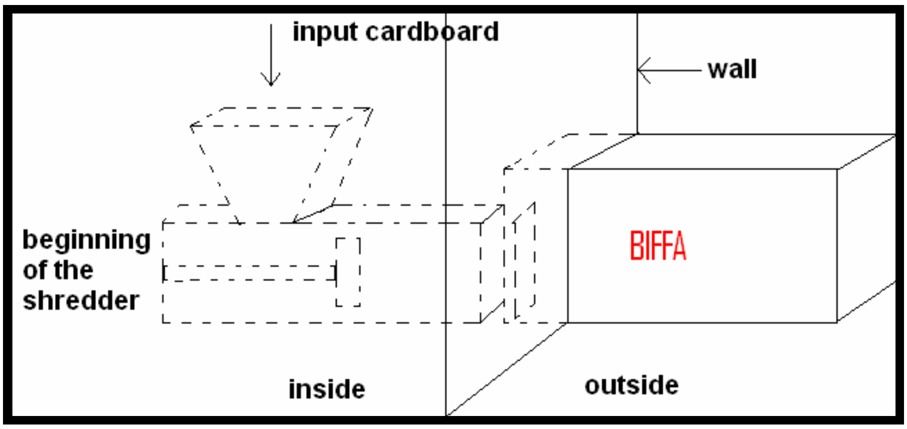

Figure 20: Position 2 of solution 2.

In conclusion, in terms of available space, it would be fine to put a container in place. As regards the automation of the shredder, it is highly recommended.

4.5.2.3. Solutions cost study

- The first solution is very low cost and requires little investment.
- For the second one, the container belongs to BIFFA. As with the first solution, it is very low cost and requires little investment. If a jack is added, it will be more expensive but the cost is not known. The price of a jack could not be ascertained.

4.5.2.4. Expected improvements in time and cost

The following time improvements could be expected:

- The theoretical processing time should easily be reached thanks to these two solutions. So, if it is assumed that the processing time for 4 pallets was 19 minutes instead of 40. 50% of time improvement is achievable.
- The cardboard solution which is the BIFFA container not only brings time savings in the loading speed but should also bring cause time saving in the lead time which could be considerably reduced. Currently, the cardboard cage can only hold the contents of 2 pallets. So, each time the operators have to bring it into the cardboard zone a distance of 240m, and they need to open and close the security gate. This takes around 8 minutes each time. For an overall of 36 pallets, they lose around 2h. With the BIFFA container solution, just one ride would be required at the end of the day.
- So, the total time to treat 4 pallets will be 20 min (processing time) + 10 min (to bring pallets, unload and store the bales) = 30 min instead of 1h as now.

To assess time and cost savings, calculations were made to find the necessary time to treat 36 pallets. As is depicted in the following table, two cases are compared: the current situation and that following implementation of solutions 1&2.

NOW			ASSUMPTION Solutions 1&2		
Time	Operation	Number of treated pallets	Time	Operation	Number of treated pallets
6:00:00	Maintenance and unloading the 3 trucks: 1h15		6:00:00	Maintenance and unloading the 3 trucks: 1h15	
7:15:00	*Start-up: 5min*		7:15:00	*Start-up: 5min*	
7:20:00	Beginning		7:20:00	Beginning	
8:20:00	Running	4	7:50:00	Running	4
9:20:00	Running	4	8:20:00	Running	4
10:00:00	Break of 15 min and machine stop time of 20 min	2,7	8:50:00	Running	4
10:20:00	*Start-up: 5min*		9:20:00	Running	4
10:25:00	Beginning		9:50:00	Running	4
11:25:00	Running	4	10:00:00	Break of 15 min and machine stop time of 20 min	1,3
12:25:00	Running	4	10:20:00	*Start-up: 5min*	
13:00:00	Lunch break for 30 min and machine stop time of 20 min	2,3	10:25:00	Beginning	
13:30:00	*Start-up: 5min*		10:55:00	Running	4
13:35:00	Beginning		11:25:00	Running	4
14:35:00	Running	4	11:55:00	Running	4
15:00:00	Break of 15 min and machine stop time of 20 min	1,6	12:15:00	End	2,7
15:20:00	*Start-up: 5min*			Total	**36**
15:25:00	Beginning				
16:25:00	Running	4			
17:10:00	Machine stop time of 20 min	3			
17:30:00	End of the day	33,6			
2nd day					
6:00:00	Maintenance: 1h15				
7:15:00	*Start-up: 5min*				
7:20:00	Beginning				
8:00:00	End	2,4			
	Total	**36**			

Summary of current situation		Summary of solutions 1&2	
Total number of start up	5	Total number of start up	2
Total running machine time	9h30	Total running machine time	4h40
Total break time	1h	Total break time	0h15
Total work time	12h30	Total work time	6h

Table 13: Comparison between the current situation and those applying solutions 1&2.

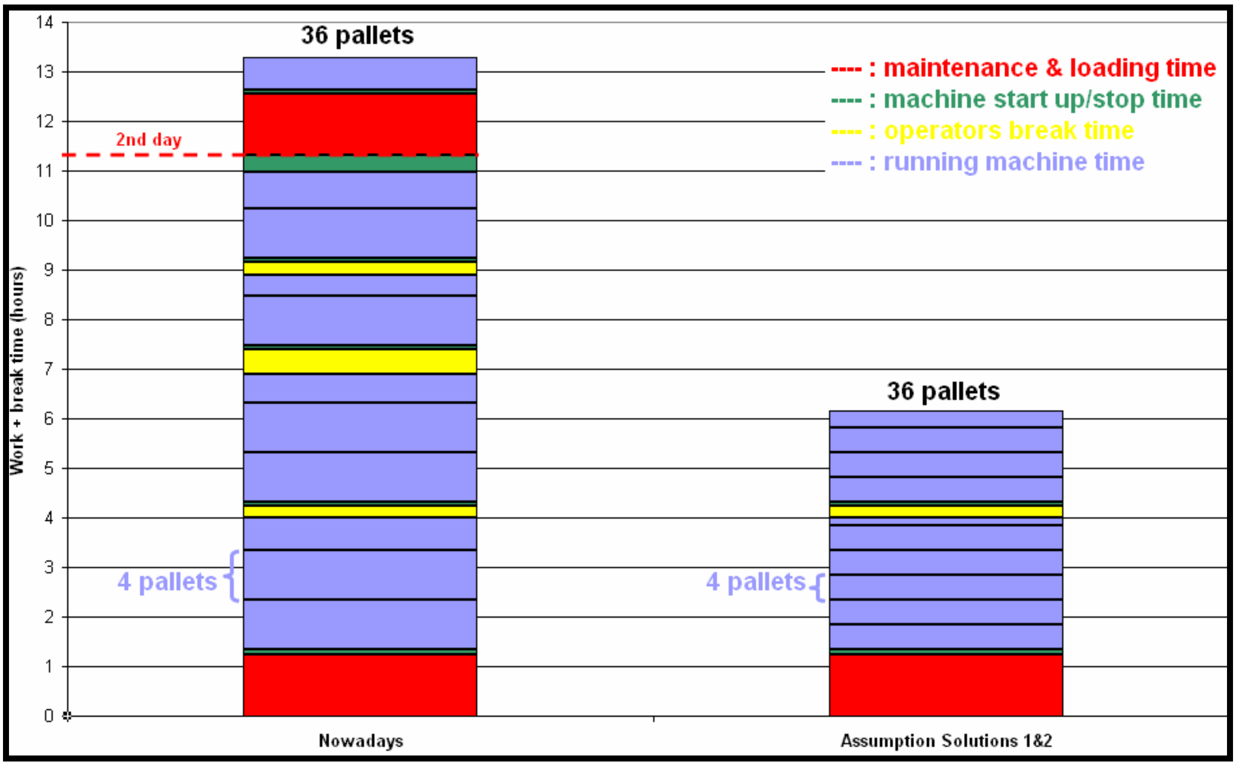

Figure 21: Comparison between the current situation and those applying solutions 1&2.

Current cost of the treatment of 36 pallets:

- Wages for 2 operators = £15/h x 2 operators x (12h30) = £375
- Electricity: £0.46/start-up x 5 + £0.75/h of running machine x (9h30) = £9
- Total = £375 + £9 = £384

Cost of the treatment of 36 pallets if solutions 1&2 are implemented:

- Wages for 2 operators = £15/h x 2 operators x (6h) = £180
- Electricity: £0.46/start-up x 2 + £0.75/h of running machine x (4h40) = £4
- Total: £180 + £4 = £184

Cost reductions:
Wages: £375 - £184 = £195 or 51%
Electricity: £9 - £4 = £5 or 53%
Total: £384 - £184 = £200 or 52%

4.5.3. Lead time (time between entry and exit)

In theory, the customer is just paying for the added value time. So, the lead time should be close to the added value time. Currently, the lead time is between one and two weeks whereas the added value time is some minutes. In reality, there are lots of lost times which have to be reduced or eliminated, such as:

- 4 stoppages per day instead of one per day
- Unloading from the truck to the storage space, is the storage time between the truck and the machines necessary? Would it be possible to process directly?
- Bringing the pallets near the shredder
- Going to empty the full cage of cardboard, distance and time too long?
- Unloading and storing 2 paper bales, distance too long

4.5.4. Suggested solutions to improve lead time

4.5.4.1. Solution n°3: Number of operators

4.5.4.1.1. Description of solution 3

The following solution would need a cultural transformation in the company but should be possible because all the operators are multi-skilled and interchangeable. Because of the timing of breaks during the day and their duration, it is impossible for the operators to treat the 36 pallets in 9h30 even if the calculated time treatment corresponds with the running machine time. Currently, operators need one day plus 2h on another day which means 2 maintenance sessions. To avoid this second maintenance session of 1h30min, consideration has been given to working according to the machine and not the operators. This would mean processing the 36 pallets all in one day with two operators working continually on the machine. At the beginning of the day, there would be operator 1 and operator 2 who would begin to work. At break time, operator 1 would stay with operator 3 (who would come from another zone). When operator 2 finishes his break, it would be operator 1 who would go to take a break and operator 2 who would work with operator 3. At the end of operator 2 is break, operator 3 would have a break and would return to his initial work.

4.5.4.1.2. Solution feasibility and cost study

This solution requires a re-organization of working practices and should not lead to additional cost.

4.5.4.1.3. Expected improvements in time and cost

To assess the time and cost savings, calculations were made to find the necessary time to treat 36 pallets. As is depicted in Appendix F, two cases are compared: the current case and the case with solution 3 implemented.

Current cost for the treatment of 36 pallets:

- Wages for 2 operators = £15/h x 2 operators x (12h30) = £375
- Electricity: £0.46/start-up x 5 + £0.75/h of running machine x (9h30) = £9
- Total = £375 + £9 = £384

Cost of the treatment of 36 pallets if solution 3 is implemented:

- Wages for 2 operators = £15/h x 2 operators x (10h20) = £310
- Electricity: £0.46/start-up x 1 + £0.75/h of running machine x (9h05) = £7
- Total: £310 + £7 = £317

Cost reductions:

Wages: £375 - £310 = £65 or 17%

Electricity: £9 - £7 = £2 or 23%

Total: £384 - £317 = £67 or 17%

4.5.4.2. Solution n°4: Storage space for input waste and bales.

When confidential papers (input waste) arrive, they go directly zone 1. They are unloaded from the truck and stored in one area dedicated for this task. Then, they are moved from this area to near the shredder and treated by the operators. So, there is one storage time between the unloading and the processing. Is it necessary and would it be possible to process the input waste directly? For reasons of space, the intermediate storage is necessary because there is not enough space to put all the input waste near the shredder. The distance between the storage space and the shredder is very short. So, the lost time is very little. However as regards as the bales storage, the problem is different and more significant. Indeed, operators need to travel 340m (there and back) to store 2 bales. For this case study, there are 24 bales made which means that the operator has to travel 340 x 12 = 4080m and need 10min x 12 = 120 min just for the task of “storage of bales”. This time could be considerably reduced if the storage space was closer.

4.5.4.2.1. Description of solution n°4

The storage space of the confidential paper bales should be moved into zone 1 as illustrated in appendix E. Indeed, the distance is too long between zone 1 and the current bales storage space. Operators spend too much time travelling through the warehouse. It would be a good solution to create storage space in zone 1 especially for the bales coming out of this zone. The problem is that the bales would need to be protected from the weather. So, it might be conceivable to use a tarpaulin or a roof in this section.

4.5.4.2.2. Solution feasibility and cost study

It will be checked that the bales storage space would fit in zone 1.

- The dimensions of one bale are *1m (height) x 1m (width) x 1.6m (length).* So, the bale surface on the ground would be *1m x 1.6m = 1.6m*^{2}.
- The production is 24 bales per week and the output frequency is twice a month. So, storage space for 48 bales is required.
- The following storage arrangement has been assumed and its total required surface would be *1.6m*^{2} *x 12 = 19.2 m*^{2}.

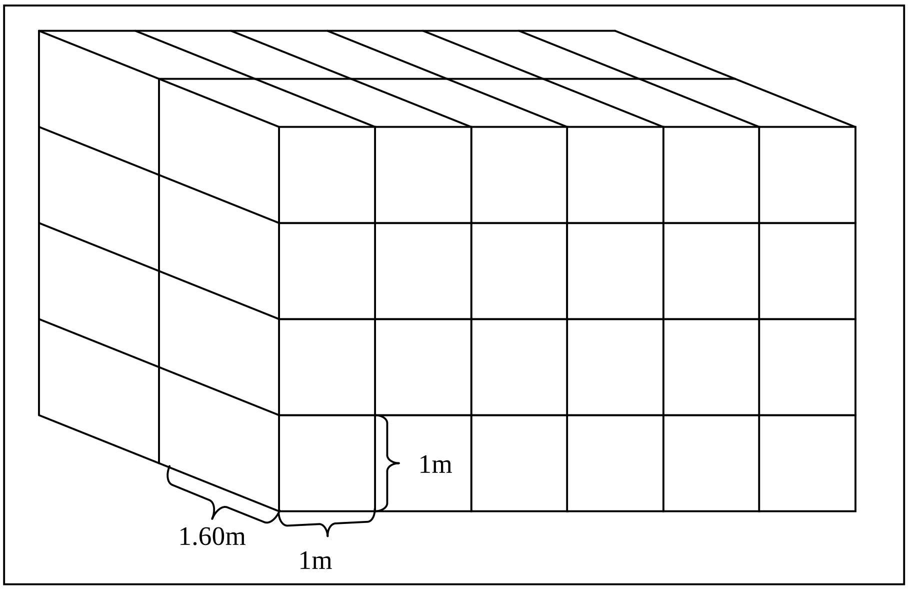

Figure 22: Bales layout for solution 3.

