A MANUFACTURING SYSTEM ANALYSIS COMBINED WITH WASTE MANAGEMENT

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ABSTRACT

A MANUFACTURING SYSTEM ANALYSIS COMBINED WITH WASTE MANAGEMENT

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This thesis presents an environmentally integrated manufacturing system analysis for companies looking for the benefits of environmental management in achieving high efficiency levels. When the relationship between environmental costs and manufacturing decisions is examined, it can be seen that the productivity of the company can be increased by using an environmentally integrated manufacturing system analysis methodology. Therefore, such a methodology is proposed and the roadmap for generating environmentally friendly and economically favorable alternative waste management solutions is elaborated. The methodology consists of data collection, operational analyses of the processes, identification of wastes and evaluation of waste reduction alternatives proposed both technically and economically. The proposed methodology is examined in a car battery manufacturing company, which generates hazardous wastes composed of lead (Pb). The main focus was on the wet-charged lead-acid battery manufacturing. It is aimed to decrease the wastes derived from the production so that the efficiency in raw materials usage is increased and the need for recycling the hazardous wastes is decreased. Following the identification of waste production points, at least one alternative is proposed for the reduction of waste. Two different alternatives are proposed for the reduction of dross formation based on the results obtained from the experiments carried out. The applicability of alternative waste management solutions is investigated from operational, technical and economical point of views and benefits and limitations are identified for each of the alternatives.

Keywords: Environmental Operations Management, Waste Management, Pollution Prevention, Cleaner Production, Battery Manufacturing.

ÖZ

ATIK YÖNETİMİYLE BÜTÜNLEŞİK BİR ÜRETİM SİSTEMİ ANALİZİ

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Bu tez, çevre yönetiminin avantajlarından yararlanarak yüksek verimlilik seviyelerine ulaşmayı amaçlayan firmalara atık yönetimiyle bütünleşik bir üretim sistemi analizi sunmaktadır. Çevresel maliyetler ve üretim kararları arasındaki bağlantı incelendiğinde, bir firmanın verimliliğinin, atık yönetimiyle bütünleşik bir üretim sistemi analizi metodolojisi kullanarak yükseltilebileceği görülmektedir. Bu sebeple bu tip bir metodoloji önerilmiş ve hem çevre dostu, hem de ekonomik çözüm alternatifleri geliştirmek amacıyla bir yol haritası ayrıntılı olarak hazırlanmıştır. Bu metodoloji; veri toplama, proseslerin operasyonal analizi, atıkların belirlenmesi ve teknik ve ekonomik olarak önerilen atık azaltım alternatiflerinin geliştirilmesini kapsamaktadır. Önerilen bu metodoloji, kurşundan (Pb) oluşan tehlikeli atıklar meydana getiren akü üreticisi bir firmada uygulanmıştır. Firmada sulu şarjlı kurşun asit akü üretimi öncelikli olarak incelenmiştir. Hammadde kullanımının verimliliğinin arttırılması ve tehlikeli atıkların geri dönüştürülmesi ihtiyacının azaltılması için üretimden çıkan atıkların azaltılması amaçlanmıştır. Atık meydana getiren üretim aşamalarının belirlenmesinin ardından, her atığın azaltılması için en az bir çözüm alternatifi sunulmuştur. Yapılan deneylerden alınan sonuçlardan yola çıkarak, curuf oluşumu için iki farklı çözüm alternatifi önerilmiştir. Her alternatifin uygulanabilirliği operasyonal, teknik ve ekonomik yönden araştırılmıştır ve her alternatif için avantajlar ve kısıtlamalar belirlenmiştir.

Anahtar Kelimeler: Çevresel Operasyon Yönetimi, Atık Yönetimi, Kirlilik Önleme, Temiz Üretim, Akü Üretimi.

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CHAPTER 1

INTRODUCTION

Nowadays, manufacturing firms are required to be aware of the importance of protecting the limited environmental resources, which increases the reputation of the firm and maintains the production sustainable. Additionally, the cost of inefficiencies in production and waste removal charges need to be decreased. For these reasons, the companies using hazardous materials in their production have started to consider environmentally integrated manufacturing system analyses.

This thesis introduces an environmentally integrated manufacturing system analysis methodology for companies aiming to achieve the benefits of environmental management in obtaining high productivity levels. This methodology is designed in a way that its implementation in different manufacturing sectors is possible. Subsequently, the proposed methodology is examined in a car battery manufacturing company because any improvement made to reduce the waste in this company will be yielding immediate environmental benefits since the waste usually consists of lead (Pb), which is hazardous (TWGBC, 2002). The application of the proposed methodology to the battery manufacturing company forms also an example about the achievability of “cleaner” production philosophies in the manufacturing sector. The waste obtained from the manufacturing process is an important cost issue for battery manufacturers because the waste produced contains significant amount of Pb. This creates important liability costs as well as environmental effects. Moreover, the content of waste in terms of Pb corresponds to the amount of the Pb lost during manufacturing. Because of this, the minimization of production wastes is important to lower the amount of raw materials used and decrease the amount of wastes sent for recycling. The aim of this thesis is to develop a methodology that will be used to decrease the waste derived from the manufacturing processes while increasing the productivity of the company.

The proposed methodology intends the integration of environmental management principles with the operations management process. Therefore, in Chapter 2, the need for adopting a sustainable development perspective is made clear by analyzing the relationship between environmental costs in manufacturing decisions. Also, environmental operations management principles and criteria affecting the environmental operations management strategy are described in this chapter. Chapter 3 covers the definition of the problem and the motivation of this thesis. The reasons for selecting battery manufacturing sector, and the specifications of the problem are provided in this chapter. The proposed methodology for the environmentally integrated manufacturing system analysis is given in Chapter 4. This chapter is very important because it gives general information about data to be collected, studies and calculations to be made. In Chapter 5, the battery manufacturing company is examined and it is decided to analyze the entire production system for a typical product, namely the wet-charged lead-acid battery. By using the proposed methodology, the manufacturing system is analyzed, the data are collected, and the process flow diagram is constructed. In the next step, wastes are identified and their quantities, as well as their costs are studied. Current waste management practices are analyzed. The waste management technologies and their applicability are analyzed and alternative waste management solutions are investigated for solving the problems identified in the first phases of the analysis. Experiments and calculations are made for some of the alternative waste management solutions and the applicability of alternatives is investigated from operational, technical and economical point of view. Implementation of the alternatives and their effects on the operations management function of the facility is discussed. The benefits and limitations are identified and analyzed for each alternative waste management solution. In this section, it is aimed to create a point of view about the alternative waste management solutions that can be investigated in order to use resources within a facility as effectively and efficiently as possible. Finally, the conclusion and summary of the thesis is given in Chapter 6.

CHAPTER 2

RELATED STUDIES

In this chapter, the impact of environmental management to the success of manufacturing firms is described. The studies illustrating the interaction between environmental management and operational management in the literature are considered.

2.1 Environmental Developments in the Industry

The increased social awareness has created the demand for production activities to be compatible with environment protection and in conformity with natural resources. This demand becomes stronger every day after the frequent environmental catastrophes, like the global warming, the diminution of the water in barrages, risk of drought and the decrease in biological diversity. The ultimate limitations of the nature are almost reached and industrialists are now aware that whether to implement sustainable environment and resource management practices or not is no longer a choice for them. As a result, the pressure exerted to productive companies by the supply chain partners and the community has increased. Companies operate in a world of dynamic competition in which technology, production processes, customer needs and, above all, environmental regulations are constantly changing. Therefore, companies should constantly find innovative solutions to survive under the pressure of competitors and regulators (Gupta and Sharma, 1996; Angell and Klassen, 1999; Claver et al., 2007). The important terms used in this study and their definitions are given in Table 2.1.

Over the last decade, the general public and business sector, as well as government and international agencies have begun to embrace the broad concept of sustainable development, with its proposition that economic growth can occur while simultaneously protecting the environment. Nowadays environmental problems have become an everyday focus all over the world. Growing environmental regulations, government pressures and international certification standards such as the International Organization of Standards (ISO) 14000, have forced firms to develop environmental policies for their manufacturing plants. The increasingly strict environmental regulations combined with the improving consciousness of consumers for environmentally friendly products have put producers in a precarious situation. Consequently, not only researchers, but also manufacturing managers are recognizing the importance of systems used for managing environmental practices (Porter and Linde, 1995; Gupta and Sharma, 1996; Xigang and ZhaoLing, 2000; Sroufe, 2003). The related environmental laws, international standards and international organizations in the environmental context are described in Appendix A.

Table 2.1 Definition of the Important Terms

Term	Definition
Sustainable Development	Meeting the needs of the current generation without compromising the ability of future generations to meet their own needs (Angell and Klassen, 1999).
End-of-pipe pollution control methods	Methods covering the elimination of pollution after the waste is generated (Claver et al., 2007).
Pollution Prevention Technologies	The modification or redesign of the production process and the introduction of new technologies throughout the product life-cycle, which contributes to the development of new internal routines and know-how's (Claver et al., 2007).
Cleaner Production (CP)	The continuous application of an integrated preventative environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment (CECP, 2001).
Eco-efficiency	A management philosophy that encourages business to search for environmental improvements which yield parallel economic benefits (WBSDC, 2000).
Environmental operations management (EOM)	The integration of environmental management principles with the operations management process for the conversion of resources into usable products (Gupta and Sharma, 1996)

An enterprise adopting traditional end-of-pipe pollution control methods focuses on its activity on the short term. In this context, the enterprise sets as its main aim to carry out environmental impact correcting actions through end-of-pipe measures that do not entail the development of new skills needed to manage new environmental processes. Therefore, it is seen that traditional pollution control methods –end-of-pipe solutions – are practically inefficient compared to prevention methods (Claver et al., 2007). Therefore it is clear that preventing environmental damage is cheaper and more effective than attempting to manage or fix it. Pollution prevention technologies, as described in Table 2.1, require going upstream in the production process to identify the source of the problem. Pollution prevention has replaced the traditional end-of-pipe methods and has become an important research topic for the process design (ANZECC, 1998; Xigang and ZhaoLing, 2000; Claver et al., 2007).

One step forward of pollution prevention is the concept of cleaner production (CP), as described in Table 2.1. For production processes, CP includes conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and toxicity of all emissions and wastes before they leave a process. For products, the CP strategy focuses on reducing impacts along the entire life cycle of the product, from raw materials extraction to ultimate disposal of the product. In CP applications, savings are often achieved with little or no capital expenditure by simply changing management practices. As the case study in ANZECC (1998) indicates, The Hotel Inter Continental spent $ 84,000 on CP techniques, resulting in financial benefits of $ 280,000 per year.