The surface of area designated for the storage of confidential papers is $342m^2$. So, there will be enough space in this area for the storage of bales too. This solution requires a re-organization of the company material resources and should not lead to additional cost.

4.5.4.2.3. Expected improvements in time and cost

Currently, operators need around 10 minutes to go and store 2 bales. If the storage space is moved, this time would be reduced to 2 min. The time gained is 8 min which means in total 96 min.

To assess the time and cost savings, calculations were made to find the necessary time to treat 36 pallets. As is depicted in Appendix G, two cases are compared: the current case and the case with solution 4 implemented.

Current cost for the treatment of 36 pallets:

- Wages for 2 operators = £15/h x 2 operators x (12h30) = £375
- Electricity: £0.46/start-up x 5 + £0.75/h of running machine x (9h30) = £9
- Total = £375 + £9 = £384

Cost for the treatment of 36 pallets if solution 4 is implemented:

- Wages for 2 operators = £15/h x 2 operators x (9h15) = £278

- Electricity: £0.46/start-up x 3 + £0.75/h of running machine x (7h50) = £7
- Total: £278 + £7 = £285

Cost reductions:

Wages: £375 - £278 = £98 or 25%

Electricity: £9 - £7 = £2 or 23%

Total: £384 - £285 = £100 or 26%

Other improvements relating to operators' safety should result. Indeed, under to this solution, operators would not leave their area anymore. So, they would not cross the warehouse, meet other operators and machines, thus reducing the risk of collision.

4.5.4.3. Solution n°5 (2bis and 4bis): Hole through the wall separating zone 1 and zone 2.

4.5.4.3.1. Description of solution n°5

If the manager does not want to implement solutions 2 and 4, it would be possible to find an easier solution, less effective in cost reduction but possibly less complicated to implement. This solution would consist of making a hole in the wall separating zone 1 and zone 2 (See appendix E). It would be large enough to enable a forklift to go directly from zone 1 to zone 2 without going outside or passing through the storage area of zone 1 or the security gates. This solution would reduce the distance to go to empty the full cage of cardboard and to go to store the bales.

4.5.4.3.2. Solution feasibility and cost study

According to the operators it should be possible. With regard to the costs of this implementation, it should not be very high.

4.5.4.3.3. Expected improvements in time and cost

The distance required to go to empty the cage full of cardboard and the distance to go to store the bales has already been calculated:

- distance there and back to empty the cage full of cardboard = 240m
- distance there and back to store the bales = 340m

With the implementation of this hole in the wall, the distance savings would be:

- 60m (there and back)
- new distance to go to empty the cage full of cardboard = 240 – 60 = 180m
- number of times for this case study = 18
- total distance saving = 18 x 60 = 1080m
- new distance there and back to store the bales = 340 – 60 = 280m
- number of times per day = 12
- total distance saving = 12 x 60 = 720m

Currently, operators need around 10 minutes to go and store 2 bales. With the hole in place, this time would be reduced to 8 min. The time gained is 2 min which means in total *12 x 2 = 24 min*. This reduction is very low in comparison with the reduction of 96 min achieved with solution 4.

Currently, operators need around 8 minutes to go and empty the full cage of cardboard. With the hole, this time would be reduced to 6 min. The gained time is 2 min which means in total *18 x 2 = 36 min*. This reduction is very low in comparison with the reduction of 144 min achieved with solution 2.

The total time saving would be one hour which is not sufficient to generate significant cost reductions.

4.5.4.4. Compilation of solutions

To assess the time and cost savings, calculations were made to find the necessary time to treat 36 pallets. As is depicted in Appendix J, two cases are compared: the current case and the case with all solutions implemented.

Current cost for the treatment of 36 pallets:

- Wages for 2 operators = £15/h x 2 operators x (12h30) = £375
- Electricity: £0.46/start-up x 5 + £0.75/h of running machine x (9h30) = £9
- Total = £375 + £9 = £384

Cost for the treatment of 36 pallets if all solutions are implemented:

- Wages for 2 operators = £15/h x 2 operators x (4h40) = £139
- Electricity: £0.46/start-up x 1 + £0.75/h of running machine x (3h23) = £3
- Total: £139 + £3 = £142

Cost reductions:
Wages: £375 - £139 = £236 or 61%
Electricity: £9 - £3 = £6 or 68%
Total: £384 - £142 = £243 or 63%

In conclusion, if all solutions were implemented, the company would achieve from 50 to 60% cost savings or £200 a week. Some investment has to be made such as shredder automation, container instead of cage but they do not represent a lot of money in comparison with the cost savings. To have an idea of the significance of the cost, they were compared with the profits. In one year, the cost savings represent 2 weeks or 4% of profits of zone 1.

5. Study of the future zone 1

5.1. Goal of this study

In the future, there will be a new activity at this site whereby instead of processing and baling all metals together (non ferrous and ferrous metals) in zone 3, will sort, process (shred) and bale the different metals in zone 1 thanks to new machines. In the following study, the researcher wanted to know if the quantities were doubled in the future; would the operators have enough space to work properly. Even if the quantities increase, will the operators be able to work in favourable conditions?

5.2. Forecast results of the future zone 1

Currently, the operators need more than one day to treat 12t of paper. In the future, if the quantities are doubled and working methods do not change, they will need 2.5 days to treat 24t of paper. However, if the changes suggested in part 3, are implemented, they will only need a little part more than one day to treat 24t of paper.

The future metals zone area resources are composed of:

- **two operators** for safety
- shredder and baler processing capacity : **1 tonne per hour**
- forecast input metals: **20 tonnes per week**

The daily work schedule and the daily operations should be the same as the preceding case study (See part 3).

The case study is based on:

- a forecast quantity of around **20 tonnes** of metals to treat **per week**

To assess the required time and cost of treating 20 tonnes of metals, calculations were made as depicted in Appendix I.

Forecast cost for the treatment of 20 tonnes of metals:

- Wages for 2 operators = £15/h x 2 operators x (26h10) = £785
- Electricity: £0.46/start-up x 10 + £0.75/h of running machine x (21h20) = £21
- Total = £785 + £21 = £805

With the forecast quantities for metals, the operators would need 2.5 days to treat 20t of metals at maximum capacity. To reach this maximum capacity, the operators should avoid waste at all times.

5.3. Conclusions

The two different input materials of zone 1 (confidential papers and metals) will not be treated at the same time. The week will be split in two, the first part dedicated to paper treatment and the other one to metal treatment. There will not be any problems of space for operators' motions. However, we are going to mention the consequences of the implementation of the different solutions for the storage space of zone 1.

5.4. Consequences if we implement all solutions in the future zone 1

If solutions 1, 2, 3 and 4, described in part 3 are implemented in zone 1 which would include area dedicated to the metals, there would not be enough space. Indeed, according to solutions, there will be in the storage area:

- confidential papers (inputs)
- bales of confidential papers (outputs) (solution 4)
- the volume of the container part which would be outside (solution 2)

The manager would like to store the input cans in zone 7 instead of zone 6. But maybe it should be more beneficial to place it in the storage area of the future zone 1. The storage area for cans would be something like 170m^2. So, the storage area of zone 1 should be expanded. There is one car park near the storage area of zone 1.It could be possible to eliminate it and expand the storage area by 65m^2. (See appendix D)

6. Study of zones 2&3

Zones 2&3 resources are composed of:

- **five operators**
- sort machine processing capacity : **250 tonnes per week** or 50 tonnes per day
- baler processing capacity : **30 tonnes per hour** or 54 bales per hour (550 kg/bale)
- average input waste : **75 tonnes per day**
- average output bales : **150 bales per day**

The daily work schedule:

- **working hours: 10h30**
  6h → 10h, 10h15 → 13h 10h15 → 13h, 13h30 → 15h, 15h15 → 17h30
- **break periods: 1h**
  10h → 10h15, 13h → 13h30, 15h → 15h15

The daily operations are:

- preventive maintenance/check/clean time = 1h30. Even if there is a preventive maintenance session carried out every morning, it is not sufficient to prevent all the breakdowns. Certain breakdowns are unpredictable as are their scale too.

The baler breakdowns can range from something simple like the wires twisting, in which case around 20 minutes are necessary to fix the problem, to a more complex problem which requires parts to be delivered from Sweden (where the baler come from), in which case it might take one or two days to fix the problem. The repair time depends on the breakdown severity. The sort line hardly ever breaks down, apart from the motor sometimes, but that can be easily fixed, normally with in a couple of hours.

- start-up time = 1 min
- stop time = 1 min
- setup time (between different grades processing) = 1 min
- number of stops and start-up per day = 4 (which correspond with the 3 operators breaks and the end of day)
- number of setups per day = 12
- **total start-up time = 4 min**
- **total stop time = 4 min**
- **total setup time = 12 min**
- **machine running time = 8h45** = 11h30 (day time) – 1h30 (maintenance) – 4 min (start-up time) – 12 min (setup time) – 1h (operators breaks)

The case study is based on:

- a quantity of around **75 tonnes of papers and 4t of plastics** to treat which are the average quantities **per day**
- **average input** deliveries **per day**: **40 trucks of paper** (1.8t of paper/truck) **and 3 trucks of plastics** (1.3t of plastics/truck)
- **average output** deliveries **per day**: **3 trucks**

6.1. Goal of this case study

The theoretical time results are easy to calculate but they do not often correspond with reality because of the various muda and, in addition, because of the lost time through unnecessary tasks and those which are necessary but not adding value to the product. However, even if the theoretical and practical results do not correspond, they can be brought close to each other reduce by eliminating these muda. Our goal in this study is to significantly reduce the existing gap between both by means, principally of a manufacturing re-organization.

6.2. Theoretical results

The baling time for 75 tonnes of papers and 4 tonnes of plastic were calculated as a function of the percentage of each input waste weight of the total weight.

Grade	OUTPUT waste	OUPUT Weight (tonnes per month)	OUTPUT Weight (tonnes per week)	%	Number of loads per month	Number of loads per week	%
4	Office pack	294,2	73,55	19%	11	2,75	16%
5	Newspapers & magazines	722,6	180,65	46%	29	7,25	42%
8	Cardboard	420,76	105,19	27%	19	4,75	28%
9	Mixed papers	48,44	12,11	3%	2	0,5	3%
12	Plastics	28,4	7,1	2%	6	1,5	9%
16	Aluminium & Steel	47,44	11,86	3%	2	0,5	3%
	Total	**1561,84**	**390,46**		**69**	**17,25**	

Table 14: Percentage of each input waste weight of total weight.

- The **baler processing capacity** for:
    - Office pack and mixed papers = 10 tonnes per hour
    - News papers and magazines = 30 tonnes per hour
    - Cardboard = 15 tonnes per hour
    - Plastics = 3 tonnes per hour
- The **different proportions of paper** are the following:
    - Office pack = 20% or 15 tonnes per day
    - Mixed papers = 3% or 2.25 tonnes per day
    - News papers and magazines = 49% or 37 tonnes per day
    - Cardboard = 28% or 21 tonnes per day
- The **processing time** should be:
    - Office pack and mixed papers = (15+2,25)/10 = **1h45min**
    - News papers and magazines = 37/30 = **1h15min**
    - Cardboard = 21/15 = **1h25min**
    - Plastics = 4/3 = **1h20min**
- Setup time = 1 min
- Number of setups per day = 12

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- **Total setup time = 12 min**
- **Total daily processing time** = **6h** = 1h45 + 1h15 + 1h25 + 1h20 + 12 min

Conclusion: operators should treat:
- 75t of paper and 4t of plastics in 6h

There is approximately 14% of input waste which needs to be sorted. The processing time for the sort line was calculated:

- Sort line processing capacity : **200 tonnes per week** or 40 tonnes a day or 4,5 tonnes a hour (one day = 9h of processing)
- **Quantity =** 11 tonnes per day (10t of office pack /day, 0,5t of white letter a day and 0,5t of mixed per day and 0,1t of polythene bags a day) or 5 trucks which represent 14% of input waste
- processing time per 11tonnes = 11/4,5 = **2h30 min**

Conclusion: operators should sort:
- 11t of paper in 2h30

6.3. Practical results and detection of muda

6.3.1. Practical results

Firstly, the different steps which contribute to supply input waste to the baler were observed and studied very carefully. These different steps are split in 2 zones: zone 2 and zone 3. 14% of the input waste goes through the sort line before going to the baler and 86% goes directly to the baler. The steps in relation to the output are mainly in zones 4 and 5. In all zones, the operators (patterns, motions, tasks, time needed for each task) and machines (capacity, productivity, break-ups) were observed and studied in order to detect the useless tasks and movements which take time and compare them with the theoretical results. As opposed to the secure area, it is not the operators who are in charge of unloading the trucks content. Trucks come into zones 2 and 3 and unload their content directly onto the ground tipping the trailer truck. This content is generally processed straight away. There is not an intermediate storage area as in zone 1. The machine locations are illustrated in appendix J.

Step 1 in zone 3. Loading the baler by conveyor belt B.
ONE OPERATOR and ONE TRACTOR

- ✓ **Quantity =** 68t of paper and plastics (or 35 trucks of paper + 3 trucks of plastics going to zone 3) which represent 86% of input waste
- ✓ The operator uses a tractor able to push 3t per lift. Based on this lift capacity and the quantity to push each day, the tractor should do 68/3 = 23 trips. However, this optimized number could not be achieved because each day 38 trucks arrive at zone 3. So, the minimum number of trips is generally 38.

Step 2 in zone 2. Loading the baler by conveyor belt A.
Input coming from the sort line.
ONE OPERATOR and ONE FORKLIFT able to push 3t per lift

- ✓ The sort line normally runs all day from 7h30 to 17h15. So, it should be running for 8h45. However the running time of the sort line it is very variable. It is really hard to say exactly how many hours the sort line runs; if it is busy it will run all day apart from breaks. It also depends on whether they are short staffed, as to whether and for how long it runs.
- ✓ **Occasional tasks which cause lost time for paper processing**. Indeed, some work takes a lot longer than other work, some is time-consuming, such as when they receive pallets of boxes that need to be cut open and emptied. Or some paper might be covered in polythene, which has to be stripped.

Step 3: Processing the wastes: baling

- ✓ The baler normally runs all day from 7h30 to 17h15. So, it runs for 8h45. But, sometimes the baler is not running constantly, operators might get a blockage so then it is all shut down and locked off. And other times it is not running constantly, if there is nothing coming in from trucks, and there is nothing to bale then the baler gets shut down. It is very hard to say exactly when the baler runs constantly and when it is idle. From one day to the next it is never the same. If one day there is a break down, trucks still come in and tip, so operators pile it all up and then run the baler to try to catch up.

Step 4 in zones 4 and 5.

Unloading the bales and loading the empty trucks

ONE OPERATOR and ONE FORKLIFT able to lift 2 bales up.

✓ *Task A. Unloading and storing the bales coming out of the baler.*

- 150 bales per day
- 2 bales per trip
- Number of trips = 150/2 =75
- Time = 1min30s per trip (or 90sec)
- **Total time = 90sec x 75 = 1h50**
- Distance = 90 x 2 = 180m
- **Total distance = 180 x 75 = 13,5km**

✓ *Task B. Loading the stored bales into the empty trucks. .*

- 40 bales per truck
- 5 trucks per day (96trucks per month)
- 200 bales per day
- 2 bales per trip
- Number of trips per day = 200/2 =100
- Time = 2min per trip or 40min per truck
- **Total time = 2 x 100 = 40 x 5 = 200min = 3h20min**
- Distance per trip = 60m
- **Total distance = 100 x 60 = 6km**

There is, for the whole plant, a fourth operator who is mobile and who helps operators who need help. For instance, this mobile operator could push the paper onto the sort line conveyor belt. There is, as well, a fifth operator who is in charge of supervising the four operators of zones 2 and 3 and the two operators of zone 1.

6.3.2. Detection of muda

As has been noticed in part 1.3.1., the different actions on a product are divided into three categories in accordance with whether they create value, or whether they do not create value but are necessary or if they are unnecessary. The different tasks presented in our case study were sorted:

- actions "creating value" = processing input waste (paper and plastics), sorting paper
- actions "not creating value but which are necessary today" = loading the input waste on the conveyor belts, removing paper clips or staples, unloading and storing 2 paper bales
- "unnecessary" actions = in these zones, there are no tasks which seem useless

Conclusion, the muda are clearly:
- muda of motion
- muda of transport

6.4. Cost appraisal for zones 2 and 3

Using the data in part 2.3, the costs for zones 2 and 3 can be calculated:

- **wages for 5 operators : £15 per hour per operator**
- it was not possible to assess the consumption of the baler and sort line and their electricity cost as the information was unavailable. However, the consumption of a shredder is much more important than that of a baler. So, it can be assumed that the electricity costs on zones 2 and 3 are insignificant in comparison with the operators' costs.

6.5. Causes of the muda

6.5.1. Added value time ≈ processing time

- The theoretical and practical times to bale 79 tonnes of wastes (paper + plastics) have already been calculated. Both these times (practical time = 8h45 or 525min; theoretical time = 6h or 360 min) will be used as the usage rate of the machines.

Ro (machines) *= theoretical time/practical time/ = 360/525 =* ***68%***

This usage rate of the baler is quite good taking in account that the baler is not running continually during the day because they is not always input waste coming into zones 2 and 3. In this case the baler is shut down. Operators were unable to estimate this time. It should be between 0 and 2h45 (difference between the practical and the theoretical time). The usage rate of the baler is directly linked to the input flow speed. Operators should focus on the task of “loading waste onto the conveyors” to reach the maximum capacity of the baler. As has been seen before, there are lots of tasks which do not create value. They have to be, if not eliminated, at least significantly reduced. The tasks in question are:

- actions “creating value” = processing input waste (paper and plastics), sorting paper
- actions “not creating value but which are necessary today” = loading the input waste on the conveyor belts, removing paper clips or staples, unloading and storing 2 paper bales
- “unnecessary” actions = in these zones, there are no tasks which seem useless

6.5.2. Observations after having tried to find solutions to improve the added value time or the loading speed

The **theoretical time** to process **79 tonnes of waste is 6h**. This should correspond with the input flow time or loading paper into the conveyors time which is the added value time. The rest of the time represents lost of money. Currently, the **practical processing time is around 8h45**. We are going to look for the reasons for this difference.

Loading in zone 3: According to the operators of this zone, the operator who is in charge of loading in zone 3 can not do more. Indeed, observing area of loading in zone 3, the input flow speed does not seem to depend on the operator work but more on the flow of trucks.

Loading in zone 2: Based on the loading in zone 2, it was not possible to calculate a usage rate for the sort line. Indeed, operators were not able to estimate the time spent on the sort line during a day because it is never the same. The input waste quantities change every day. Moreover, the task of the sort line operator is not only concentrated on sorting paper but also, on removing paper clips or staples. This task takes time and during this time, the operator does not work on sorting paper.

So, taking in account the information obtained by the researcher, it seems difficult to find a solution to increase the input flow speed in zones 2 and 3.

6.5.3. Lead time (time between entry and exit)

In theory, the customer is just paying for the added value time. So, the lead time should be close to the added value time. Currently, the lead time is between one and two weeks whereas the added value time is some minutes. In reality, there are lots of lost times which have to be reduced or eliminated like:

- Unloading and storing 2 paper bales, distance too long

As opposed to the first zone, the stop times are not a problem because they take less time than the operators' breaks.

6.5.4. Suggested solutions to improve lead time

The key to minimizing the distance and time lost through the task of "storage of bales" is to move the baler and the bales storage area closer to each other. According to the actual layout of the plant (except zone 1), it seems quite complicated to find solutions without investment. Unlike solutions for zone 1, these ones will be more costly.

6.5.4.1. Description of both solutions

The two following solutions were found without the operators who did not have any idea of improvements for this zone:

- ***Solution 1***: Move the baler. Even if this solution might seem impossible at the moment because moving the baler would mean stopping processing for some days or more which is not acceptable for the company. However, it is important to speak about it in the event of a general reorganization in the plant. The idea would be to have conveyor belt A going not directly to the baler but to conveyor belt B. Conveyor belt B should go to the opposite direction that is to say in the direction of the actual storage area. Conveyor belt B would go to the baler which would be at the end of conveyor belt B that is to say in the actual inside storage area. Then, the baler would be in the inside storage area and near the outside storage area.

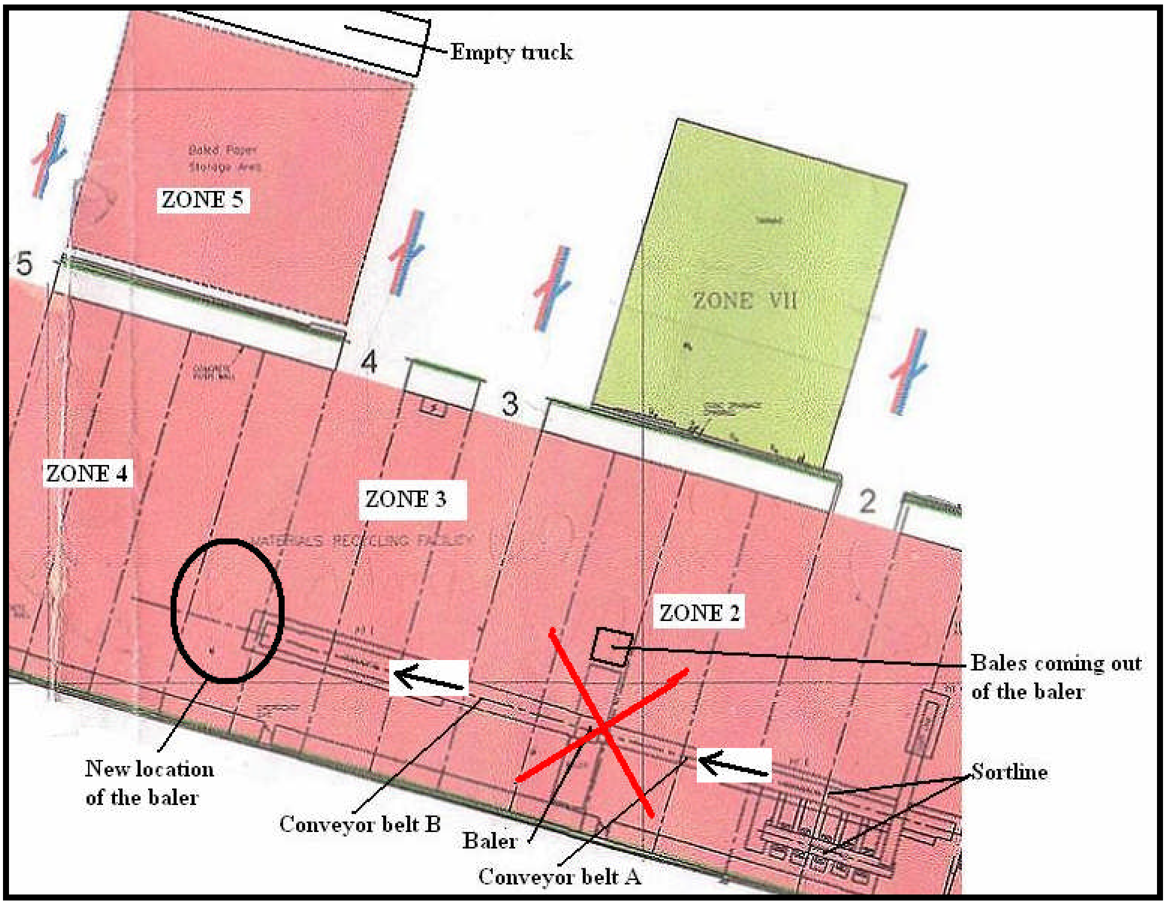

Figure 23: New layout for zone 3 moving the baler.

- ***Solution 2***: Move the storage area. This idea is a little part more complicated because it would involve considerable disruption. In the first solution, it was the baler which was moved to be closer of the storage area. In this solution, we are going to move the storage areas to be closer of the baler. Zone 5 and zone 7 would be inverted. The present zone 7 would become the new outside storage zone. The gates through which the trucks would pass to tip their contents would be 5 and 4 instead of 4 and 3. The gate to go to store the bales and to fill the empty trucks would be 3 instead of 5. There would be some problems in implementing this solution. The first one would be the space to store the bales which go inside. Would the space between zone 2 and zone 3 be big enough to store all the inside bales? The second question is: the empty truck would be near the entrance gates, will there be enough space to allow the trucks to enter in the site?

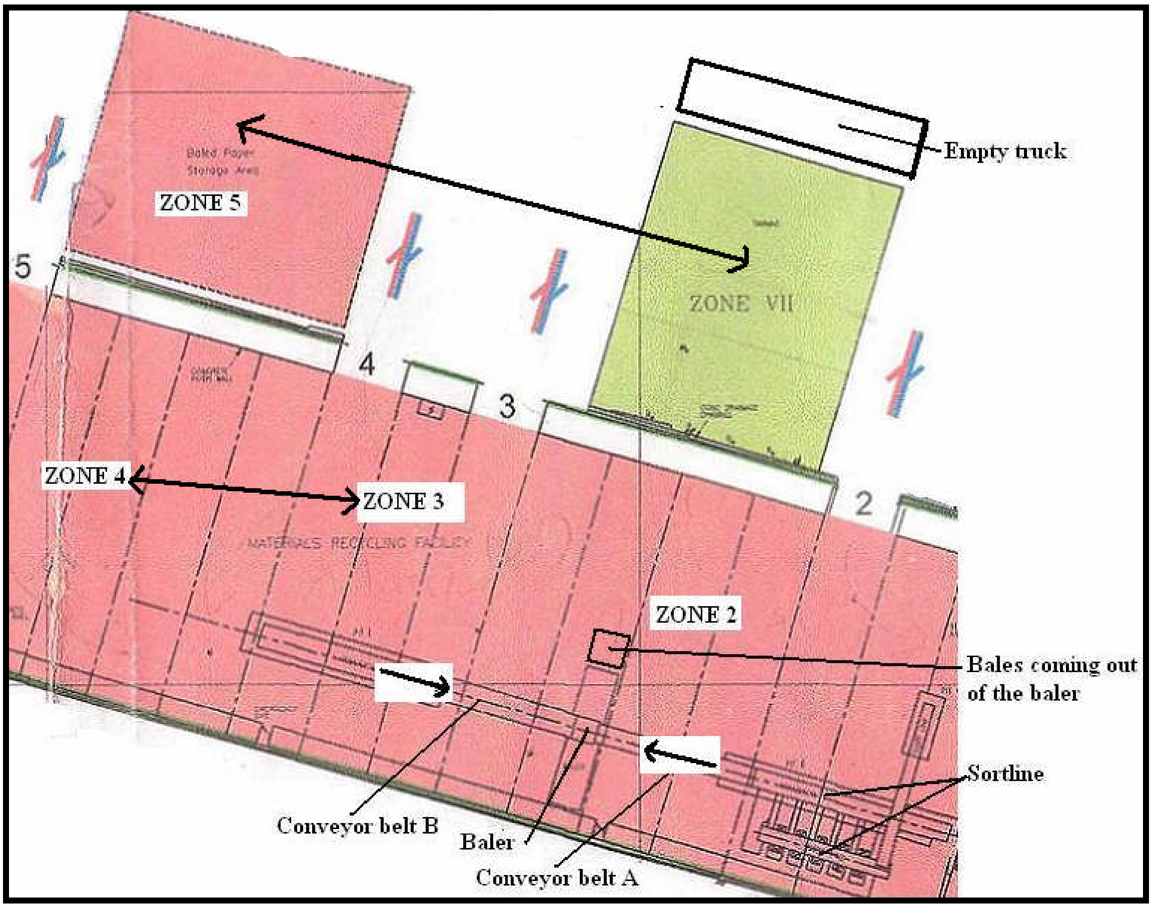

Figure 24: New layout for zone 3 moving the storage areas.

6.5.4.2. Solutions feasibility and cost study

Both solutions are workable but the first one would require a lengthy stoppage of processing and the second one would require a complete reorganization of the storage areas. As regards the cost, though they are just changes of locations but they would be quite expensive.

6.5.4.3. Expected improvements in time and cost

This juxtaposition of the baler and storage areas would enable the operator to save around 50% of distance and time required to store 150 bales.

The current cost of baling 150 bales per day:

- Wages for 1 operator = £15/h x 1 operator x (1h50) = £28

Cost of baling 150 bales per day if one or both solutions are implemented:

- Wages for 1 operator = £15/h x 1 operator x (55 min) = £13

Cost reductions:

Wages: £28 - £13 = £15 or 53%

This juxtaposition of the baler and storage areas is not going to produce distance and time savings in the task of “filling empty trucks”.

In conclusion, thanks to these solutions, the company could achieve around 50% of cost savings for the task of “storing the bales” or £75 a week which is practically nothing in comparison with the savings achieved in zones 2, 3, 4 and 5. The investment which

7. Conclusions

Throughout this study, the different parts of the project have been explained in detail. In this chapter, the stages followed during the project are summarised and the success of the study is evaluated. Further research is also suggested in order to improve the study, what will be positive for the company and will help it thrive.