Many successful case studies show that CP can provide opportunities for making sound choices for both environmental concerns and economic benefits (Jia et al., 2005). One of the most basic reputations of CP is that it improves efficiency and productivity in industry. These improvements result in lower expenditure on resources such as energy and water, increased efficiency in production, fewer risks associated with environmental impacts, and decreased waste generation that leads to savings in landfill fees and pollution licenses. Due to the CP context, continuous improvement is required not only in technology and know-how, but also in managerial skills and policies. CP offers much for operations management researchers to draw on as they explore the linkages between process and product technology, environmental management and performance. Incorporation of CP practices also leads to greater employee involvement in, and commitment to, the production process that often leads to higher quality product (ANZECC, 1998; Angell and Klassen, 1999; Xigang and ZhaoLing, 2000).

Eco-efficiency, as described in Table 2.1, is a CP method aiming “doing more with less”. Using fewer natural resources and less energy during the production process, reducing the volume of residues and lowering pollution levels is definitely positive for the environment and, at the same time, proves benefits to the enterprise, as its production and management costs decrease (Claver et al., 2007; Glavic and Lukman, 2007).

2.2 The Relationship between Environmental Costs and Manufacturing Decisions

A major barrier to the adoption of environmental management systems is that firms often do not know the environmental costs of operating their business and therefore do not know the financial benefits that can be obtained by reducing their environmental impacts. Until only a few decades ago, it was assumed that both environment protection measures and the regulation were barriers to competitiveness because they require costly investments and the introduction of new techniques, all of which made the enterprise’s fixed costs grow. There was a belief that any investment in improved environmental performance would contribute to increased costs, which will finally reduce profits. Previously, environmental costs were generally defined as costs dealing with environmental laws, regulations, and taxes. Often, the costs of common natural resources such as air, water and energy were subsumed into a one line ‘operating cost’ or ‘administrative cost’ that was regarded as independent of production (indirect cost). Firms have tended not to measure environmental costs because management accounting systems have focused on clearly identifiable costs but not on the costs and benefits of alternative actions. Especially the water consumption, which may be very high in most of the industries if it is not controlled, was not measured. Companies used to look at water as a cheap resource that has not much incidence on the economic balance of manufacture. No one has thought that water is a limited resource, and independent of its price, must be spent carefully (ANZECC, 1998; Claver et al., 2007).

In 1991, Porter put forward a new standpoint to the interaction between profitability and pollution prevention. This interaction has increased theoretical and practical interest in the possibility that profitability and pollution reduction were not conflicting goals. According to Porter, pollution was simply a diminishing value in production and was an indication of problems in products and/or processes. Therefore, contrary to previous opinions, reducing or eliminating pollution/waste would not weaken but strengthen corporate competitiveness.

After Porter’s study, a radical change has come in management’s views on pollution reduction and better environmental management. Companies became aware of the important role that environmental costs play in the calculation of total costs of production. It is now recognized that the true environmental costs includes: costs of resources, waste treatment and disposal costs, the cost of poor environmental reputation, and the cost of paying an environmental risk premium. With this point of view, environmental costs are transferred from overall (or indirect) costs to direct costs (Spengler et al., 1998; Melnyk et al., 2003). As a result, it is seen that the calculation and evaluation of environmental costs provides better understanding of the production cost of a product, and that it properly allocates costs to product, process, system or facility. Environmental costs calculations also allow making improvements in processes because environmental problems become visible while doing environmental accounting. Measuring environmental costs also improves the correctness of the pricing and gives profitability and competitive advantage, therefore increases the overall management system of a company. As a result, environmentally integrated manufacturing decisions require the consideration of technical, economic and ecological aspects simultaneously (Spengler et al., 1998; Melnyk et al., 2003; Wu and Chang, 2004).

2.3 Environmental Operations Management (EOM)

It is obvious that an operations management team is not only responsible of the achievement of the desired products in terms of quality and quantity, but also has to control working practices, resources consumption, emissions, and the flow of hazardous materials. Thus, operations managers are directly concerned with environmental issues in their operational responsibilities and play a critical role in developing management systems that affect environmental performance (Gupta and Sharma, 1996; Angell and Klassen, 1999).

Due to Environmental Operations Management (EOM) principles, instead of looking at environmental management as a “cost”, companies can use EOM as an opportunity to improve their position by eliminating waste, removing non-value added materials and equipment, and reducing both short-term cost and long-term liability. The firm will be able to plan and design products that do not create toxic wastes or require environmentally hazardous processes – from the introduction of the product to its final disposition. A long-term competitive advantage can be obtained by setting EOM principles to the production process (Gupta and Sharma, 1996). EOM is a concept integrating environmental management principles into the operations management process as shown in Figure 2.1. In order to create an environmental operations strategy, the operations management team is constrained by criteria such as: dependability, efficiency, flexibility and quality.

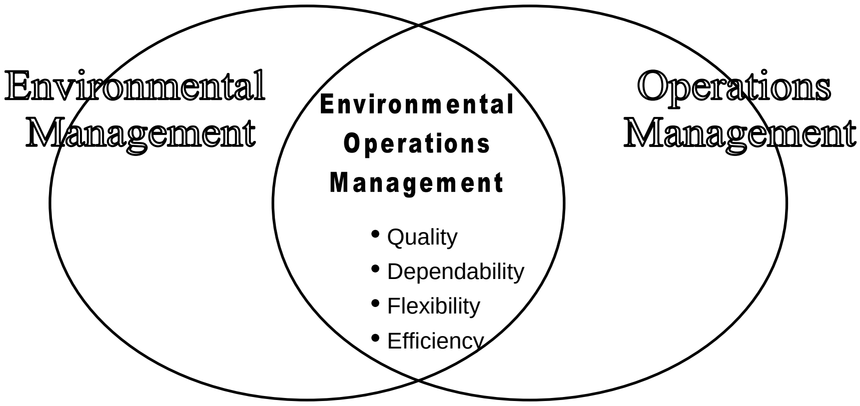


Figure 2.1 Environmental Operations Management Approach

The trend associating quality with the “greenness” of products presents a challenge and opportunity for EOM. The quality or the environmental attributes of the products are important criteria for consumers willing to buy. The dependability of a company is affected by the use of hazardous materials and processes. Accidents involving the shipment, transfer, and use of hazardous materials often result in temporary shutdowns of manufacturing plants. In addition, the capital investment needed to process and dispose hazardous materials is often high and affects the dependability. The flexibility of the company is limited by the materials and processes necessary for the production and by the types and quantities of hazardous materials discharged into the environment. Efficiency can be achieved by finding less expensive and less environmentally hazardous materials and processes to manufacture the desired products (Gupta and Sharma, 1996).

There are many studies demonstrating that pollution prevention is almost the most cost-effective constituent of integrated waste management strategies in different manufacturing systems. For example, metal electroplating and galvanizing is one of the industries causing high quantities of hazardous wastes during the production process. Dahab et al. (1994) has made a study in the considered industry with the main concern of reducing the amount of wastewater used for rinsing. The reduction of the rinse water by 85% has created a significant change in the costs and environmental impacts of the company. Additionally, several changes and modifications are also recommended and improvements in housekeeping practices are achieved, such as increasing the electroplating efficiency by raising temperature.

Sectors working with non-hazardous materials are also aware of the importance of reducing wastes for improving profitability and sustainability. Akkerman and Van Donk (2006) have accomplished a study in the food-processing industry for decreasing product losses. A research framework is created to collect and analyze data and a decision support tool is developed to evaluate different scenarios for the planning decisions and production parameters. One of the valuable findings of the case study is that a longer planning horizon is beneficial for reducing the planning-related amount of product losses. This finding is significant in considering the effects of operational decisions on the wastes produced. The planning-related losses are reduced by nearly 20% in the food-processing industry with the development of this tool.

The car battery manufacturing industry is one of the critical industries in the implementation of pollution prevention studies because of the lead (Pb) used in production. Wastes should be decreased in order to prevent the hazardous effects of Pb to the environment and human health. Many studies involving technology changes and pollution prevention options are accomplished for the battery manufacturing industry. Dahodwalla and Herat (2000) have demonstrated how cleaner production can be applied to the car battery manufacturing industry. Several cleaner production options are discussed based on their technical and environmental feasibility. The on-site recycling of wastes, instead of off-site recycling, has created a reduction of 49% of the total quantity of lead waste generated. It is also possible to make technological changes in the production process of car battery manufacturing to decrease the waste production. Boden and Loosemore (2007), by changing the chemical structure of the paste, have eliminated the need of the curing process that uses high energy and creates high costs to the company. With the change in the chemical structure of the paste, the production time of a battery could be significantly decreased. Similarly, Ferreira et al. (2003) have used an active-material additive in order to improve plate processing and to lower the cost of various operations. Energy consumption was reduced and air quality was also improved within the facility.

CHAPTER 3

MOTIVATION FOR THE STUDY AND PROBLEM DEFINITION

This chapter covers the definition of the problem considered. The concept of environmentally integrated manufacturing system analysis is described and the motivation of the study is given.

3.1 Motivation for the Study

Operations management is the process of managing people, resources and production systems in order to convert inputs into outputs. The inputs of the system are energy, materials, labor, and capital. The outputs of the system are the products demanded by customers. The manufacturing process shown in Figure 3.1 is a general representation for most of industry and process types. It can be adapted to all of the production industries. Moreover, it can represent different types of production processes such as assembly or drilling.

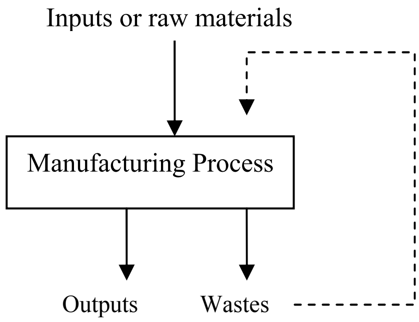


Figure 3.1 The General Manufacturing Process

In order to operate efficiently, a firm coordinates the manufacturing operations with the activities of marketing and finance. Marketing information let the production planner to know the demand (or give the ability to forecast it) in order to plan raw material purchases and production scheduling. Furthermore, the selling price of the products is an important factor affecting the manufacturing decision because it influences financial decisions about production technologies and raw material purchase. Therefore, the most important value affecting the operations strategy is the cost of products, which consists of materials, equipments, and labor costs. Clearly, these costs affecting the operations strategy are the main duties of finance, purchasing and marketing departments. Likewise, new developments in the operations strategy affect the decisions made in the overall company, especially marketing and financial decisions (e.g., raw material changes, new equipment purchasing etc.) (Nahmias, 2004, p. 11).