7.1.1. Summary of the project steps

The project began with a meeting with the Biffa Avonmouth site manager. The project objectives were:

- To compare the theoretical and practical processing time and detect some muda
- To identify areas where improvements could be possible and the most significant (especially problems dealing with handling and logistics) in the different zones
- To suggest solutions to improve these areas;
- To calculate cost reductions due to these suggested solutions.

After having defined the project, the researcher could begin to collect data in the site. The aim was to collect information about the different zones, their operators and their machines. A set of data was gathered and it helped in the cost calculations. They were the following ones:

- Machine capacities and their features
- Machine operational costs
- Productivity
- Income from receiving waste
- Selling prices of output materials
- Operators' costs (wages)
- Different steps required to complete a product process
- Time and distance for these steps.

After the data collection, the work focused on the cost calculations. The software used to calculate was Microsoft Excel. The aim of these calculations was to compare the current cost of processing with the cost of processing if the suggested solutions were implemented. Costs processing were significantly reduced then the objectives of the project have been fulfilled.

Indeed, thanks to these solutions, the company could achieve around 50% of cost savings in all zones. However, the investment are variable according to each zone and sometimes, it is not relevant to make too high investment to get little cost savings.

7.1.2. Benefits to the company

The recycling business is an activity that it is trying to grow. This study is the first stage to demonstrate that manufacturing knowledge could have lots of positive effects in the waste sector. One of the most important would be cost reductions. Another one could be a better understanding of the way to optimize human and materials resources.

7.1.3. Limitation of the research: reliability of the data

With regard to the inputs and outputs data, they were those of the month of June/July and the site manager assured us that data were representative of those of the year.

Regarding zones data, they were not precise. In this case study, approximations were done to calculate costs. Calculations were used to have an idea of the possible cost reductions. Several data taken in several days would be necessary to make exact calculations. So, it should be someone of the company who should later do a deeper study.

Conclusions

This report describes a project which sought to test the relevance and value of manufacturing knowledge to waste site operators, by bringing together the expertise and the manufacturing knowledge to waste operators. The industrial aim is to significantly reduce operating costs.

1. Results, improvements and costs reductions

At the beginning of the project, the researcher thought that the potential scale of these changes can be very important and advantageous when we consider that the Japanese car manufacturer, Toyota, used lean manufacturing to show the then world leading Ford how to reduce production costs by 30%. The researcher worked closely with two waste companies (EnvironCom and Biffa) and their data. The researcher analysed their current operations, implemented some manufacturing knowledge in their plants, suggested some improvements and specific proposals for changing operations and predicted the possible results and cost reductions achieved from these implementations. Both companies have to be distinguished and it is necessary to discuss the two different projects. The Biffa project was focused on analysing their manufacturing practices and improving them to reduce their processing costs. The EnvironCom project was however focused on applying manufacturing knowledge to determine the operations strategy for a new recycling plant in order to maximise its effectiveness and the value of material streams coming out of the machine. Both projects were aimed at increasing company profits. At the Biffa site, costs had to be reduced in order to increase the profits whereas at EnvironCom, revenue had to be increased in order to increase the profits.

With regard to the Biffa case study, different manufacturing problems were detected handling and logistics. The suggested improvements could involve significant cost reductions if they were to be implemented. Indeed, the researcher predicted, according to each suggested solution, cost reductions from 17% to 52%. If all solutions were implemented, Biffa could achieve a cost reduction of 63%.

It has been shown throughout the EnvironCom case study that manufacturing knowledge is needed in the recycling business so that it can be successful. At this moment, it is a developing business and it needs to gain experience in order to become more profitable. The use of softwares in order to manage the different processes is vital for speeding up the decision-making. The model explained in this study is part of this movement and it represents the first stage of the development of a more sophisticated tool. More efforts have to be dedicated to the collection of data in order to enhance the reliability of the tool. The recycling business will benefit from it.

2. Which parts of manufacturing knowledge are most relevant?

To select, adjust and implement some parts of manufacturing knowledge in both companies, it was necessary to take into account an exhaustive literature review on lean manufacturing and the results of questionnaires and interviews made with waste companies. Lean concept is a very complete concept. It is not a simple production method but a management system rooted in key principles (continuous improvement, respect and involvement of employees), with key objectives (create only value for products, stable long-term growth), supported by methods and tools (Kaizen, Just-in-Time, 5S, standard work, cellular manufacturing, total productive maintenance, etc.). This concept and its methods and tools take a lot of time to be implemented. Therefore, to have an idea of the significant results that a company can achieve, it is possible to progressively begin the implementation and distinguish 3 levels of lean thinking:

- Definition of the product’s added value that is created by the company,
- Development of an original management system,
- Development of a characteristic production system.

In the Biffa case study, the researcher used these 3 levels of lean thinking. Firstly, she tried to define the true value of the output products according to the customers and divide the different actions on the product into three categories (actions “creating value”, actions “not creating value but which are necessary today” and “unnecessary” actions). This important phase was helpful to detect muda, work on their elimination and focus on the actions creating value for products. None of the methods and tools described above were used because of the lack of time. However, the researcher used simple things such as cost analysis, simulation, scheduling, site layout and material handling. It was sufficient to demonstrate the possible results and cost reductions. Moreover, it is important to mention that Biffa has a significant advantage in comparison with most waste companies; the operators' team of this facility is multi-skilled. This is an important force for the site manager if he wants to implement lean manufacturing in his company. Indeed, employees are one of the keys of success for the lean manufacturing implementation.

3. Levels of manufacturing knowledge in the waste sector?

The rapid transformation of the waste sector has significantly altered the nature of the traditional waste processing business and the nature of competencies required to manage it. With the increase in volume of waste being processed, one element of the transformation of the waste sector, is the move from a craft-industry often with agricultural methods to a post-industrial sector processing high volumes of materials efficiently and effectively. The waste sector is relatively immature at managing material flows, particularly within a facility. Traditional layout, often based on site history, is one cause. A focus on efficient use of a critical technological investment is another. Over the last two centuries the manufacturing sector has also moved from a craft industry to one that has learnt how to use technology for material processing, and then learnt how to organise for efficient high-volume production. In the latest revolution the mass-production paradigm has been replaced by that of lean production.
To know the levels of manufacturing knowledge in the waste sector, it was first necessary to get an exhaustive knowledge in manufacturing, particularly of lean manufacturing. It is a business model and a set of methods that helps eliminate muda (overproduction, waiting, transport, overprocessing, inventories, motion and defective parts) while delivering quality products on time and at minimal cost with greater efficiency. It is the systematic elimination of muda from all aspects of an organization's operations, where muda is viewed as any use or loss of resources that does not lead directly to creating the product or service a customer wants when they want it.

Once this manufacturing knowledge was understood and acquired by the researcher, waste operators current practices in operations management were characterised and their existing access to manufacturing knowledge was described; based on a questionnaire and interviews with several waste companies.

It was concluded that the manufacturing knowledge of waste companies is very low. The first issue was the vocabulary; most interviewed companies did not know the vocabulary dealing with manufacturing and had some difficulties to understand the different questions not because of the complexity but because of the technical words. So, most of the time, the researcher has to explain the questions. The second problem is that most waste companies do not think they have organizational problems. From their point of view, all is running well and when problems occurred they tried to manage them as quick possible to not lose money. They do not think it is possible to run their company a different way to reduce their cost, to improve the products quality, to improve their benefits because they do not question their questions.

4. Conclusions and recommendations for the future

The research has provided some evidence to support the conclusion that if a minimum of manufacturing knowledge would be acquired by waste sector, waste companies could considerably improve profits. But applying methods and tools from manufacturing demands that waste companies understand and acquire knowledge of manufacturing's own lessons, learnt over two centuries. The knowledge is neither complex nor difficult to use, but it does need to be adjusted for easy application in waste companies. The companies studied appeared to be good practitioners, yet significant improvements were possible; for many of the waste companies surveyed there was a belief that the company "is running well", which would indicate potential for denial of the value of such external knowledge. One lesson from the recent history of manufacturing is that a business is a very complex system where even if it seems to be running correctly it may be possible to improve performance very significantly.

Manufacturing training and support could be organized or supported by DEFRA for waste companies. Initial focus should be on giving waste companies an increased awareness of manufacturing, its vocabulary, its tools and their performance advantages, and its differences in comparison with waste sector. This would beneficially include organized company visits to help the waste sector understand the way to implement techniques and tools of manufacturing. Various schemes are already used within the manufacturing and other sectors to use this knowledge (such as the ‘Industry Forum’ model and Manufacturing Advisory Service), these have proven delivery and tested methods which should be studied to assess their applicability and value to the sector.

Finally, to begin the process of improving waste sector understanding of the value of manufacturing knowledge, DEFRA could use its own activities and dissemination routes, as well as creating a website dedicated to manufacturing practices. DEFRA could also specifically sponsor different forms of projects in waste companies to demonstrate practices, changes and improvements.

References

Books

- ✓ Harrington, HJ. *Business Process Improvement, The Breakthrough strategy for total quality, productivity and competitiveness.* McCraw-Hill Book company, new york, 1991.

- ✓ Womack, J.P. and Jones D.T. *Lean Thinking: Banish Waste and Create Wealth in your Corporation* Simon and Schuster, New York and London, 1996.

- ✓ Womack, J.P., Jones, D.T. and Roos, D. *The Machine that Changed the World* Rawson. Macmillan: New York and Oxford, 1990.

Journals articles

- ✓ Jirang, Cui and Eric, Forssberg. Mechanical recycling of waste electric and electronic equipment: a review. *Journal of Hazardous Materials.* B99, 2003, p. 243-263.

- ✓ Melton, T. The benefits of lean manufacturing. What Lean Thinking has to Offer the Process Industries. *Chemical Engineering Research and Design.* Vol.83 No.A6, 2005, p. 662-673.

Internet resources

- ✓ ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie). http://www2.ademe.fr/servlet/getDoc?id=11433&m=3cid=96. (accessed November 2005).

- ✓ DEFRA (Department for Environment, Food and Rural Affairs). http://www.defra.gov.uk/environment/statistics/waste/kf/wrkf02.htm. (accessed October 2005).

- ✓ Ecotic.http://www.ecotic.es/opencms/opencms/ecotic/es/index.html. (accessed March 2006).

- ✓ EnvironCom (Waste electric and electronical recycling). http://www.environcom.co.uk/. (accessed October 2005).

- ✓ Industry Council For Electronic Equipment Recycling (ICER). http://www.icer.org.uk/. (accessed October 2005).
- ✓ Lean Enterprise Institute (USA). http://www.lean.org/.(accessed October 2005).
- ✓ SITA. http://www.sita.co.uk/. (accessed March 2006).
- ✓ Strategos, consultants, engineers, strategists. http://www.strategosinc.com/. (accessed October 2005).
- ✓ US Environmental Protection Agency. http://www.epa.gov/lean/. (accessed November 2005).

Bibliography

Books

- ✓ Bicheno, John. *The new lean toolbox: towards fast, flexible flow.* Buckingham: PICSIE Books, 2004.
- ✓ Conner, Gary. *Lean manufacturing for the small shop*. Dearborn, MI: Society of Manufacturing Engineers, 2001.
- ✓ Duggan, Kevin J. *Creating mixed model value streams: practical lean techniques for building to demand.* NY: Productivity Press, 2002.
- ✓ Harrington, HJ. *Business Process Improvement, The Breakthrough strategy for total quality, productivity and competitiveness.* McCraw-Hill Book company, new york, 1991.
- ✓ Hines, Peter. *Value Stream Mapping***.** Addison Wesley, 1999.
- ✓ Hines, Peter and Taylor, David. *Going Lean: A Guide to Implementation.* Lean Enterprise Research Centre, Cardiff, 2000.
- ✓ Jordan, James A. and Michel Jr Frederick J. *The lean company: making the right choices.* Dearborn, Michigan: Society of Manufacturing Engineers, 2001.
- ✓ Kotter, JP. *Leading Change, Why transformation efforts fail.* Harvard business review, 1995.
- ✓ Tapping, Don, Luyster, Tom and Shuker, Tom. *Value Stream Management*. NY : Productivity,Inc, 2002.
- ✓ Womack, J.P. and Jones D.T. *Lean Thinking: Banish Waste and Create Wealth in your Corporation* Simon and Schuster, New York and London, 1996.
- ✓ Womack, J.P., Jones, D.T. and Roos, D. *The Machine that Changed the World* Rawson. Macmillan: New York and Oxford, 1990.

Conferences papers

- ✓ Hines, Peter, James, Richard and Jones, Owen. The Supplier Development Grid: A Tool for Awareness Raising, Acceptance and Successful Implementation. *Proceedings of the 2nd International Symposium on Logistics*, The University of Nottingham, 11-12 July 1995, pp. 87-94.

Journals articles

- ✓ Ahmad, Munir, Dhafr, Nasreddin, Benson, Roger and Burgess, Brian. Model for establishing theoretical targets at the shop floor level in specialty chemicals manufacturing organizations. *Robotics and Computer-Integrated Manufacturing.* Vol.21 pp 391-400, 2005

- ✓ Brennan, L., Gupta, S.M. and Taleb, K. N. Operations Planning Issues in an Assembly/Disassembly Environment. *Introduction Journal of Operations and Production Management.* Vol.14 No.9, 1994, p. 57-67.

- ✓ Brunt, D. Value stream mapping tools: application and results. *Logistics and Transport Focus*, 7(2), 1999, p. 24–31.

- ✓ De Ron, A. and Penev, K. Disassembly and recycling of electronic consumer products: an overview. *Technovation.* Vol.15 No.6, 1995, p. 363-374.

- ✓ Emiliani, M.L. and Stec, D.J. Leaders lost in transformation. *Leadership & Organisation Development Journal.* Vol.26 No.5, 2005, p. 370-387.

- ✓ Hines, P., Holweg, M. and Rich, N. Learning to evolve. A review of contemporary lean thinking. *International Journal of Operations & Production Management* Vol.24 No.10, 2004 p. 994-1011.

- ✓ Hines, P. and Rich, N. The Seven Value Stream Mapping Tools. *International Journal of Operations and Production Management*, 17(1), 1997.

- ✓ Gungor, A. and Gupta, S.M. Issues in environmentally conscious manufacturing and product recovery: a survey. *Computers And Industrial Engineering.* Vol.36, 1999, p. 811-853.

- ✓ Jirang, Cui and Eric, Forssberg. Mechanical recycling of waste electric and electronic equipment: a review. *Journal of Hazardous Materials.* B99, 2003, p. 243-263.

- ✓ Kizilkaya, E. and Gupta, S.M. Material Flow Control and Scheduling in a Disassembly Environment. *Computers ind. Engineering.* Vol.35 No.1-2, 1998, p. 93-96.

✓ Melton, T. The benefits of lean manufacturing. What Lean Thinking has to Offer the Process Industries. *Chemical Engineering Research and Design.* Vol.83 No.A6, 2005, p. 662-673.

✓ Motwani, Jaideep. A business process change framework for examining lean manufacturing: a case study. *Industrial Management & Data Systems.*

✓ Simons, David and Zokaei, Keivan. Application of lean paradigm in red meat processing. *British Food Journal.* Vol.107 No.4, 2005, p. 192-211.

✓ Wiendahl, H.P., Seliger, G., Perlewitz, H. and Bürkner, S. A general approach to disassembly planning and control. *Production planning and control.* Vol.10 No.8, 1999, p. 718-726.

Theses

✓ Amiot, G. *Study of the implementation of just-in-time manufacturing system at Hepworth Plumbing Products*. Thesis (M.Sc.) - Cranfield University, School of Industrial and Manufacturing Science, 2004.

✓ Campos Martos, Natalia. *Production flow improvements in Eaton aeroquip*. Thesis (M.Sc.), Cranfield University, School of Industrial and Manufacturing Science, EMMS, 2001.

✓ De Veer, M. *Impact of the WEEE legislation in UK-based manufacturing companies: an exploratory study.* Thesis (M.Sc.) - Cranfield University, School of Industrial & Manufacturing Science, 2004.

✓ Kamali, Saman. *The implementation of lean thinking to a medium sized construction company*. Thesis (M.Sc.), Cranfield University, School of Industrial & Manufacturing Science, 2002.

✓ Richards, D.P. *Application of lean and agile concepts in industry*. Thesis (MRes.), Cranfield University, School of Industrial and Manufacturing Science, 2002.

Internet resources

✓ ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie). http://www2.ademe.fr/servlet/getDoc?id=11433&m=3cid=96. (accessed November 2005).

✓ Biffa Waste Services. http://www.Biffa.co.uk/. (accessed October 2005).

✓ Cardiff University Waste Research section Sustainable Waste Management. http://www.wasteguide.org.uk/. (accessed October 2005).

- ✓ Chartered Institution of Wastes Management (CIWM). http://www.ciwm.org.uk/. (accessed October 2005).
- ✓ DEFRA (Department for Environment, Food and Rural Affairs). http://www.defra.gov.uk/environment/statistics/waste/kf/wrkf02.htm. (accessed October 2005).
- ✓ Ecotic.http://www.ecotic.es/opencms/opencms/ecotic/es/index.html. (accessed March 2006).
- ✓ EnvironCom (Waste electric and electronical recycling). http://www.environcom.co.uk/. (accessed October 2005).
- ✓ Environmental Data Services Ltd (ENDS)**.** http://www.ends.co.uk/. (accessed October 2005).
- ✓ Environmental Services Association. http://www.esauk.org/. (accessed October 2005).
- ✓ European Environment Agency. http://www.eea.europa.eu/. (accessed October 2005).
- ✓ Industry Council For Electronic Equipment Recycling (ICER). http://www.icer.org.uk/. (accessed October 2005).
- ✓ Integrated Waste Management Centre. http://www.cranfield.ac.uk/sims/waste/. (accessed October 2005).
- ✓ Iswa International Waste Association. http://www.iswa.org/. (accessed October 2005).
- ✓ Land Regeneration Network (Cardiff University). http://www.grc.cf.ac.uk/lrn/resources/waste/management/recovery/index.php. (accessed October 2005).
- ✓ Lean Entreprise Academy (Ross-on-Wye, Herefordshire, UK). http://www.leanuk.org/. (accessed October 2005).
- ✓ Lean Enterprise Institute (USA). http://www.lean.org/.(accessed October 2005).
- ✓ Lean Enterprise Research Centre. Cardiff University Business School (UK). http://www.cf.ac.uk/carbs/lom/lerc/. (accessed November 2005).
- ✓ Lean Manufacturing Tools. http://www.managementsupport.com/leantools.htm. (accessed November 2005).
- ✓ LetsRecycle. http://www.letsrecycle.com/equipment/electronics.jsp. (accessed November 2005).

- ✓ Manufacturing Institute. http://www.manufacturinginstitute.co.uk/. (accessed October 2005).
- ✓ Projet Lean Enterprise (France). http://www.lean.enst.fr/. (accessed October 2005).
- ✓ SITA. http://www.sita.co.uk/. (accessed March 2006).
- ✓ SMMT: Industry Forum. http://www.industryforum.co.uk/default.shtml. (accessed October 2005).
- ✓ Strategos, consultants, engineers, strategists. http://www.strategosinc.com/. (accessed October 2005).
- ✓ The Environment Agency. http://environment-agency.gov.uk/. (accessed October 2005).
- ✓ US Environmental Protection Agency. http://www.epa.gov/lean/. (accessed November 2005).
- ✓ Waste and Resources Action Programme. http://www.wrap.org.uk/. (accessed November 2005).
- ✓ Waste Online. http://www.wasteonline.org.uk/. (accessed November 2005).
- ✓ Waste watch. http://www.wastewatch.org.uk/research/downloads/RethinkingWasteManagementToReapRewards1.pdf . (accessed November 2005).
- ✓ Wikipedia. http://fr.wikipedia.org/wiki/Lean. (accessed October 2005).

Appendix

Appendix A: Questionnaire design

Questionnaire investigating lean manufacturing knowledge of waste companies.

Instructions to fill the questionnaire:

1. READ carefully the following questionnaire.
2. They are 2 kinds of questions:
    a. Questions where the answer is "a number, a short sentence or just YES or NO"
    b. Multiple choice questions where you have to tick the appropriate box
3. If you don't know the answer, put "I DON'T KNOW" and if it is possible the CAUSE: through lack of data, misunderstood question etc…
4. If you operate more than one site, or are commenting on the industry in general. Please choose one particular site and give answers in relation to its data.
   What is the chosen site/company ?

Information about your company

Name:

Address:

Tel:

Fax:

Email:

Website:

Contact:

Position:
(or you can choose to staple your business card to this sheet)

Number of employees:

Type of Operation:

Products and Services:

Manager's Background:

1. Market

1.1 What is your company turnover?

1.2 What are your company benefits?

1.3 About regulations:

- Which ones influence your business?
- How do they influence it?

1.4 About customers (before treatment):

- Kind of customer? (council, independent, company …)
- What is the monthly frequency of delivery?
- Reliability of supply of raw waste? (% variation)
- Number of customers total?
- Average number of customers in one week (or other time period)?
- Purchase price (give a range)

1.5 About customers (post-treatment):

- Kind of customer? (council, independent, company …)
- What is the monthly frequency of delivery?
- Reliability of supply of raw waste? (% variation)
- Number of customers total?
- Average number of customers in one week (or other time period)?
- Give maximum and minimum number of customers that you can have in one year.
- Sales price (give a range)

1.6 About suppliers:

- Do you have anything supplied?
- What is it? (tools, products)

2. Materials

2.1 What is the nature of waste coming in (green, WEEE etc…)?

2.2 What is the quantity of input waste…

- …per year?
- …daily average?
- …maximum & minimum?

2.3 How many different kinds of WASTE are in INPUT?
(which need a change of machine or process)

2.4 How many different kinds of PRODUCT are in OUTPUT? (things you sell)

3. Flow & Layout & Handling & Logistics

3.1 What portion of total space is used for storage and material handling? (%)

3.2 What portion of the plant space is organized by function or process type? (%)

3.3 What portion of input wastes is delivered directly to the point of use without incoming inspection or storage? (%)

3.4 How would you characterize material handling (movement, time)?

- Load : (put a X in the correct answer)
  1. larger (pallet-size) □
  2. tote-size □
  3. smaller □

- Distance : (put a X in the correct answer)
  1. long (> 100) □
  2. intermediate □
  3. short (< 25) □

- Flow pattern : (put a X in the correct answer)
  1. complex □
  2. apparent with study □
  3. simple & direct □

3.5 How would you rate overall housekeeping and appearance of the plant? (put a X in the correct answer)

1. messy & filthy □
2. occasional mess & some dirt □
3. neat & tidy □

3.6 Have you changed your transport/logistics arrangements to improve performance? (internal and/or external)

If yes – what were the changes, and why did you change?

4. Maintenance

4.1 Have you got equipment records & data? Including records of uptime, repair history, and spare parts. Including repairs and parts manual. (put a X in the correct answer)

1. none stored □
2. substantially complete □
3. complete & accurate □

4.2 Does maintenance have and follow a defined preventive schedule?

4.3 How often do equipment breakdowns limit or interrupt production? (put a X in the correct answer):

1. Rarely □
2. Occasionally □
3. Frequently □

4.4 What is the overall average availability of plant equipment? (%)

5. Setups & WIP (Work-In-Progress)

5.1 Is your equipment (put a X in the correct(s) answer(s)):

1. expensive/automated/single purpose □
2. cheap/manual/multiple purpose □

5.2 What is the number of machines?

5.3 Which machine(s) cause bottlenecks?

5.4 What is the average overall setup time for major equipment? (in minutes)

5.5 What is the lead time? (between in-gate and out-of-gate)

5.6 What is the added value time? (What is the customer paying for?)

6. Quality

6.1 What is the quality of input waste? (impurities) (put a X in the correct answer)

1. low □
2. intermediate □
3. good □

6.2 What is your quality monitoring system?

6.3 Do you use Statistical Process Control (SPC)?

6.4 Amount of scrap from process (failed operation)?

7. Scheduling & Control

7.1 What portion of work-in-process flows directly from one operation to the next without intermediate storage? (%)

7.2 What portion of work-in-progress is under Kanban or similar control? (%) (Kanban= when you observe something is empty, you order from the previous operation)

7.3 What is the on-time delivery performance? (%)

7.4 How do you manage variation in throughput volumes? – for example by (put a X in the correct(s) answer(s)):

1. **…Scheduling inputs** *(Chasing extra deliveries or Turning away orders)*
   ☐

2. **…Scheduling machines** *(Delaying maintenance or Delaying Change-overs)*
   ☐

3. **…Scheduling labour** *(Shift pattern changes or Overtime & flexibility & annual hours or Laying-off & hiring temporary workers)*
   ☐

4. **…Keeping enough raw materials available to fill any delivery gaps**
   ☐

5. **…Others**
   ☐

7.5 Process predictability: Is there variation in your process times? (the time it takes to process a known amount of material through one stage). **If yes, how do you plan the timing for when the next item/batch is available and ready for processing?**

8. Strategy

8.1 What are the key business drivers? (profit, growth, volume, etc)

8.2 What factors most influence your success? (managing cost, reducing waste, adding value, delivering a variety of products/services, reducing WIP, etc)

9. Management Team Approach

9.1 To what extent are managers and workers measured and judged on…(put a X in the correct(s) answer(s)):

- …Setup Performance:

1. Not at all ☐
2. Informally ☐
3. During appraisal ☐
4. Automatically monitored ☐
5. Others ☐

- …Output:

1. Not at all ☐
2. Informally ☐
3. During appraisal ☐
4. Automatically monitored ☐
5. Others ☐

- …Input (effort/hours):

1. Not at all ☐
2. Informally ☐
3. During appraisal ☐
4. Automatically monitored ☐
5. Others ☐

- …Finance (transparency):

1. Not at all ☐
2. Informally ☐
3. During appraisal ☐
4. Automatically monitored ☐
5. Others ☐

- …Other strategy or discipline? (Cleanliness, improvement suggestions, on-time or on-quality work)

9.2 For the categories of Finished Goods, Work-In-Process (WIP) and Purchased/Raw Materials, what portion of managers can state from memory the current turnover and the purpose of each type?

9.3 Do you change your methods to improve labour efficiency?

9.4 What is the typical skills level of people in production? (put a X in the correct(s) answer(s)):

1. Unskilled ☐
2. Team of multi-skilled ☐

9.5 What kind of organization is in your company? (put a X in the correct(s) answer(s)):

1. Directive ☐
2. Formal process (bureaucratic) ☐
3. Consultative ☐
4. Participative ☐
5. Highly participative ☐

9.6 How are workers on the factory floor compensated? (put a X in the correct(s) answer(s)):

1. Individual incentive ☐
2. Weekly wage ☐
3. Work group incentive ☐
4. Salary ☐
5. Annual bonus ☐

9.7 To what extent do people have job security?

9.8 What is the annual personnel turnover? (in %)

9.9 What % of personnel has received at least 8h of teambuilding training?

9.10 What % of personnel are active members of formal work teams, quality teams or problem-solving teams?

10. 7 Muda

10.1 Do the following common concerns arise in your company? (put a X in the correct(s) answer(s)):

1. The extent of warehouse space needed and used ☐
2. Development and production organization imbalance ☐
3. An ever changing process (tweaked) ☐
4. Large engineering costs/time associated with facility modifications ☐

MUDA view point: If you answered YES to any part of the previous questions, there is "OVERPRODUCTION MUDA".

10.2 Do the following common concerns arise in your company? (put a X in the correct answer):

1. There are large amount of 'work in progress' held up in the manufacturing process
– often seen on the balance sheet and as 'piles of inventory' around the site ☐

MUDA view point: If you answered YES to any part of the previous questions, there is "WAITING MUDA".

10.3 Do the following common concerns arise in your company? (put a X in the correct(s) answer(s)):

1. There is movement of pallets of intermediate product around a site or between sites ☐
2. Large warehousing is needed and continual movement of intermediate material on and off site rather than final product ☐

MUDA view point: If you answered YES to any part of the previous questions, there is "TRANSPORT MUDA".

10.4 Do the following common concerns arise in your company? (put a X in the correct answer):

1. Larger buffer stocks within a manufacturing facility and also large warehousing on the site; financially seen as a huge use of working capital ☐

MUDA view point: If you answered YES to any part of the previous questions, there is "INVENTORY MUDA".

10.5 Do the following common concerns arise in your company? (put a X in the correct(s) answer(s)):

1. The reaction stage is typically complete within minutes yet we continue to process for hours or days □
2. We have in- process controls which never show a failure □
3. The delay of documents to accompany finished product □

MUDA view point: If you answered YES to any part of the previous questions, there is "OVERPROCESSING MUDA".

10.6 Do the following common concerns arise in your company? (put a X in the correct(s) answer(s)):

1. Large teams of operators moving to and from the manufacturing unit but less activity actually within the unit □
2. Data entry being seen as a problem within IT systems □

MUDA view point: If you answered YES to any part of the previous questions, there is "MOTION MUDA".

10.7 Do the following common concerns arise in your company? (put a X in the correct(s) answer(s)):

1. Missed or late orders □
2. Excessive overtime □
3. Increased operating costs □

MUDA view point: If you answered YES to any part of the previous questions, there is "DEFECTS MUDA".