As it is seen in Figure 3.1, wastes can be produced when converting raw materials into products. Wastes are considered as non-value-added outputs that create extra costs to the production of the product. The reduction or elimination of wastes in the production has always been a goal in operations management (e.g., lean manufacturing) (Gupta and Sharma, 1996). In order to provide the best use of raw materials, operations managers have to minimize the amount of the waste produced, namely, to reduce the cost and impact of the waste. An efficient approach undertaking this target is to integrate waste management into the operations management decision. With this integrated point of view, several major firms now see pollution and inefficiency to be identical problems, and define pollution as “the inefficiency in converting raw materials, water and energy into products” (Angell and Klassen, 1999).

Operations management deals with the optimization of the manufacturing process and covers decisions involving production planning, scheduling, capacity planning, inventory management, material management, workforce management, and quality management. It can be remembered that the traditional objective of inventory control, scheduling and production planning is to minimize production costs and improving measures such as worker idle time, work-in-process inventory levels, and production lead times while recognizing constraints such as limited space. Undoubtedly, by the integration of waste management into the manufacturing decision, the objective function should not include only the cited objectives but also environmental ones. Manufacturing decisions should not be made in isolation from decisions in environmental management. To illustrate this fact, one should remember that firms intend to increase their Return on Investment (ROI), which is the ratio of the profit realized by a particular operation over the investment made in that operation. In order to improve the ROI, a firm will make investments in new technologies, and accordingly will gain the chance to improve its efficiency, quality of product, and productivity. Therefore, it is clear that investigating and improving new production perspectives and technologies creates profits for the long-term success of a firm because it allows the fastest response to unpredictable changes in customer demands. The question is how to create the motivation for implementing an environmentally integrated manufacturing system analysis in firms, especially in companies whose budgets are limited. As illustrated in Figure 3.2, for a company targeting to increase its profits with a limited budget, it is more significant to prove them “how protecting the environment may help the company”, rather than “how the company should help to protect the environment”, even though the results are the same. Targeting “cleaner” production is a new way of thinking about processes and products and is a new approach to solve manufacturing problems. In recent years, many production planners and decision makers have started to recognize the role and significance of the integration of economic and environmental efforts in a single production-planning program. New concepts connecting manufacturing practices, pollution prevention and operations are recently being used in order to increase the efficiency of converting raw materials into products. Specifically, studies are carried out in order to create decision support tools for analyzing the effects of planning decisions on the amount of product losses (Akkerman and Van Donk, 2006). Firms are willing to organize their production systems to enhance resource productivity by adopting an environmental approach. Based on this kind of approach, a company can include environmental principles in the mission statement, incorporate the cleaner production philosophy into product and process design and, consequently, develop an environmental business strategy in order to gain competitive advantage.

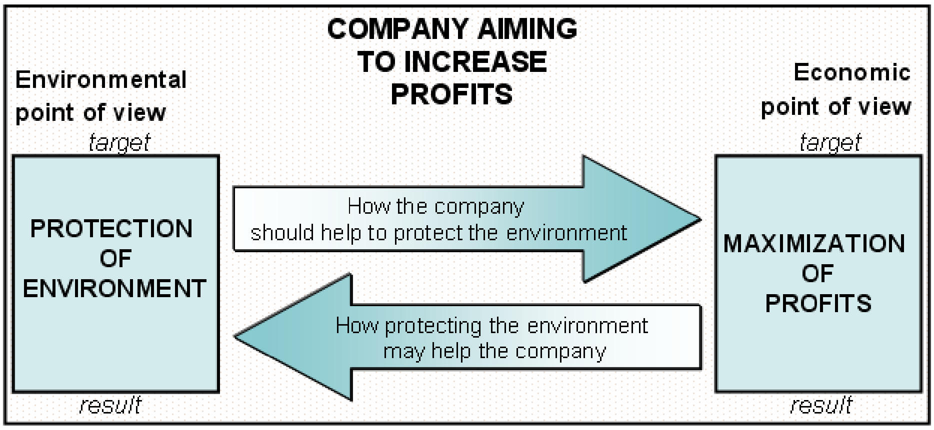


Figure 3.2 The Strategy for Introducing CP to the companies with Limited Budget

3.2 Problem Definition

The waste produced from the manufacturing process is an important cost issue for manufacturers. Waste of raw material creates important costs and environmental effects, especially when the raw material is hazardous. In the case of using hazardous raw materials, the wastes derived from manufacturing processes can not be sent to trash, instead they are sent to the recycling or treatment facility. Obviously, wastes that can not be used within the facility create inefficiency in the usage of raw materials. Therefore, the problem considered is to decrease the formation of wastes in order to decrease waste management costs and improve raw material usage. A solution to this problem may be to use an environmentally integrated manufacturing system point of view aiming to decrease product losses, while reducing costs and improving profitability. In this thesis, a methodology providing the minimization of the environmental and economical effects of production wastes is presented. The proposed environmentally integrated manufacturing system methodology is expected to give a roadmap for generating environmentally friendly and economically favorable alternative waste management solutions. The objectives of the study are

- to create a point of view about the types of alternative waste management solutions that can be determined and to show their benefits,
- to discuss how the operations management functions of a facility will be affected by the implementation of an alternative waste management solution,
- to discuss what types of limitations can be encountered in a facility while implementing an alternative waste management solution,
- to give an example about the practicability of pollution prevention philosophies to the manufacturing sector.

By using the methodology, alternatives on using resources as effectively and efficiently as possible will be determined. It is important to notice that such a method is critical to a firm's ability to reduce waste and pollution while simultaneously improving overall performance. Therefore, the consequences of the alternative waste management solutions and their effects on the overall performance will be discussed.

3.3 Selection of the Sector

This study is accomplished in a lead-acid battery manufacturing plant. Lead-acid battery manufacturing is a sector dealing with hazardous materials such as lead and sulfuric acid. Therefore, it is needed to minimize the effects of batteries in each step of the life cycle, namely, the production, usage and recycling.

In Turkey, similar to other countries, the used batteries are collected with special equipments and are sent to the recycling facility. In the recycling facility, used batteries are processed so that plastic, lead and sulfuric acid are separated. These materials are sent to proper users and are operated in different recycling processes. When properly applied and controlled, recycling of used batteries provides an economical and environmental solution to the management of lead-acid batteries. As shown in Figure 3.3, a battery manufacturing company from United States, Crown Battery, indicates that it is possible to recycle 99% of a manufactured battery and each battery can be comprised 87% of previously recycled materials. The raw material consumption of the sector can be decreased by using an effective recycling system because the recycled lead can be reused as a raw material. This example is an important motivation showing that if the necessary actions are taken, it is possible to considerably decrease the harmful impacts of the battery manufacturing process.

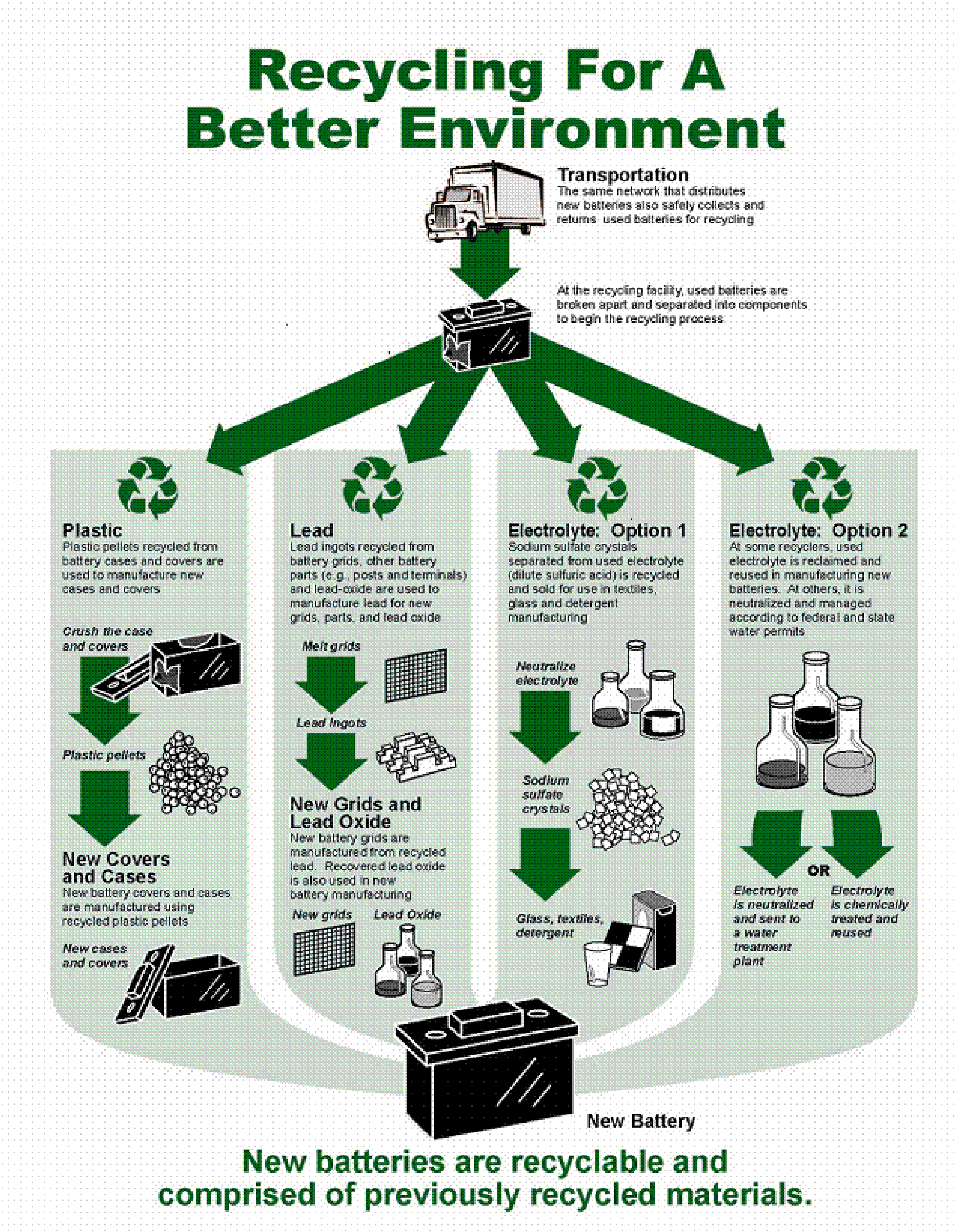


Figure 3.3 Recycling System of a Used Battery (Source: BCI, 2008b, n.p.)