11.About Lean Manufacturing:

If you have any problems in answering these questions, please look at the "lean manufacturing" presentation which is on the next page, after the questionnaire.

11.1 Do you have a previous knowledge of lean manufacturing?

Do you have previous knowledge of manufacturing practices?

11.2 What are the key concepts that might interest you?

What are the main things you remember?

11.3 Do you think there is any value to a waste business in using lean techniques? Where is the greatest opportunity to improve?

11.4 What operational problems do you think that waste businesses have now?

Thank you for answering the questionnaire.

Now, please can you look at the following "lean manufacturing" presentation.

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Integrated Waste Management Centre

Lean Manufacturing

&

Waste companies

January 2006

1

Cranfield UNIVERSITY

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1. History of Lean Manufacturing

→ 1910s: Mass production: Henry Ford
large high volume production of standardized products
with minimal product changeovers (PUSH system)

→ 1940s: Toyota Production System: Taichi Ohno (opposite of Ford's philosophy)
products are made only when customers order them (PULL system)

→ 1st book: *The Machine that Changed the World* (Womack et al., 1990)
high-lights Japanese production methods

→ Key book: *Lean Thinking: Banish Waste and Create Wealth in your Organization* (Womack and Jones, 1996)
coined the LEAN term and summarized
the lean manufacturing principles

2

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2. Advantages of Lean Manufacturing

- Driving force: boost company profits and competitiveness
- Advantages :
  - Reduction production resource requirements and costs
  - Improvement product quality
  - Customer satisfaction
- Some improvements of certain companies:
  - Lead time: 23,5 → 4,5 days
  - Added value time: 184 → 169s
  - Changeover time: 60 → 10 min
  - Inventories: 17130 → 3250 pieces
  - Defective parts: 5 → 0,5%

3

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3. Lean Manufacturing

- IS NOT a simple production method BUT IS a management system, framework of processes and procedures used to ensure that an organization can fulfill all tasks required to achieve its objectives.
- 3 levels of lean thinking:
  - Definition of the product's ADDED VALUE that is created by company
  - Development of an original MANAGEMENT system
  - Development of a characteristic PRODUCTION system
- Basic principle: elimination of 7 wastes
  1. overproduction
  2. waiting
  3. unnecessary transport of materials
  4. over-processing
  5. inventories
  6. unnecessary movement by employees during their work
  7. production of defective parts

4

3.1 Product ADDED VALUE

→ Define the true value according to customers. Actions on a product are divided in 3 categories :
- actions "creating value"
- actions "no creating value but necessary today"
- actions "unnecessary"

→ Establish the value stream of the product.
Tools: *value stream mapping (VSM) & process mapping*

VSM: diagram showing the different steps, activities, material flows, communications involved with a process. The process will identify all of the processes in the value stream and differentiate value form waste.

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3.2 Original MANAGEMENT system: Kaizen

→ Lean based on principles of CONTINUOUS IMPROVEMENT (Kaizen in Japanese) & EMPLOYEES INVOLVEMENT

→ Focus of Kaizen:
- Eliminating waste
- Improving productivity
- Sustain continuous improvement

→ Way to implement it:
- Suggestion scheme; improvement process that fixes the improvement
- Workers organized in cross-functional teams
  - Tools: *value stream mapping (VSM), 5 whys…*
- Improvement of workers skills by training and job rotations

→ Ultimate goal of lean : PERFECTION or Ø wastes

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3.2 Who is LEAN?

EASYJET

- No thrills, only web tickets
- Plane is to fly not to stay on the ground, 22 minutes from landing to taking off
- 2002: Order of 120 aircrafts in 5 years with option for 120 in next 5 years
- Plane not full? Sell tickets for 10 Euros (pricing algorithm)

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DELL

- Orders directly from customer by phone or internet
- 1 week to deliver the computer with customer's options
- Inventory is minimised, 11 days of stocks MAXIMUM
- Cheap basic product, earn from adding options
- Principle of 'single person-build'. One person assembles one unit. Improvement of quality.

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3.3 Characteristics PRODUCTION system

- 2 basic principles of production system: FLOW & PULL
- Assure the FLOW of value stream to fight against batch and queue
- Assure it is a PULL system, i.e. wait for the customer order. Not like in mass production where it is a PUSH system.
- First thing to do: calculate the *takt time*
  it allows to synchronise the production rate with customer demand

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- An important concept: Just-In-Time (JIT), provide with the right part, in the right quantity, and at the right time.
  Tools: *Heijunka, Kanban, Single Minute Exchange of Die (SMED)*
- From a traditional "batch and queue" layout to *Cellular Manufacturing*
- Good working conditions & Standardized work
  Tools: *5S, Standard Operation Procedures (SOPs), Total Productive Maintenance (TPM), Jidoka (or Automation) and Poka-yoke*
- *Transparency* or *visual control*

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3.4 Implementation

- 3 components:
  - Roadmap for a succession of change initiatives
  - Transformation of cross-functional infrastructure and processes
  - Cultural transformation
- Make changes consistent with company strategy and lean principles
- Make the right changes at the right times
- Evaluate the benefits of lean change initiatives with metrics

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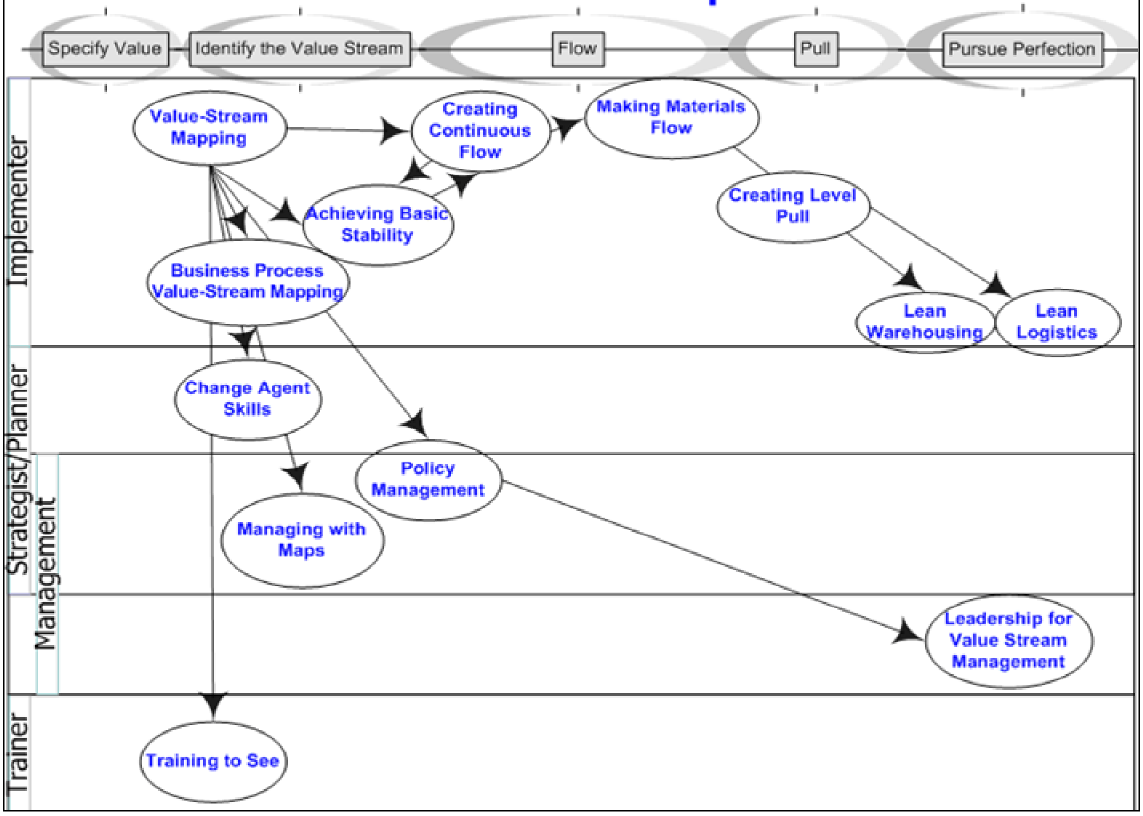
Lean Road Map



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3.5 What has LEAN done for manufacturing?

- → SIMPLIFY
- → REMOVE WASTE
- → FLOW
- → USE BRAINS (continuous improvement)
- → Until a reduction of 90% for lead time, inventory, cost, defective parts…

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4. Differences between Manufacturing & De-Manufacturing

	System characteristics	Manufacturing	De-manufacturing
MARKET	Demand sources	Converge to Single	Diverge to Multiple
	Market position	Seller	Seller & Service Company
	Market dynamic	Predictable	Hard to predict
	Demand	Dependent	Low
	Delivery time	Short	No importance
	Delivery Performance	High	High
	Disposal Cost	-	Low
	Price	Appropriate	Low/unpredictable
	Quality	Appropriate	High
COMPANY	Machine utilization	High	High
	Value of products/raw materials or discarded products	High	Low
	Inventories	Low	No importance
	Storage cost	Low	Low
	Products variety	Normal	Enormous
	Operation times	Predictable	Hard to predict

Appendix B: Questionnaire results compilation

		Maximum Points	1. Donarbon	Score 1.	2. EnvironCom	Score 2.	3. Shanks	Score 3.
0. Information about company	0.1 Name		Ian Paton (consultant)		Bill Milliken		Richard Lucas and Martin Lowe	
	0.2 Choosen location		Donarbon		Grantham		Murph in Glasgow	
	0.3 Employees number		-		65		1200	
	0.4 Company Type		Composting		WEEE		Household waste	
1. Market	1.1 Turnover		-		3,5 millions		-	
	1.2 Benefits		from disposal wastes		for recycling electrical waste		waste management	
	1.3 Regulations							
	which one		EBPR (enhanced biological phosphorus removal)		ODS, WEEE, RoHS		Environmental and landfill regulations. Waste incineration directive.	
	how they influence?		very stric about hygiene		force councils to use waste processes instead of landfill		new technology and new services.	
	1.4 Customers (before)							
	type		council, small independent industries		waste management companies		50% local authorities, 50% waste companies	
	monthly frequency of delivery		5d/w. Regularity depends on the collect system.		daily		daily	
	reliability of supply or raw waste		variation are important in composting plant.		massive fluctuation		busy after christmas. July/august = slow down	
	number				100 (55 represent 80%)		6000	
	average						2000	
	max/min				100/20			
	purchase price		20-40£/t		100-200£/t		30-35£/t	

1. Market	**1.5 Customers (after)**							
	type		independent landscapers, builders		independent companies		reprocessors	
	monthly frequency of delivery				daily		daily	
	reliability of supply or raw waste				6			
	number						300/400	
	average						100	
	max/min				8-4 customers			
	sales price				0, -94£, 1700£		10-15£/t	
	1.6 Suppliers							
	something supplied or no		YES		YES		NO	
	if yes, what		mechnical materials.(loading, scapes, lorries, compactors...)		safety equipment, bags.			
2. Materials	**2.1 waste nature**		residues, organic material		WEEE		All	
	2.2 quantity							
	per year		15 000t/ year ??? (green waste): 50% from council + 50% from independent landscapers. 45 000t/ year (curb wastes). Other site: 20 000t/year (council). ??? + 10 000t of green waste + 200 000t residues stuff.		200 000 fridges, 300 000 TVs, 500 t of WEEE		2000 tonnes of waste	
	daily average				/365			
	max/min				capacity for 300 000 fridges, 500 000 TVs, 100 000t of WEEE			
	2.3 diversity of INPUT waste, how many different?		green, curb, residues materials, paper/cardboard.		6 (fridge, TV, white goods, small WEEE, IT, commercial fridges)		3 or 4	

2. Materials	2.4 diversity of OUTPUT waste, how many different?		compost		14 Fry steel, tin aluminium, stain steel, mix steel/copper, aluminium copper radiators, plastics, landfill, 3 types of glass, brackets, cables, compressors, motors, plugs, full machine…it will increase of 10.		12 (metals, plastics, wood, glass, paper, compost...)	
3. Flow & Layout & Handling & Logistics	3.1 %space for storage and mat.handling	4	as less as possible	2	85%	0	70-80%	0
	3.2 %space is organized by function	4	to be careful to the cross contamination.	0	70%	0	6 different kinds of materials	0
	3.3 %portion of input material is delivered directly without inspection	4	50%	3	50%	3	30%	2
	3.4 mat. Handling	4		0		1		3
	load							
	larger,tote-size,smaller		larger		larger		larger	
	distance							
	long > 100, intermediate, short < 25		long		short		intermediate	
	flow pattern							
	complex, apparent with study, simple & direct		complex		complex		simple and direct	
	3.5 state of housekeeping							
	messy, occasional mess, neat	4	messy	0	messy	0	occasional mess	2
	3.6 change or logistics or no?	4	YES	4	YES	4	YES	4
	why?		cutting cost, moving materials quicker.		logistic based on the concept of layout		change the routes.vehicle in -drop out- process is key	
	total 3	24		9		8		11

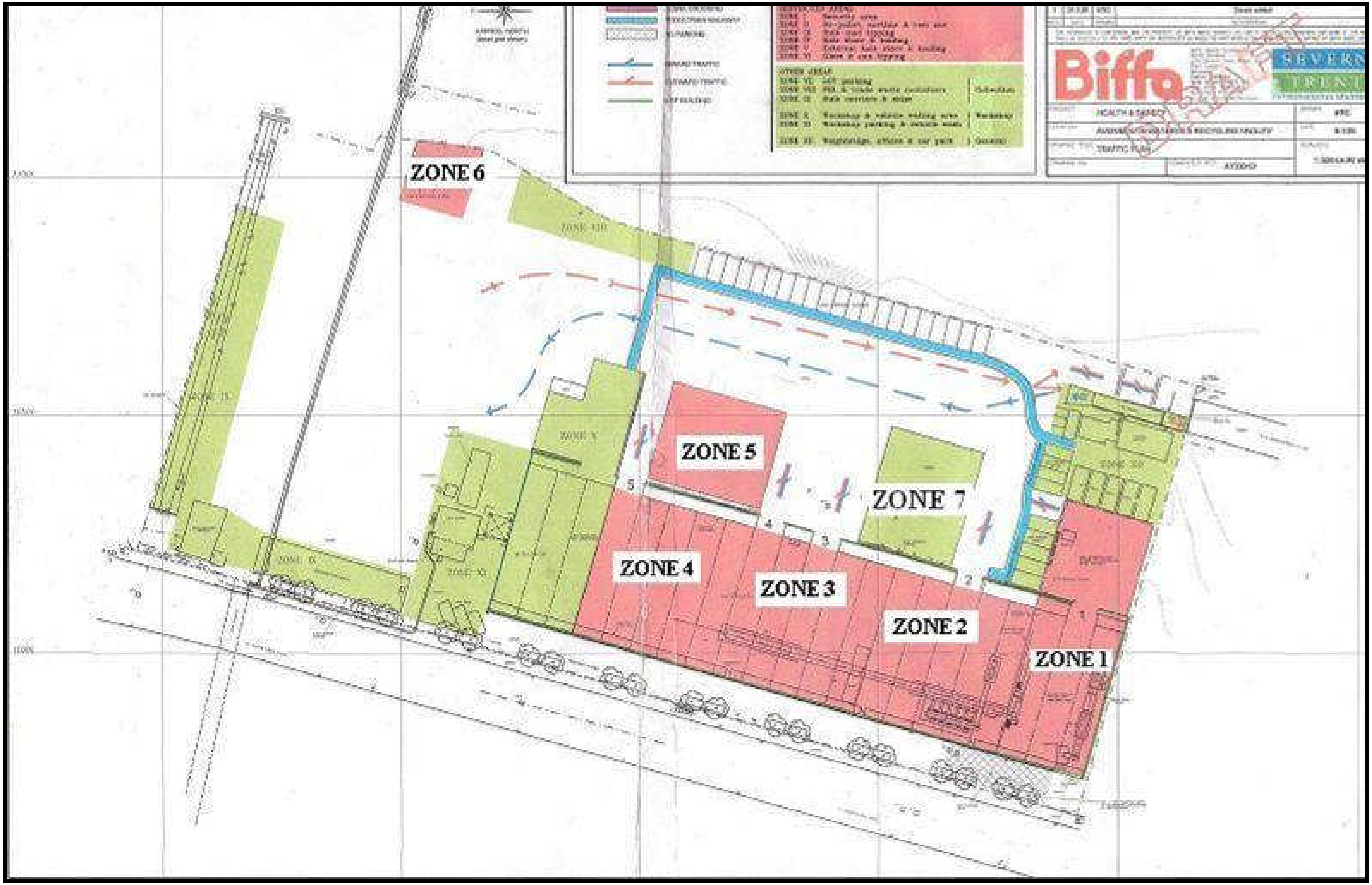
4. Maintenance	4.1 equipment records							
	none stored, substantially complete, complete	4	complete&accurate	4	substantially complete	2	substantially complete	2
	4.2 preventive scedule or no?	4	good maintenance but NO plan.	2	YES	4	Yes. 80/85%	4
	4.3 frequency equipment breakdowns							
	frequently, occasionally, rarely	4	occasionally	2	frequently	0	occasionally	2
	4.4 % availability of equipment	4	80%	0	95%	4	80-85%	0
	total 4	16		8		10		8
5. Setups & WIP	5.1 equipment							
	expensive or cheap	4	expensive	0	expensive (80%) + cheap (20%)	1	expensive (80%) + cheap (20%)	1
	5.2 number machines		5 (shredder, loaders, turning up, screener)		6		10-12 machines. (3-4 conveyors belt, magnets, 2 bailers)	
	5.3 machine is cause bottle neck		vessel (because of requirement for EBPR)		number of loaded/unloaded inputs		bailers	
	5.4 setup time for major equipment	4	1,5h to load up.	0	fridge (1h30 min), WEEE plant (4h)	0	between input batches; after holidays.	0
	5.5 lead time		6-8 weeks.		2-10 days		2-15 days	
	5.6 added value time				10 mins (fridge), 5 mins (TVs)		30-45 min	
	total 5	8		0		1		1
6. Quality	6.1 quality							
	low, intermediate, good	4	depends on market	2	good but delivery is bad	4	good. 10% impurities	4
	6.2 quality monitoring system		each 2 weeks. Tracability.		subjective and visual process control (qualitative)		visual control	
	6.3 statistical process control	4	based on experience	0	NO	0	NO	0
	6.4 amount of scrap	4	1 batch/year. Very little.	4	5% efficiency (&10% landfill)	2	15/20%	1
	total 6	12		6		6		5

7. Scheduling & control	7.1 % WIP is direct	4	100	4	100	4	100	4
	7.2 % WIP under Kanban	4	0	0	0	0		0
	7.3 % on time	4	100	4	performances are not very good	1	100	4
	7.4 variation of volumes:							
	inputs, machines, labour, others		inputs, labour		labour & machines		labour	
	7.5 variation in your process times		yes in the maturing pattern.		NO			
	total 7	**12**		**8**		**5**		**8**
8. Strategy	8.1 Key business drivers		profit		growth		shareholders.profit	
	8.2 What factors for your success		long term contract.treatment disposal cost.		get feedstock		keeping customers, reducing costs, understanding costs, finding markets.	
9. Management team approach	9.1 Judgement of managers & workers...	4		0		1		3
	setup performance							
	not at all, informally, during appraisal, automatically monitored, others...		not at all		not at all		not at all	
	output							
	not at all, informally, during appraisal, automatically monitored, others...		informally		others: management system		automatically monitored	
	input							
	not at all, informally, during appraisal, automatically monitored, others...		not at all		during appraisal, others: management system		automatically monitored	
	finance							
	not at all, informally, during appraisal, automatically monitored, others...		not at all		informally		automatically monitored	
	other strategy				informally		safety:automatically monitored and regularly	
	9.2 % portion of managers can state from memory the current turnover						70%	
	9.3 change methods for labour efficiency	4	NO	0	YES	4	YES (via KPLs)	4

9. Management team approach	**9.4 skills level of people**							
	unskilled or team multi-skilled	4	unskilled except for supervisors	2	unskilled	0	70% unskilled and 30% team multiskilled	2
	9.5 kind of organization							
	directive, formal process, consultative, participative, higly participative	4	directive (for small companies), formal process (international companies)	0	directive	0	consultative, participative	2
	9.6 compensation of workers							
	individual incentive, weekly wage, work grou^incentive, salary, annual bonus	4	weekly wage + maintenance payment + annual bonus	4	weekly wage	1	weekly wage + work group incentive + salary + annual bonus	4
	9.7 job security	4	pretty good job security	2	pretty good job security	2	high	2
	9.8 annual personnel turnover	4	low	1	20/25%	1	low	1
	9.9 %personnel receiving teambuilding training	4	0	0	0	0	60/70%	3
	9.10 %personnel are part of work teams	4	0	0	0	0	most of people	3
	total 9	**36**	**total 9**	**9**	**total 9**	**9**	**total 9**	**24**
	TOTAL	**108**	**TOTAL C1**	**40**	**TOTAL C2**	**39**	**TOTAL C3**	**57**
	en %	**100**	**en %**	**37%**	**en %**	**36%**	**en %**	**53%**
10. 7 Muda	Overproduction	4	YES(4/4)	0	YES (4/4)	0	YES(3/4)	1
	Waiting	4	NO (0/1)	4	YES (1/1)	0	NO (0/1)	4
	Transport	4	NO (0/2)	4	YES (1/2)	2	NO (0/2)	4
	Inventory	4	YES (1/1)	0	YES (1/1)	0	YES (1/1)	0
	Overprocessing	4	YES (2/3)	1	YES (1/3)	3	NO (0/3)	4
	Motion	4	NO (0/2)	4	YES (2/2)	0	YES (1/2)	2
	Defects	4	YES (1/3)	3	YES (3/3)	0	YES (2/3)	2
	TOTAL (10)	**28**	**TOTAL (10) C1**	**16**	**TOTAL (10) C2**	**5**	**TOTAL (10) C3**	**17**
	en %	**100**	**en %**	**57%**	**en %**	**18%**	**en %**	**61%**

11. About lean manufacturing	**11.1 Previous knowledge of lean**				YES			
	About manufacturing				YES			
	11.2 Key concepts interesting in lean				kanban, less people, continuous improvement, visual management, stretch target			
	Main things you remember				product added value, business process mapping			
	11.3 value of lean in waste companies							
	the greatest opportunity				preventive maintenance, overall efficiency, flow			
	11.4 operational problems				downtime (cultural change)			

Appendix C: BIFFA site map


ZONE 6
ZONE 5
ZONE 7
ZONE 4
ZONE 3
ZONE 2
ZONE 1
Biffa
SEVERN
TRENT

Appendix D: Inputs and outputs

Biffa

Charge: +, purchase: -

Paper, Glass, Metals, Plastics

Month: 13/06/06 - 12/07/06

Zone 1: Security area

BIFFA charge 6£/bag, 1 bag = 20 kgs, 50 bag = 1t

Grade	INPUT waste	INPUT Weight (tonnes per month)	INPUT Weight (tonnes per week)	Number of loads per month	Number of loads per week	Charge (£) / Tonne	Total charge (£) /week
9	Confidential papers	47.86	11.965	56	14	300	3589.5
	Total	47.86	11.965	56	14	300	3589.5

Grade	OUTPUT waste	OUPUT Weight (tonnes per month)	OUTPUT Weight (tonnes per week)	Number of loads per month	Number of loads per week	Sell price (£) / Tonne	Total sell price (£) /week
4	Light letter	42.32	10.58	2	0.5	87	920.46
4	Office Pack	5.54	1.385	1	0.25	74	102.49
	Total	47.86	11.965	3	0.75	161	1022.95

Zone 1 Benefit (£)/week	4612.45	18%	Zone 1 Quantity (t)/week	11.97
Zone 1 Average Benefit (£)/tonne	385.50			2%

Zone 2 & 3: Paper, plastics and cans

BIFFA charge 3.5£/lift, 1 lift = 200 kgs

BIFFA pay 30£/tonne

BIFFA charge 3£/lift, 1 lift = 200 kgs

Grade	INPUT waste	INPUT Weight (tonnes per month)	INPUT Weight (tonnes per week)	Number of loads per month	Number of loads per week	Charge or purchase (£) / Tonne	Total charge (£) /week
4	White sulphite lightly printed	7.21	1.8025	5	1.25		0.0
4	Office pack	1.55	0.3875	1	0.25	17.5	6.8
5	Newspapers & magazines	703.1	175.775	216	54	-30	-5273.3
8	Container baled	90.78	22.695	96	24	-30	-680.9
8	Container loose	382.27	95.5675	273	68.25	-30	-2867.0
8	Mixed cardboard	0.07	0.0175	3	0.75	-30	-0.5
9	Unsorted office loose	154.12	38.53	106	26.5	17.5	674.3
9	Mix paper	31.04	7.76	15	3.75	15	116.4
9	Unsorted printers	124.52	31.13	78	19.5	17.5	544.8
9	Reel center	2.58	0.645	6	1.5	17.5	11.3
11	Kraft paper	8.72	2.18	2	0.5		0.0
12	Plastics	32.29	8.0725	60	15	Free of charge	0
16	Aluminium & Steel	37.58	9.395	182	45.5	103.32	970.69
	Total	1575.83	393.9575	1043	260.75	68.32	-6497.4

BIFFA pay 30£/tonne and they charge 4£/bin (1 bin = 30 kgs)

Grade	OUTPUT waste	OUPUT Weight (tonnes per month)	OUTPUT Weight (tonnes per week)	Number of loads per month	Number of loads per week	Sell price (£) / Tonne	Total sell price (£) /week
4	Office pack	294.2	73.55	11	2.75	74	5442.7
5	Newspapers & magazines	722.6	180.65	29	7.25	55	9935.75
8	Cardboard	420.76	105.19	19	4.75	55	5785.45
9	Mixed papers	48.44	12.11	2	0.5	39	472.29
12	Plastics	28.4	7.1	6	1.5	180	0.00
16	Aluminium & Steel	47.44	11.86	2	0.5	900	2668.50
						80	711.60
	Total	1561.84	390.46	69	17.25	1383	25016.29

Zones 2&3 Benefit (£)/week	18518.85	70%	Zones 2&3 Quantity (t)/week	393.96
Zones 2&3 Average Benefit (£)/tonne	47.01			77%

aluminium sell price : £900/t, aluminium represents 25% of total

steel sell price : £80/t, steel represents 75% of total

Zone 6: Glass

BIFFA pay 5£/tonne and they charge 4£/bin (1 bin = 300 kgs)

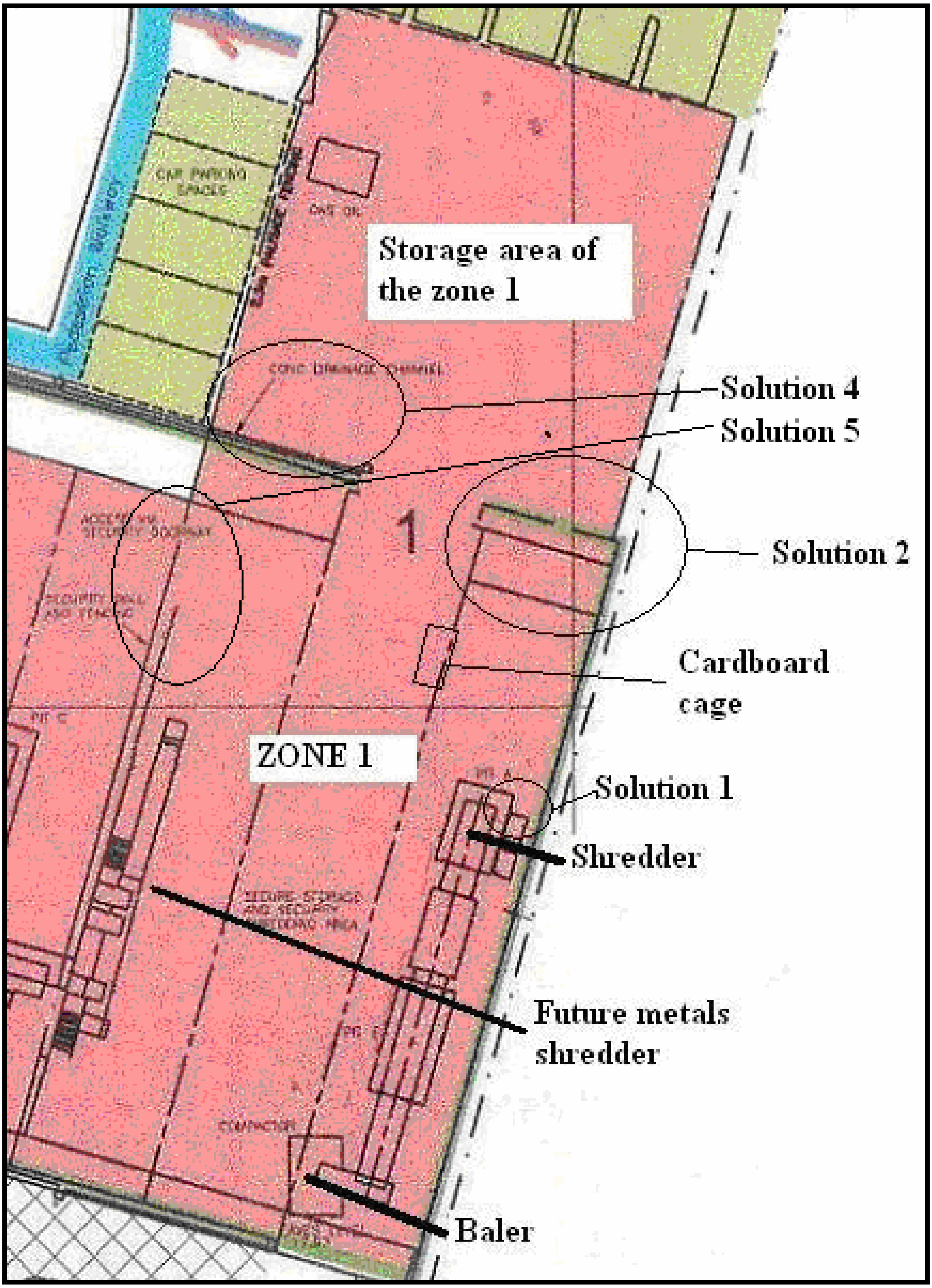
Grade	INPUT waste	INPUT Weight (tonnes per month)	INPUT Weight (tonnes per week)	Number of loads per month	Number of loads per week	Charge or purchase (£) / Tonne	Total charge (£) /week
13	Glass	423.83	105.9575	229	57.25	8.32	881.57
	Total	**423.83**	**105.9575**	**229**	**57.25**	**8.32**	**881.57**