In addition to recycling of used batteries, there are some wastes containing significant amounts of lead during the production of the batteries and they are also transferred to recycling facility for the recovery of lead. However, if the company can decrease the amount of lead waste, then the company will have higher productivity, that is the ratio of input to output. Since the waste is classified as hazardous, the companies may even search the applicability of on-site recovery techniques for lead to prevent the risks associated with the storage of the waste in the production area, its handling and transportation. The battery manufacturers, therefore, should seek for ways of converting more lead into batteries within the production area to increase their efficiency and to lessen the impacts of the production on the environment and human health. In other words, production wastes of the battery manufacturing industry should be minimized to lower the usage of raw materials and to decrease the need for wastes recycling.

The recycling system of batteries creates a basis for identifying the economic and environmental costs of the battery manufacturers. Since the unit costs of wastes are identified, it is possible to make a comparison of the results of the improvements and the initial situation of the manufacturing process based on the quantities of wastes produced. As a result, the battery manufacturing sector is chosen for this study because the economical benefits obtained by improving the current system of manufacturing based on waste management correspond to immediate environmental benefits.

CHAPTER 4

THE ENVIRONMENTALLY INTEGRATED MANUFACTURING SYSTEM ANALYSIS

This chapter presents a methodology for the environmentally integrated manufacturing system analysis. The proposed methodology provides a roadmap for companies willing to apply an integrated preventive waste management approach in their manufacturing plant. Many possible working areas and information to be collected are given so that this methodology can be applied in different manufacturing sectors and companies.

The design of the methodology firstly involves the investigation of techniques aiming the reduction of wastes in the manufacturing area. Waste auditing methodologies are examined in this context. Operations management techniques involving the reduction of material losses are then analyzed. The problem solving techniques are used for the identification of manufacturing problems, the investigation of possible solutions and the selection of the best solution. The methodology is established by integrating operations management perspectives to the classical waste auditing methodology. Waste auditing generally covers three steps. The first step, which is the pre-assessment, covers the division of the processes into unit operations and the construction of the process flow diagram. The second step, which is the material balance, covers the identification of inputs, outputs and the current reuse and recycling methods. The final step which is the synthesis, deals with the evaluation of waste reduction options and the creation of the waste reduction action plan (UNIDO and UNEP, 1991). The proposed methodology, different from the classical waste auditing, cautiously focuses on the operations of the manufacturing facility. Processes are analyzed based on the inputs used, working practices, capacities of machines, and byproducts and outputs derived from the processes. A summary of the proposed methodology is given in Table 4.1.

4.1 Analysis of the System

In the first step of the methodology, the analysis of the manufacturing system should be accomplished. This analysis will provide the information about the current manufacturing and waste management system. By analyzing the data collected, it will be possible to find the processes operating with low efficiencies.

Table 4.1 The Proposed Methodology

Methodology for the Environmentally Integrated Manufacturing System Analysis
1 Analysis of the System
1.1 Data Collection
1.2 Manufacturing System Analysis
1.3 Construction of a Process Flow Diagram
1.4 Current Waste Management Practices
1.5 Environmental Impacts of Materials Used in Production
2 Identification of Alternative Waste Management Solutions
2.1 Investigation of Waste Management Technologies
2.2 Investigation of Alternative Waste Management Solutions
3 Evaluation of the Alternative Waste Management Solutions
3.1 Operational Analysis of Alternative Waste Management Solutions
3.2 Technical Analysis of Alternative Waste Management Solutions
3.3 Economical Analysis of Alternative Waste Management Solutions
4 Comparison of Alternative Waste Management Solutions

4.1.1 Data Collection

The data collection phase involves a thorough assessment of the company, from the purchase of various inputs (e.g., raw materials, energy and water) to the output itself (products). This phase implicates the collection of data such as: product types, raw materials used and their prices, the demand of products and their prices, material requirement planning, and supply chain partners.

4.1.2 Manufacturing System Analysis

The manufacturing process is considered as one of the important sources of environmental impacts of the industrial production. Therefore, it is essential to analyze in detail all the elements of the manufacturing system in order to prevent the pollution at the source. The information about the system as a whole is gathered in this part by combining the data collected about processes and their operational conditions, material management, capacity planning, production planning and scheduling, quality management, workforce management, supply chain management, and logistics. The operations forming wastes are determined in this part of the system analysis. It is important to obtain real data in this step, because even if it is not optimal, the current manufacturing system of the company will be a basis for comparison in this study.

4.1.3 Construction of a Process Flow Diagram

With the aid of data collected in the first and second steps, it is now possible to generate a process flow diagram for a complete manufacturing process including sequence of operations, raw materials, semi-finished products, products and wastes. The process flow diagram may be considered as the output of the previous steps.

4.1.4 Current Waste Management Practices

The waste management system of a company involves the entire procedure of collecting, transporting, processing, recycling or disposal of waste materials. Waste management can involve different methods and fields of expertise for solid, liquid, gaseous or radioactive substances, with the aim of reducing the effects of these wastes on the health and environment. In this phase, the investigation of current waste management practices in the company is accomplished. Data such as the quantity and rate of generation of production wastes are collected. The content of wastes and the waste management costs are also investigated. Current waste management practices in the company should be determined correctly and then analyzed with respect to their appropriateness. A waste management application may be efficient in treating a waste completely, but it may be very costly or may cause extra usage of raw materials. On the other hand, a simple and inexpensive application may be financially welcomed but may gradually create serious damages in worker's health or environment. As a result, measurements should be made to find out the real needs of the system in order to solve each problem efficiently.

4.1.5 Environmental Impacts of Materials Used in Production

Investigating the environmental impacts of raw materials, production processes and products is important. Investigations may give ideas about the substitution of hazardous raw materials with non-hazardous materials. These kinds of substitutions may give benefits such as the decrease in employee exposure to pollution and decrease in costs due to the hazardousness of the material, such as special transportation costs, fees, etc (Dahodwalla and Herat, 2000). Making detailed analyses about the environmental impacts of materials is also an important action for convincing people to implement the alternative waste management solutions suggested. The workers and the management of the company can be influenced to take environmental precautions by informing them about impacts of products produced or materials used. After clarifying the environmental impacts of raw materials, production processes and products, it will be effective to suggest alternative waste management solutions as a new way of achieving better working conditions in the facility.

4.2 Identification of Alternative Waste Management Solutions

This section covers the investigation of possible alternatives aiming to reduce or reuse waste. The alternatives that generate possible solutions to the wastes defined in the previous sections are identified in this section.

4.2.1 Investigation of Waste Management Technologies

Once the production wastes and inefficient processes in manufacturing are identified, the next step is to investigate the available waste management technologies or practices in the literature. Current operational conditions of the company must be compared with the conditions reported in the relevant literature. The investigations may draw upon basic research results, literature searches, field research, and discussions with industry experts and technology-users. The reports of the Environmental Protection Agency (U.S. EPA) may be a good source for this purpose. This process will make it possible to recognize environmentally friendly methods, the best available technologies, and the newest technologies.

4.2.2 Investigation of Alternative Waste Management Solutions

Alternative waste management solutions are prepared by using information about wastes and processes operating with low efficiencies. The collected information is accumulated and a corporate environmental management approach is given in order to optimize the raw material consumption and the use of wastes. Alternative waste management solutions involving the integration of economic and environmental efforts are investigated. According to this integrated point of view, waste is accepted as a resource that can be used in the production process. The investigation of alternative waste management solutions will pursue the following hierarchy:

1. Reduction at source
2. Internal (on-site) and external (off-site) recycling
3. Treatment of waste streams
4. Controlled disposal when there is no other solution.

The reduction of wastes at source may be accomplished by the purchase of new equipments or materials, or may simply involve small changes in the production process. Pollution prevention alternatives aiming the reduction of waste at the source are at the first priority. The environmental and economic benefits of reducing waste at source are much higher than other alternatives because the raw material usage and the waste management costs can both be reduced. If the formation of waste can not be prevented at source, internal and external recycling alternatives must be considered in order to minimize the waste treated/disposed. With the recycling opportunities, wastes from one industrial process can serve as a raw material for another, therefore the impact of the industry on the environment is reduced. Specifically, on-site recycling is very valuable because it eliminates the cost of sending the waste to an off-site facility, therefore increases the productivity of the company. In cases where the waste can not be prevented or can not be reused within the facility, off-site recycling is a choice allowing to send out the waste from the facility and to allow its reuse by other industrial processes. Therefore, the impact of the waste to the environment is diminished. However, off-site recycling creates a cost due to the transportation of wastes to the recycling facility, and more importantly, due to the inefficient use of raw material that can not be converted into a product. The treatment of waste streams is accomplished to remove the hazardous portion of a waste from the non-hazardous portion, such as water. Various techniques are available to reduce the volume of a waste through physical treatment. For example, concentration techniques including vacuum filtration, filter press or heat drying are commonly used to dewater the sludge. These techniques are used to reduce the volume, and thus the cost of disposing a waste material. Moreover, once the material is concentrated, there is a greater likelihood that the materials in the waste can be recovered. This allows the potential use of the waste streams as a raw material for other companies or for the company itself (Freeman, 1988, p. 5.13). Controlled disposal is a solution for wastes which can not be treated by pollution control technologies. Disposal is the last preferred waste management option. Nevertheless controlled disposal is an important part of environmental management; even though it is the least effective one.

4.3 Evaluation of Alternative Waste Management Solutions

Each investigated alternative waste management solution in the previous step of the methodology must be analyzed in order to evaluate how beneficial or practical the implementation of this alternative will be. It is important to use an inter-disciplinary point of view while evaluating each alternative waste management solution since the entire production system is aimed to be optimized. By this integrated point of view, it will be possible detect the positive and negative results of each alternative waste management solution proposed.

It is important to make detailed operational, technical, and economic analyses while evaluating alternative waste management solutions. The scope and complexity of an apparently feasible alternative waste management solution can change after the analysis of the initial problems or after the design of the system. An alternative that is feasible may become infeasible after it is evaluated. A alternative waste management solution is feasible if it works with available or obtainable resources, produces better results in both environmental and economical point of view and if it does not conflict with other management functions. For example, while a alternative waste management solution may be feasible due to machine schedules, it may be infeasible due to the demand pattern of the products. As a result, it may not be possible to implement this alternative. It is also important for a alternative waste management solution to have a reasonable reimbursement time. Evaluations of solutions alternatives are made under the title of the following measures.

4.3.1 Operational Analysis of Alternative Waste Management Solutions

Each alternative waste management solution should be analyzed in order to see if it is operationally feasible. The operational viability generally consists of measures such as the applicability of an alternative. In order to see if an alternative waste management solution is desirable in an operational sense, it should be proved that the alternative is practical and efficient. In other words, it should be demonstrated that the alternative makes maximum use of available resources including raw materials, people, and time. Before evaluating an alternative waste management solution, it should be verified if the current work practices and procedures support a new system. This verification also covers the adaptation of end users and managers to the change. The flexibility and expandability of the alternative must also be taken into account because capacity changes can take place in the company as a result of future needs and projected growth.

4.3.2 Technical Analysis of Alternative Waste Management Solutions

Each alternative waste management solution should be analyzed in order to see if it is technically feasible. The technical viability generally consists of measures such as the practicality of an alternative and the availability of technical resources and expertise within the facility. An important aspect identifying if the alternative waste management solution is technically feasible is the availability of the required technology. Some alternatives may involve solutions that can be applied without the need of a new technology or equipment. Conversely, there may be alternative waste management solutions that need the investigation of the market availability of the required technology or equipment. If the required technology is produced or sold within the country, it is needed to compare the different sellers and selling prices. On the other hand, if the required technology is exported, it is needed to investigate the different countries, selling prices and transshipment rates (Sullivan, 2002).

In order to see if an alternative waste management solution is desirable in a technical sense, the company should verify if the technical requirements, impediments and competing technologies are identified. By evaluating current technology options and limitations, the company can define how difficult it will be to build the new system. For some alternative waste management solutions, there may be critical elements that require feasibility demonstration. Therefore the company may require making tests and experiments in order to see if the considered alternative waste management solution is technically feasible. By this way, the performance of experiments and tests can be compared with preliminary technical requirements and objectives. The experiments and tests will enable the presentation of a path forward for the next stage of the alternative. Moreover, written results, models, or laboratory process outputs demonstrating technical concepts and benefits will improve confidence that the alternative waste management solution will successfully meet the goals of the company (U.S. DOE, 2007).

4.3.3 Economical Analysis of Alternative Waste Management Solutions

If an alternative waste management solution is operationally and technically feasible, then the economical analysis of the alternative should be carried out to examine if it is affordable or not. The economical viability generally consists of measures such as the quantitative estimation of benefits of an alternative waste management solution, which are typically reduction in costs or risks. An alternative waste management solution that is economically desirable is regarded as justified because the economic aspects are generally the bottom line of many projects. In the economical analysis phase, the costs, benefits and incomes of the current system should also be identified. By this way, it will be possible to compare the economic aspects of the current system and the suggested alternative waste management solution. This will allow realizing the cost of not developing the new system.

In order to see if an alternative waste management solution is desirable from an economical point of view, the cost-benefit analysis should be made and the cost-effectiveness of the alternative should be proved. By this analysis, it will be demonstrated if the benefits outweigh the estimated costs of development, installation, operation and maintenance. When making an economical analysis, it is important to predict tangible and intangible benefits. Furthermore, the timing of costs and benefits is an important factor determining the payback period, which is also an important decision criterion affecting the applicability of an alternative waste management solution.

4.4 Comparison of Alternative Waste Management Solutions

As it is known from operations research, optimizing a variable may not always give the overall optimal solution, especially when several aspects such as productivity and environmental performance are both aimed (Nahmias, 2004, p. 671). Therefore, the consequences of the alternative waste management solutions and their effects on the overall performance should be discussed. If an alternative waste management solution is found to be feasible, the company may decide to proceed with this solution after comparing it with other alternatives generated for the considered problem. In selecting the best alternative, a company often considers trade-offs. The final decision can be determined by working with end-users, reviewing operational, technical and economic data. On the other hand, decisions criteria such as dependability, efficiency, flexibility and quality may be used for creating an environmental operations strategy. Therefore, if a company aims to accomplish an environmentally integrated manufacturing system analysis project, a multi-disciplinary team should be formed and operational, technical and economic aspects should be compared for each alternative waste management solution by taking account the criteria mentioned above.

It is essential that the company reviews and changes its environmentally integrated manufacturing plans dynamically to assure high environmental standards. An important issue in improving the manufacturing system is the use of feedback information in order to continually adjust the mix of inputs and technology needed to achieve desired outputs. Information derived from environmentally integrated manufacturing system analysis will continually change production planning decisions such as demand forecasting, purchasing, production and personnel scheduling, quality control, and inventory control issues. The team leader should constantly monitor the manufacturing system and its environment in order to plan, control and improve the system.

CHAPTER 5

AN APPLICATION IN THE LEAD-ACID BATTERY MANUFACTURING COMPANY

This chapter covers the application of the environmentally integrated manufacturing system analysis in a lead-acid battery manufacturing company. The lead-acid battery manufacturing company, founded to produce starter type batteries in 1976, occupies now a total space of 22,500 m^2 in its manufacturing plant in Ankara. The company produces different types of lead-acid batteries and also supplies different types of semi-finished products like grids, raw plates, charged plates as well as lead monoxide. There are 2,200 franchisers in Turkey, which allow direct access of the product to final users. The company is the main supplier of MAN and Türk Traktör in Turkey while exporting to about 27 countries around the world. The production capacity is 1,500,000 batteries per year and there are 50 white-collar and 250 blue-collar workers.

The following assumptions are considered in the context of the study:

- The manufacturing process of wet-charged batteries is considered.
- Prices of products are assumed to be constant for every customer.
- Data collected about the manufacturing system is considered as input data.
- The unit waste management cost of an on-site recycled waste consists of its raw material cost. Labor and overhead costs associated to the considered waste are included if a change in these costs is obtained according to the evaluation of alternative waste management solutions.
- The unit waste management cost of an off-site recycled waste consists of its raw material cost and transportation cost, apart from the selling price to the recycling facility.
- The unit waste management cost of discarded wastes consists of the raw material cost.
- The unit waste management cost of wastewater consists of the raw material cost. Energy usage in the wastewater treatment facility is ignored. Chemical usage costs are included to costs calculations if a change in chemical usage is obtained according to the considered alternative waste management solution.
- In the net present value calculations, the costs are assumed to derive at the end of each month and the monthly interest rate is assumed to be 1.6%.
- The company works 6 days a week. Each day consists of 3 shifts, which are 8 hours each.

- The company does not hold end-product inventory and there is no cost associated to inventory carrying.
- There is no problem associated to the limited storage area.

5.1 Analysis of the System

The system analysis of the company provides general information about batteries, operations management system, production processes and waste management system of the company.

5.1.1 Data Collection

The data collection phase enables to obtain data about product types and demands, raw materials, prices, material handling techniques, and supply chain partners. These data can be obtained from production planning, purchasing, marketing and finance departments. At the beginning of the analysis, the types of products (batteries) and their demands are obtained from the production planning department. Types of batteries are determined based on the difference in ampere levels used for charging the battery. In other words, batteries are charged for different ampere levels to be used in different vehicles, as given in Table 5.1.

Table 5.1 Ampere Level due to Types of Vehicles

Ampere Level	**Type of Vehicle**
35-90 Ah.	Automobile
90-120 Ah.	Tractor & Pick-up
120-225 Ah.	Truck

The types of batteries considered in this study and their demands in year 2006 are given in Appendix B1. The products having the highest demands are considered in this study. It can be seen that the most demanded product is the typical car battery, which has an ampere level of 60 Ah. The pricing procedure of the company involves that the production cost of a product occupies the 85% of its selling price. The prices of products in 2006 are obtained from the marketing department. As it is seen in Appendix B2, batteries with high ampere levels have higher prices. High ampere levels require high processing times because the ampere value increases with the number of plates in the battery and the dimension of the battery. Accordingly, as the number of plates increase, the time required for charging increases, which is also one of the reasons of higher production costs and higher prices. Information about raw materials and the prices of raw materials are obtained from purchasing and finance departments. Raw materials used in the production of lead-acid batteries are pure lead and alloyed lead, containers and covers, separators, water, sulfuric acid, fiber and other additives. The company imports its lead raw material, which is transported in form of ingots (Figure 5.1). The other raw materials are purchased from Turkey. The company does not operate with the lead recycled in recycling facilities because the purity of recycled lead is less than 100%.

Figure 5.1 A Lead Ingot

The material requirements plans are controlled by the production planning department. When a need for raw material occurs, the production planning department sends the requirements to the purchasing department with the appropriate due date. The purchasing department sends the “raw material order forms” to suppliers, which provide the raw materials at the due date demanded. General information about batteries and parts of batteries are described in the following sections.

5.1.1.1 Batteries

A lead acid battery is an electrochemical device that produces voltage and delivers electrical current. The battery is the primary source of electrical energy used in vehicles today. Batteries power the starter motor, the lights and the ignition system of a vehicle’s engine. Batteries can be classified based on the lead alloy used in manufacturing. Lead is alloyed with antimony, calcium and selenium in order to obtain different strength and electrical properties. A battery does not store electricity, but rather it stores a series of chemicals which participates in reactions and create electrical energy. At the positive plates (cathode), lead dioxide (PbO_2) is converted into lead sulfate ($PbSO_4$). At the negative plates (anode), metallic lead is converted into lead sulfate. The electrolyte, sulfuric acid (H_2SO_4), acts as a chemical bridge between them. For every electron generated at the anode, there is an electron consumed at the cathode, and the equations become:

Anode: $Pb_{(s)} + SO_4^{2-}{}_{(aq)} \rightarrow PbSO_{4\,(s)} + 2e^-$

Cathode: $PbO_{2\,(s)} + SO_4^{2-}{}_{(aq)} + 4H^+{}_{(aq)} + 2e^- \rightarrow PbSO4_{(s)} + 2H_2O_{(l)}$

Complete Reaction: $Pb_{(s)} + PbO_{2(s)} + 2H_2SO_{4(aq)} \rightarrow 2PbSO_{4(s)} + 2H_2O_{(l)}$

When the battery discharges while operating, the sulfate ions become incorporated in the lead sulfate that is being formed in electrodes. As the process continues, the speed of this reaction decreases and the battery becomes unable to provide electric energy. Most of the lead oxide and porous lead will be then in the lead sulfate form. When the battery is to be recharged, an external source of electric energy is connected to the battery to revert the reaction so that lead sulfate is electrochemically transformed into lead and lead oxide again. The discharge-recharge process can be repeated several hundred times with a good response of the battery. After a certain time, the battery is no longer capable of being recharged and becomes a “used battery”. Under ideal conditions, an automobile battery can last up to six years. At the end of its life, the battery is classified as a hazardous waste and is handled with special equipments and protections while being collected, stored and transported in order to prevent damage to human health or to the environment (TWGBC, 2002).

In general, lead-acid batteries may be classified in two categories: wet-charged and dry-charged. In a wet-charged lead-acid battery, electrolytic solution (sulfuric acid) is filled in the battery, whereas, in a dry-charged battery sulfuric acid is provided separately with the battery and is to be added only when the battery is being used. Wet-charged batteries are ready to be used immediately and they are rechargeable. Dry-charged batteries have a longer stock time so they can be stored in inventory and sold when the customer demand arrives. The manufacturing process of wet and dry-charged batteries is different from each other. Although the company manufactures both types, only the wet-charged battery is considered in this study since its production rate is much higher than dry-charged battery. Most of the wet-charged lead-acid batteries are 12 Volt and principally consist of six cells. A cell is the basic electrochemical current-producing unit in a battery and produces 2 Volt of energy (Figure 5.2). A cell combines positive and negative plates, separators, and electrolyte. Cells are connected with metal that conducts electricity from one cell to the next to produce 12 Volt voltages.