Grade	OUTPUT waste	OUPUT Weight (tonnes per month)	OUTPUT Weight (tonnes per week)	Number of loads per month	Number of loads per week	Sell price (£) / Tonne	Total sell price (£) /week
13	Glass	348.16	87.04	24	6	22	2331.07
	Total	**348.16**	**87.04**	**24**	**6**	**22**	**2331.07**

Zone 6 Benefit (£)/week	**3212.63**	**12%**	**Zone 6 Quantity (t)/week**	**105.96**
Zone 6 Average Benefit (£)/tonne	**30.32**			**21%**

TOTAL Site Benefit (£)/week	**26343.93**	**TOTAL Site Quantity (t)/week**	**511.88**

Appendix E: Zone 1 map


Storage area of the zone 1
Solution 4
Solution 5
Solution 2
Cardboard cage
ZONE 1
Solution 1
Shredder
Future metals shredder
Baler

Appendix F: Zone 1, solution 3

NOW			ASSUMPTION Solution 3		
Time	Operation	Number of treated pallets	Time	Operation	Number of treated pallets
6:00:00	Maintenance and unloading the 3 trucks: 1h15		6:00:00	Maintenance and unloading the 3 trucks:	
7:15:00	*Start-up: 5min*		7:15:00	*Start-up: 5min*	
7:20:00	Beginning		7:20:00	Beginning	
8:20:00	Running	4	8:20:00	Running	4
9:20:00	Running	4	9:20:00	Running	4
10:00:00	Break of 15 min and machine stop time of 20 min	2,7	10:20:00	Running	4
10:20:00	*Start-up: 5min*		11:20:00	Running	4
10:25:00	Beginning		12:20:00	Running	4
11:25:00	Running	4	13:20:00	Running	4
12:25:00	Running	4	14:20:00	Running	4
13:00:00	Lunch break for 30 min and machine stop time of 20 min	2,3	15:20:00	Running	4
13:30:00	*Start-up: 5min*		16:20:00	End	4
13:35:00	Beginning			Total	**36**
14:35:00	Running	4			
15:00:00	Break of 15 min and machine stop time of 20 min	1,6			
15:20:00	*Start-up: 5min*				
15:25:00	Beginning				
16:25:00	Running	4			
17:10:00	Machine stop time of 20 min	3			
17:30:00	End of the day	33,6			
2nd day					
6:00:00	Maintenance: 1h15				
7:15:00	*Start-up: 5min*				
7:20:00	Beginning				
8:00:00	End	2,4			
	Total	**36**			

Summary of current situation		Summary of solution 3	
Total number of start up	5	Total number of start up	1
Total running machine time	9h30	Total running machine time	9h05
Total break time	1h	Total break time	0
Total work time	12h30	Total work time	10h20

Appendix G: Zone 1, solution 4

NOW			ASSUMPTION Solution 4		
Time	Operation	Number of treated pallets	Time	Operation	Number of treated pallets
6:00:00	Maintenance and unloading the 3 trucks: 1h15		6:00:00	Maintenance and unloading the 3 trucks: 1h15	
7:15:00	*Start-up: 5min*		7:15:00	*Start-up: 5min*	
7:20:00	Beginning		7:20:00	Beginning	
8:20:00	Running	4	8:10:00	Running	4
9:20:00	Running	4	9:00:00	Running	4
10:00:00	Break of 15 min and machine stop time of 20 min	2,7	9:50:00	Running	4
10:20:00	*Start-up: 5min*		10:00:00	Break of 15 min and machine stop time of 20 min	0,8
10:25:00	Beginning		10:20:00	*Start-up: 5min*	
11:25:00	Running	4	10:25:00	Beginning	
12:25:00	Running	4	11:15:00	Running	4
13:00:00	Lunch break for 30 min and machine stop time of 20 min	2,3	12:05:00	Running	4
13:30:00	*Start-up: 5min*		12:55:00	Running	4
13:35:00	Beginning		13:00:00	Lunch break for 30 min and machine stop time of 20 min	0,4
14:35:00	Running	4	13:30:00	*Start-up: 5min*	
15:00:00	Break of 15 min and machine stop time of 20 min	1,6	13:35:00	Beginning	
15:20:00	*Start-up: 5min*		14:25:00	Running	4
15:25:00	Beginning		15:00:00	Break of 15 min and machine stop time of 20 min	2,8
16:25:00	Running	4	15:20:00	*Start-up: 5min*	
17:10:00	Machine stop time of 20 min	3	15:25:00	Beginning	
17:30:00	End of the day	33,6	16:15:00	End	4
2nd day				Total	**36**
6:00:00	Maintenance: 1h15				
7:15:00	*Start-up: 5min*				
7:20:00	Beginning				
8:00:00	End	2,4			
	Total	**36**			

Summary of current situation		Summary of solution 4	
Total number of start up	5	Total number of start up	4
Total running machine time	9h30	Total running machine time	7h50
Total break time	1h	Total break time	1h
Total work time	12h30	Total work time	9h15

Appendix H: Zone 1, all solutions

NOW			ASSUMPTION Solutions 1&2&3&4		
Time	Operation	Number of treated pallets	Time	Operation	Number of treated pallets
6:00:00	Maintenance and unloading the 3 trucks: 1h15		6:00:00	Maintenance and unloading the 3 trucks: 1h15	
7:15:00	*Start-up: 5min*		7:15:00	*Start-up: 5min*	
7:20:00	Beginning		7:20:00	Beginning	
8:20:00	Running	4	7:42:00	Running	4
9:20:00	Running	4	8:04:00	Running	4
10:00:00	Break of 15 min and machine stop time of 20 min	2,7	8:26:00	Running	4
10:20:00	*Start-up: 5min*		8:48:00	Running	4
10:25:00	Beginning		9:10:00	Running	4
11:25:00	Running	4	9:32:00	Running	4
12:25:00	Running	4	9:54:00	Running	4
13:00:00	Lunch break for 30 min and machine stop time of 20 min	2,3	10:16:00	Running	4
13:30:00	*Start-up: 5min*		10:38:00	End	4
13:35:00	Beginning			Total	**36**
14:35:00	Running	4			
15:00:00	Break of 15 min and machine stop time of 20 min	1,6			
15:20:00	*Start-up: 5min*				
15:25:00	Beginning				
16:25:00	Running	4			
17:10:00	Machine stop time of 20 min	3			
17:30:00	End of the day	33,6			
2nd day					
6:00:00	Maintenance: 1h15				
7:15:00	*Start-up: 5min*				
7:20:00	Beginning				
8:00:00	End	2,4			
	Total	**36**			

Summary of current situation		Summary of all solutions	
Total number of start up	5	Total number of start up	1
Total running machine time	9h30	Total running machine time	3h25
Total break time	1h	Total break time	0
Total work time	12h30	Total work time	4h40

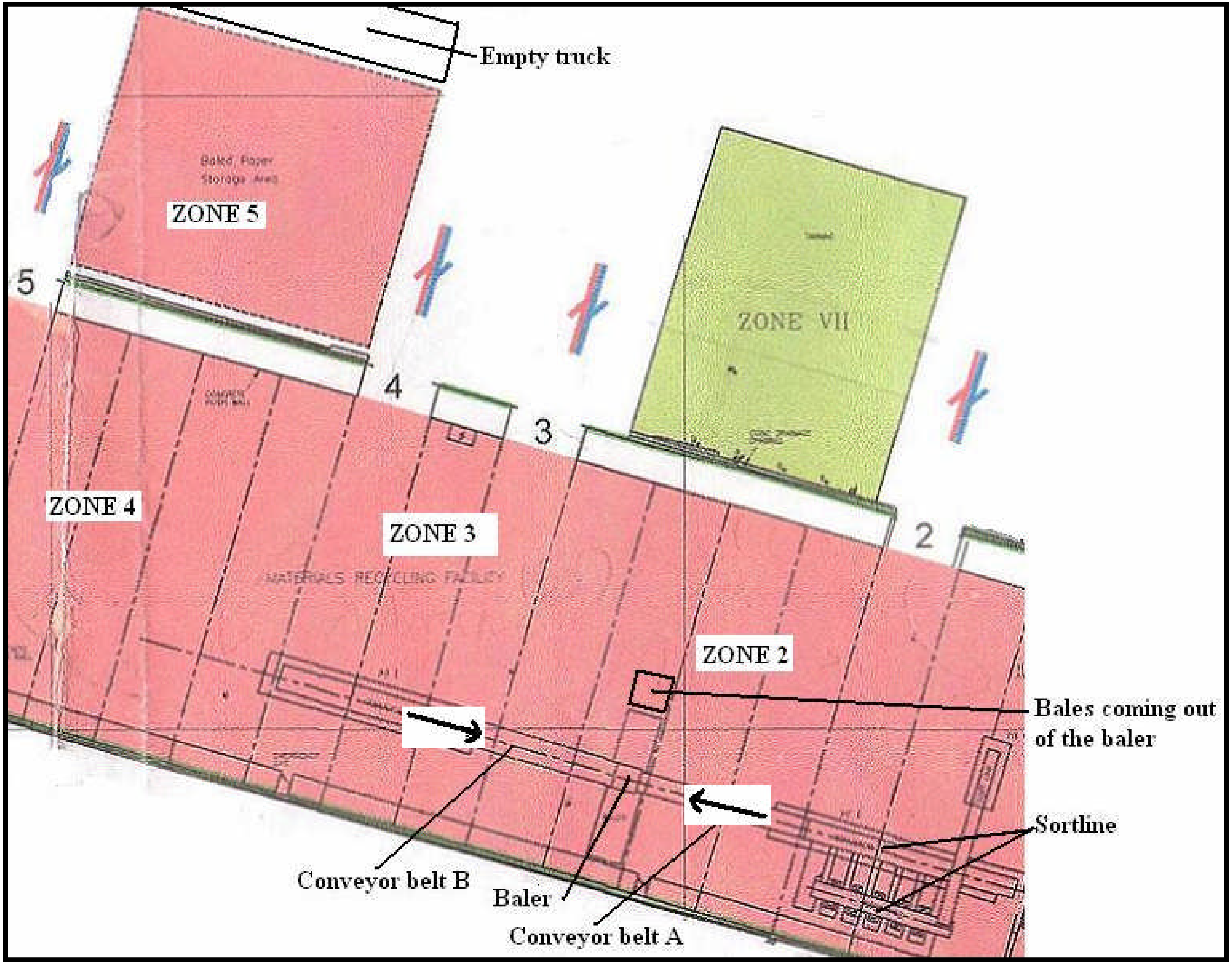
Appendix I: The future zone 1

Processing time for metals in the future		
Time	Operation	Number of treated tonnes
6:00:00	Maintenance and unloading the 3 trucks: 1h15	
7:15:00	*Start-up: 5min*	
7:20:00	Beginning	
8:20:00	Running	1
9:20:00	Running	1
10:00:00	Break of 15 min and machine stop time of 20 min	0,5
10:20:00	*Start-up: 5min*	
10:25:00	Beginning	
11:25:00	Running	1
12:25:00	Running	1
13:00:00	Lunch break for 30 min and machine stop time of 20 min	0,5
13:30:00	*Start-up: 5min*	
13:35:00	Beginning	
14:35:00	Running	1
15:00:00	Break of 15 min and machine stop time of 20 min	0,5
15:20:00	*Start-up: 5min*	
15:25:00	Beginning	
16:25:00	Running	1
17:10:00	Machine stop time of 20 min	0,75
17:30:00	End of the day	8,25
2nd day		
6:00:00	Maintenance and unloading the 3 trucks:	
7:15:00	*Start-up: 5min*	
7:20:00	Beginning	
8:20:00	Running	1
9:20:00	Running	1
10:00:00	Break of 15 min and machine stop time of 20 min	0,5

10:20:00	*Start-up: 5min*	
10:25:00	Beginning	
11:25:00	Running	1
12:25:00	Running	1
13:00:00	Lunch break for 30 min and machine stop time of 20 min	0,5
13:30:00	*Start-up: 5min*	
13:35:00	Beginning	
14:35:00	Running	1
15:00:00	Break of 15 min and machine stop time of 20 min	0,5
15:20:00	*Start-up: 5min*	
15:25:00	Beginning	
16:25:00	Running	1
17:10:00	Machine stop time of 20 min	0,75
17:30:00	End of the day	16,5
3rd day		
6:00:00	Maintenance and unloading the 3 trucks:	
7:15:00	*Start-up: 5min*	
7:20:00	Beginning	
8:20:00	Running	1
9:20:00	Running	1
10:00:00	Break of 15 min and machine stop time of 20 min	0,5
10:20:00	*Start-up: 5min*	
10:25:00	Beginning	
11:25:00	End of the day	1
	Total	**20**

Total number of start up	10
Total running machine time	21h20
Total break time	2h15
Total work time	26h10

Appendix J: Zones 2&3 map


Empty truck
Baled Paper
Storage Area
ZONE 5
ZONE VII
5
4
3
2
ZONE 4
ZONE 3
MATERIALS RECYCLING FACILITY
ZONE 2
Bales coming out of the baler
Sortline
Conveyor belt B
Baler
Conveyor belt A