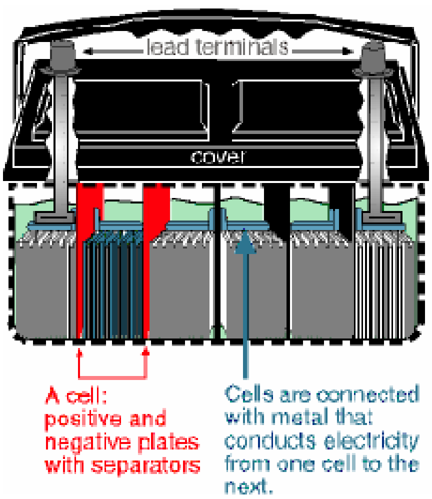


Figure 5.2 Cells in a Battery (Source: BCI, 2008a, n.p.)

5.1.1.2 Parts of a Battery

In general, a battery combines plates, separators, electrolyte solution, lead terminals and a container as seen in Figure 5.3.

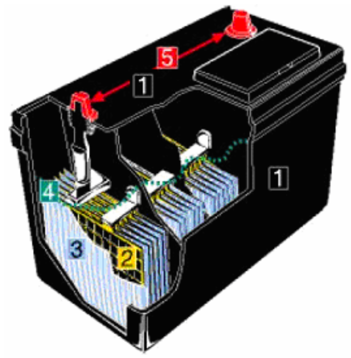


Figure 5.3 Parts of a Battery (Source: BCI, 2008a, n.p.)

Container and Cover

The container is the outside case of the battery which is closed by a cover. The cover and container are made of polypropylene. The container and cover allow the battery to

- withstand the temperature extremes of cold and heat,
- resist damage caused by mechanical shock in rough road service,
- resist acid absorption.

Plates

Plates (as shown in Figure 5.4) are the most important parts giving energy to the battery. Each plate consists of two parts:

- *A rectangular lead grid*: A grid is a lead alloy framework that supports the active material of a battery plate and conducts current. The grids are made from an alloy of lead that contains antimony, calcium or selenium.
- *A spongy paste:* The paste needed for the grids is created from a mixture of lead oxide, sulfuric acid, and water. The spongy paste is plastered on the grid and pressed into the holes of the grid. This paste allows the acid to react with the lead inside the plate. The paste mixture may also contain other additives, like fiber, in order to attach the active material together.

An element is a single unit in the battery construction containing a set of positive and negative plates and a set of separator. As shown in Figure 5.4, a lug is the extension from the top frame of each plate, connecting the plate to the strap. Two types of plates are needed to create the current in a cell:

negative and positive plates. The positive and negative plates are paired in a structure called the “element” as seen in Figure 5.5. An element is a single unit in the battery construction containing a set of positive and negative plates and a set of separator.

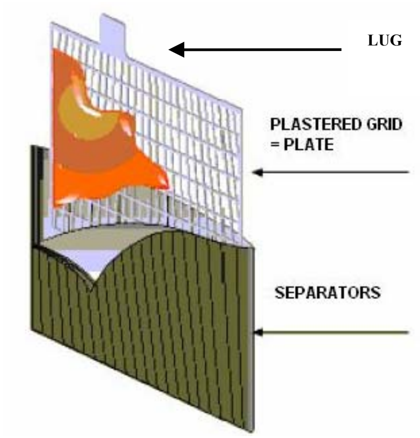


Figure 5.4 A Plate Enveloped by a Separator (Source: BCI, 2008a, n.p.)

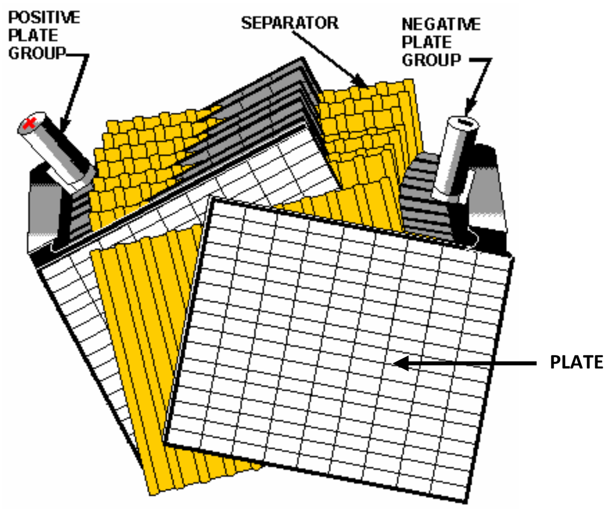


Figure 5.5 An Element (Source: Integrated Publishing, n.d., n.p.)

Separators

A separator is a thin sheet of electrically insulating, finely porous material that permits the passage of charged ions of the electrolyte between the positive and negative plates. A separator is usually made from polyethylene. Separators, as shown in Figure 5.5, keep positive and negative plates from touching each other and shorting out. If a positive plate touches a negative plate, a short circuit results and all the plates in the cell lose their stored energy. Therefore, separators are corrugated or ribbed by using lead alloyed ribs to insure proper distance between plates and to avoid too large displacement of electrolyte.

Electrolyte

Plates are submerged into an electrolyte solution which consists of 35% sulfuric acid and 65% water. This submersion causes a chemical reaction that releases electrons, allowing them to flow through lead terminals to produce electricity. Chemical reactions in the electrolyte solution take place when the battery is charged and discharged, as explained previously.

Lead Terminals

Lead terminals are the connection points between the battery and the car. The positive terminal is where the current flows and the negative terminal is where the current completes the circuit.

5.1.2 Manufacturing System Analysis

This section covers analysis of manufacturing processes and their operational conditions, material management, capacity planning, production planning and scheduling, quality management, workforce management, facilities planning, supply chain management, and logistics.

Since the demands of products are obtained in the previous phase, the demand forecasting procedure of the operations management system should be analyzed in first priority. The production planning department indicates that the demands of products are considered as seasonal. Three periods are considered due to the level of demand: The first period (January – April) which has a moderate demand, the second period (May – August) which has the lowest demand, and the third period (September – December) which has the highest demand. The demands of products are forecasted based on the demands of the previous year. A growth rate of 15% is added to the demands of the previous year when forecasting demands. The bill of material of a battery (Appendix C) obtained from the production planning department is used for identifying production processes and material balances. The weight of a battery and the total weight of lead in the battery are also data obtained from the production planning department for further calculations.

The production planning department is responsible for establishing production plans/schedules and controlling the warehouse activities for developing material requirement plans. The production planning department receives the demand of products from the marketing department via order forms. The production planning department creates the production schedule after reviewing the design cards of products and stock levels of raw materials. The demands of products under a certain level are rejected. Specifically, if the monthly demand of a product is below the production capacity of this product in one shift, this product is not produced. On the other hand, if the monthly demand of the product is close to the capacity of one shift, the monthly demand is scheduled to be produced in a single shift, with the additional overtime if necessary. Alternatively, if the monthly demand of a product is highly above the capacity of one shift, then the production of this product is partitioned into the month. The company works 6 days a week. Each day consists of 3 shifts, which are 8 hours each. The production capacities of the two assembly lines are demonstrated in Appendix B3. Since these capacities show the amount of product that can be produced in one shift (8 hours), these data can be easily transformed to standard times of products. For instance, the second assembly machine can produce 500 units of the product 88-Ah in 8 hours. Therefore, the standard time of this product is calculated to be 0.9 minutes/unit for this machine. To illustrate the relation between the monthly demand, production capacity and standard time, the demand of product 88-Ah in January 2006 is examined. The monthly demand is 716 units (Appendix B1) and the production capacity of the assembly line is 500 units (Appendix B3). Since the monthly demand of 88-Ah is close to the production capacity of one shift, this product will be operated in the assembly line in one shift with the addition of overtime work of 194 minutes.

The schedule of the production plan is prepared on a weekly basis and is reviewed each day. The scheduling of the "battery assembly" machines is taken as a basis for generating weekly schedules because setup operations are needed in the battery assembly machines when a new type of product is produced. Therefore, the first step of scheduling the weekly plan is the schedule of the battery assembly machines. The due dates of the initial operations are determined based on the schedule of the battery assembly operation since backward scheduling method is used to schedule the initial operations of battery manufacturing. After the manufacturing is completed, the final products placed in the storage area waits 1-3 days and controls are made in order to see if there is any leakage in batteries. After the duration of inspection, products are directly carried to customers. Therefore, the company does not hold end-product inventory and there is no cost associated to inventory carrying. The capacity of the storage area is sufficient to store the controlled products, therefore there is no problem associated to the limited storage area.

The company actually possesses the quality certificates TS EN ISO 9001:2000 (which involves quality management systems), ISO/TS 16949 (which is an automotive quality standard), and TS EN ISO 14001 (which involves environmental management systems). Raw materials, production processes, and products are controlled in order to decrease the loss of raw materials and increase the quality of products. For instance the acid used as a raw material for the electrolyte is controlled by the means of the iron test, density test and color test. Quality control tests are also accomplished for final products (toleration to excess charging test, vibration test, etc.). The production processes of the facility are monitored by the quality control department. Control plans of setup operations of machines are described due to the ISO/TS 16949 Quality Standard. These control plans shows the period of setup operations and the quantity of tested materials. For example, the control plan for the battery closing machine indicates that machine adjustments should be made in the covering machine for each type of battery. Therefore, one battery should be tested when a new type of product will be operated in the closing machine. The quality control department has also the right to change the period of setup operations and the quantity of tested materials. For instance, if tests made in a period of time shows that no defect is found, it is possible to increase the period or decrease the number of tests. The inputs, outputs and properties of each manufacturing process are analyzed for the battery manufacturing process in the company. The manufacturing process of the company investigated in this study is explained in the following sections. The production processes of a lead-acid battery can be understood better by using the manufacturing scheme as shown in Figure 5.7.

5.1.2.1 Oxide Milling

Ingots of pure lead are the input for this operation as shown in Figure 5.1. Ingots of pure lead are melted at 400–425°C and put into a mixer. After the blending, lead is adhered into the walls of the mixer. In order to create the oxidation, lead is sent to another compartment where water is gushed from a pipe. Through the compression, lead reacts with the oxygen in water and forms lead oxide (PbO). The lead oxide is then passed into a cyclone separator and bag filter. The particles of lead oxide are separated from the air stream in these equipments. The separated lead oxide is then transferred using screw conveyors into storage tanks, called silos. Lead oxide required for the paste material is obtained as a final output in the oxide milling operation.

5.1.2.2 Grid Casting

Alloyed lead ingots are the input for this operation as shown in Figure 5.7. The lead alloy may contain small percentages of antimony or calcium and tin depending on the type of the battery. The ingots are dropped into the melting pot, which is placed behind the grid casting machines. These ingots are heated up to 460-510 ^{o}C in the pot. In order to produce lead grids, the molten lead alloy is poured into the molds. After cooling, the molten lead is transformed into a pair of grids, as shown in Figure 5.6. The wastes derived from this process are excess parts and rejected grids, dross and fugitive lead emissions.

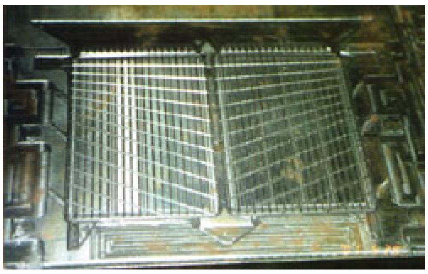


Figure 5.6 Pairs of Lead Grid

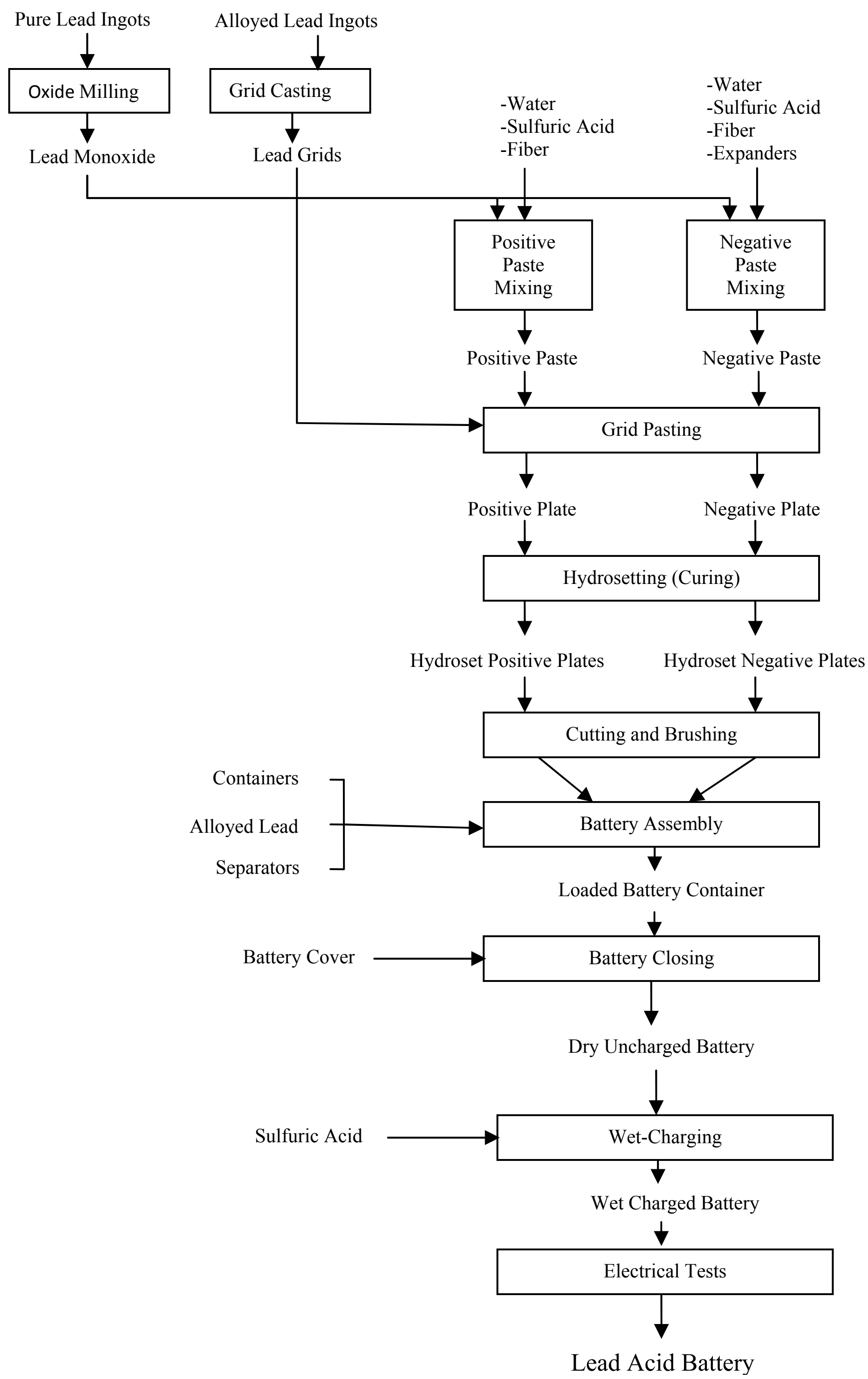


Figure 5.7 Manufacturing Scheme of a Lead-Acid Battery

5.1.2.3 Paste Mixing

Lead oxide, water, sulfuric acid, fiber and expander materials are required for the production of positive and negative paste (Figure 5.7). The positive and negative pastes applied on the grids are manufactured in separate paste mixing operations. The production of positive and negative pastes is the same, except expander materials such as ligno-sulphonates, $BaSO_4$ and active carbon are added to the negative paste. In the paste mixing process, water, acid and other additives are added to the lead oxide and the mixture is blended. The quantity of the water and acid and the duration of mixing the paste are important factors because they control the density of the paste. The outputs of the paste mixing operation are positive and negative pastes that will be used in the grid pasting operation. The wastes derived from this process are paste with improper density and fugitive lead emissions.

5.1.2.4 Grid Pasting

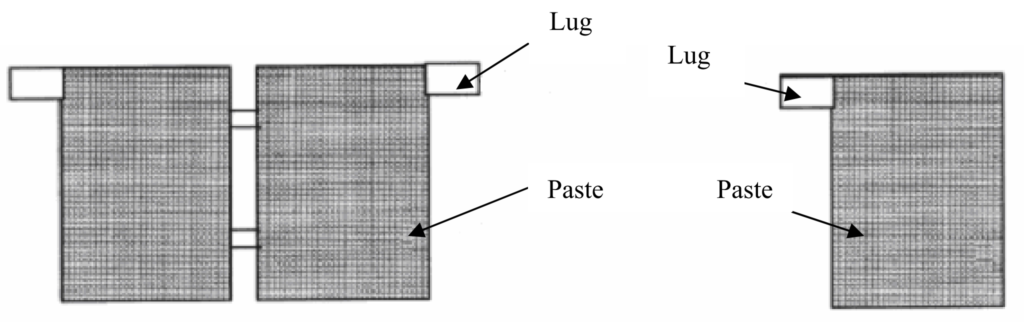
Positive and negative plates are obtained in this process (Figure 5.7). Grid pasting operation is performed by using automated machines. This process can be divided into four sections namely; feeding, pasting, drying and collection. In the feeding section, grids are carried to the pasting machine by a conveyor belt. In the pasting section, the pasting machine spreads the paste on the grids and compresses the grids so that the paste enters into the holes of the grids. This spongy paste allows the acid to react with the lead inside the plate. Plastered plates are then transferred to a furnace at 500^{o}C temperature to remove the humidity from paste. Dry plate surface ensures that the plates do not stick to each other during the following procedures. The high temperature for drying is necessary to harden the surface of the paste surface. At the end of the pasting machine, plastered grids are collected, brushed and arranged by the operators. The wastes derived from this process are rejected plates and drained paste.

5.1.2.5 Hydrosetting

The hydrosetting process is also referred as “curing” of the plates (Figure 5.7). Positive and negative plates are transmitted to “cure rooms” having a relative humidity (90%) and a controlled temperature (30-35°C). Before curing, the paste contains approximately 15-20% free lead. Plates stay in cure rooms for about 36 hours. The hydrosetting process converts the free lead to PbO, using the oxygen from surrounding air. When the reaction is complete, the plates are stronger than before curing, and adherence of the paste to the grids is high. The hydroset plates are then collected for cutting and brushing.

5.1.2.6 Cutting and Brushing

The first operation of this process is executed in the cutting machine. Grids, which are casted in pairs (Figure 5.8-a), are separated into two parts (Figure 5.8-b) because plates are used as a single unit with one lug in the battery assembly. After that, the lugs are cut from their extremities by operators. Plate lugs are brushed and oxide is removed from the lug during the brushing operation. At the end of this process, plates become ready to be carried to the battery assembly section (Figure 5.7). The wastes derived from this process are lug wastes, lead dust and rejected plates.



(a) (b)

Figure 5.8 Paired and Cut Plates (Source: Dahodwalla and Herat, 2000, p. 6)

5.1.2.7 Battery Assembly

At the beginning of this process, the positive and negative plates and separators are assembled in the enveloping machine (Figure 5.7). Battery plates are placed so that each negative plate is followed by a positive plate with the interposition of a plate separator, which is made from polyethylene. The separators are used in order to avoid short circuit between two consecutive plates. This process continues until there are 6 to 20 pairs of negative and positive plates aligned and electrically isolated. Depending on the type of battery being produced, different numbers of positive and negative plates are assembled and enveloped. This assembly creates the “element” as described in Section 5.1.1.2. The elements are then transported to the assembly line. The wastes derived from this process are wasted separators and rejected plates.

The second operation in the assembly line is executed in the automatic Cast-on-Strap (COS) machine (Figure 5.9). Elements are firstly inserted into compartments that are located in a basket. While the basket moves automatically, those compartments are transported from one workstation of the COS machine to another. The process of the COS machine is described as follows:

- Parts are firstly brushed. This operation makes the attachment of the positive and negative plates stronger.
- Connection nodes are dipped into melted alloyed lead pool and after cooling, the parts of the element are connected to each other from their nodes.
- Elements are dipped into melted lead pool again and ribs are attached to the top of elements. Ribs are produced in the COS machine in order to support the plates installed in the container and to ensure proper distance between plates.
- Parts are moved to the insertion section. In this section, operators clean excess parts, check the sequence of positive and negative grids, and insert the parts into containers.

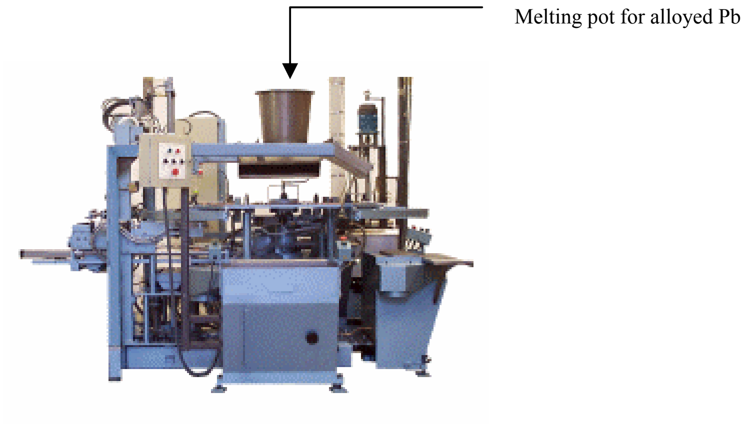


Figure 5.9 A Cast-on-Strap Machine

Finally, the plates are assembled and inserted into the cells of the battery container in this process. The loaded battery container becomes ready to be closed with a cover. The wastes derived from this process are rib wastes, dross, and rejected plates.

5.1.2.8 Battery Closing

The loaded battery container with plates and the cover are necessary for the battery closing operation (Figure 5.7), which is also stated as the "heat treatment phase". In this process, the worker places the cover on top of the container and the covering machine closes the container by melting the cover connections on it. Process temperature is 380-400^{o}C and takes about 4-6 seconds. At the end of this process, a dry uncharged battery is obtained. The wastes derived from this process are battery covers and containers and refurbished batteries.

5.1.2.9 Wet-Charging

In order to obtain a wet-charged battery, the dry uncharged battery needs to be charged with the addition of sulfuric acid (H_2SO_4). The wet-charging operation, which transforms the dry uncharged battery into a wet-charged battery, consists of the following steps:

- The batteries filled with sulfuric acid are placed in cooling pools. The acid is filled into the cells up to a level just above the plates. Since the added sulfuric acid rapidly increases the temperature of the batteries as a result of its reaction with Pb and PbO, there is a need to cool the batteries continuously. This process causes the formation of wastewater.
- The charging plugs are fastened to positive and negative terminals.
- The positive and negative terminals of the battery are connected to electric connections. The current is passed through the battery continuously and charging is complete when there is no change in the specific gravity over 3 hours period.
- The battery is then carried to the finishing line by conveyors. The battery arrives at the finishing line with a decreased electrolyte level. The reason of this decrease is the evaporation of water during charging process.
- Charging plugs are removed and water is added to the electrolyte. Final plugs of the battery are fastened to positive and negative terminals.
- The battery is then washed and dried in order to clean the container and the terminals to prevent the corrosion caused by the drainage of the acid.

5.1.2.10 Electrical Tests

After the wet-charging operation, the charged battery needs to be tested (Figure 5.7). In the electrical test, the batteries are checked for short circuit between the components of the battery container. If any shortage exists, the control machine signals it and separates the defected battery from the line. Finally, batteries are packed and become ready to ship to the customer.

5.1.3 Construction of a Process Flow Diagram

The data obtained when analyzing the operations management system are represented with the help of the process flow diagram. The manufacturing scheme for the production of a lead-acid battery is previously shown in Figure 5.7 to describe the production processes. The wastes produced from each process are inserted into this scheme in this section and the process flow diagram of a lead-acid battery is obtained as shown in Figure 5.10.

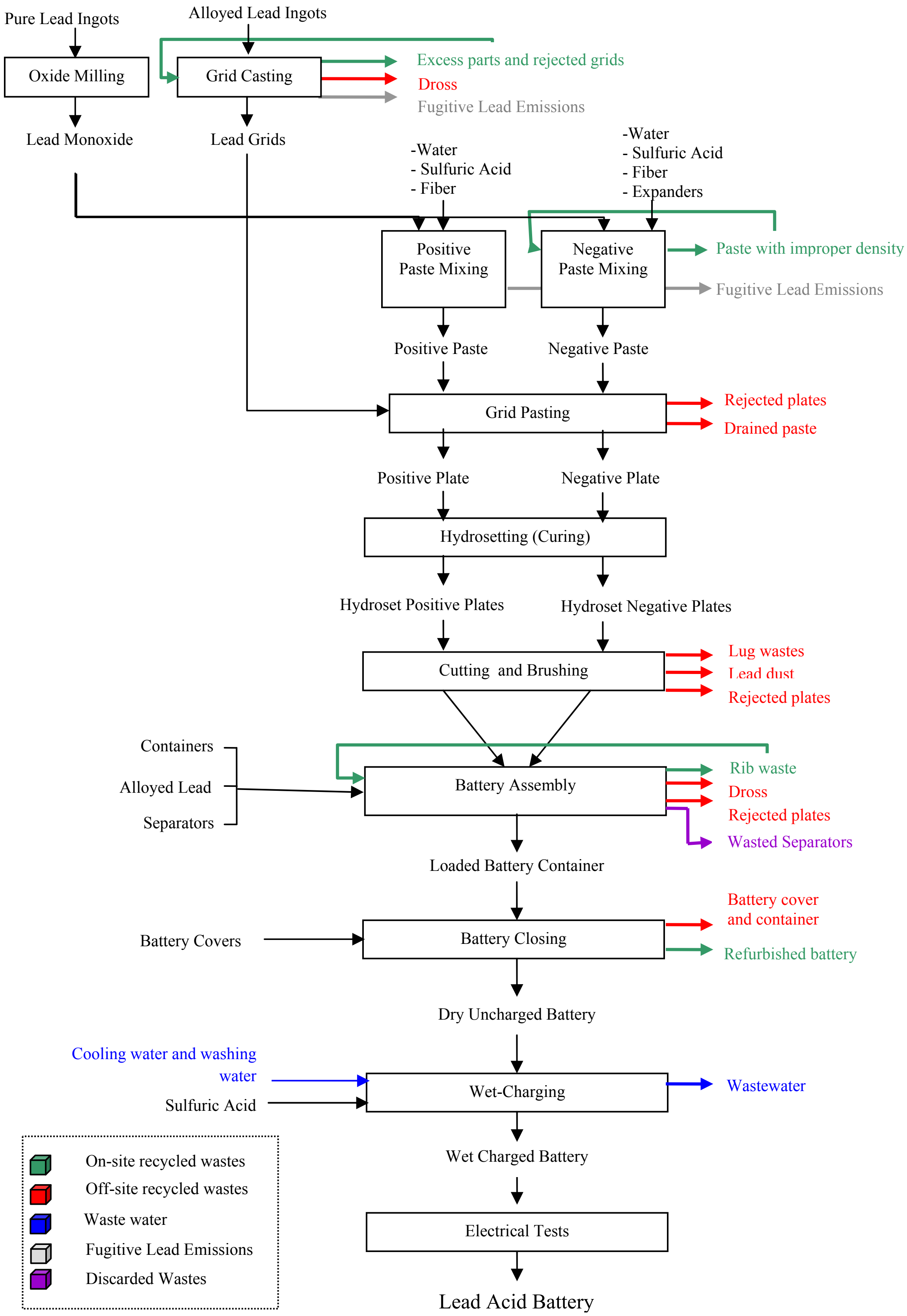


Figure 5.10 Process Flow Diagram of a Lead-Acid Battery

5.1.4 Current Waste Management Practices in the Company

The wastes obtained from manufacturing processes are identified when examining the operations management system in the previous section. In this section of the study, data are collected about wastes. The reasons of the waste and the current waste management practices of the battery manufacturing process are analyzed.

The definition of wastes is the first subject to be analyzed when investigating the waste management system of the company. Processes causing wastes are identified by observing the manufacturing processes and getting information from operators and production planning department. After the wastes are defined, the quantities of wastes in year 2006 are obtained from the quality control department. The Material Safety Data Sheet (MSDS) of a battery, which is also obtained from the quality control department, is an important source indicating the contents and hazards of a battery (Appendix D).

After the collection of information about wastes, currently applied waste management practices of the company are analyzed. In other words, the categorization of wastes is accomplished as: on-site recycled wastes, off-site recycled wastes, discarded wastes, wastewater and fugitive lead emissions. The reasons of wastes are investigated. The waste management practices are carefully investigated in order to decide the appropriateness of implementing these practices. The procedure of sending these wastes to the recycling facility is investigated. The wastes are transported to a recycling facility in Eskişehir by the means of the licensed trucks of the company. Therefore, a transportation cost associated to the recycling of wastes occurs. Since the capacity of licensed trucks is 20 tones, wastes are sent to the recycling facility when 20 tones of waste are collected, which takes approximately 9 days.

Information about the ventilation system is obtained from the quality control department. The capacity of the cooling pools in the wet-charging operation is investigated because it is observed that high amount of water is used in the wet-charging department. Another issue analyzed in the waste management system is the wastewater treatment plant of the company. The materials used in this plant and their quantities are analyzed. The processes of wastewater treatment are examined.

Wastes produced from the battery manufacturing process of the company are classified in five categories: on-site recycled wastes, off-site recycled wastes, wastewater, discarded wastes, and fugitive lead emissions. The wastes obtained from the manufacturing process are shown in Figure 5.11. On-site recycled wastes can be defined as wastes that are found to be reusable within the production process in the company without any prior treatment or process. These wastes may be sent back to the process that is originating the waste or may be used in another process, as shown in Figure 5.11. Therefore these wastes can be called as reused wastes too. Off-site recycled wastes are the wastes that cannot be reused within the facility. These wastes contain a hazardous but valuable material: lead (Pb). Since the company does not have special equipments needed to recycle these wastes, it is necessary to send the wastes to a recycling facility to recover the Pb. Obviously; it is much more expensive to transport the wastes to a recycling facility than to recycle them in the company. Moreover, off-site recycling means poor usage of the raw material. Therefore, it is always advantageous to reduce the amount of off-site recycled wastes at source. Wastewater derives from the manufacturing line of a lead-acid battery because water is used in the manufacturing process for cooling or washing purposes. The pH of the wastewater is very low and the wastewater contains dissolved lead particles. Therefore, the wastewater obtained from the manufacturing processes can not be sent to the sewage system and creates important costs to the company. The wastewater is treated in the wastewater treatment plant of the company; however, since the hardness of the treated wastewater is high, it can not be reused in the production processes. Discarded wastes are the wastes that are not reused within the facility or in a recycling facility. These wastes are sent to trash. Discarded wastes means inefficient use of raw materials because it is not possible to create a value from these wastes. Fugitive lead emissions are atmospheric discharges from raw materials or processes that are released to the atmosphere without passing through any filtering device or control mechanism designed to reduce or eliminate the hazardous content or amount of the materials. Wastes obtained from each of the manufacturing processes of a lead-acid battery and current waste management practices are described in the next sections.

5.1.4.1 Wastes from Grid Casting

The wastes obtained from the grid casting process and waste management practices associated to these wastes are shown in Figure 5.11 and described as follows.

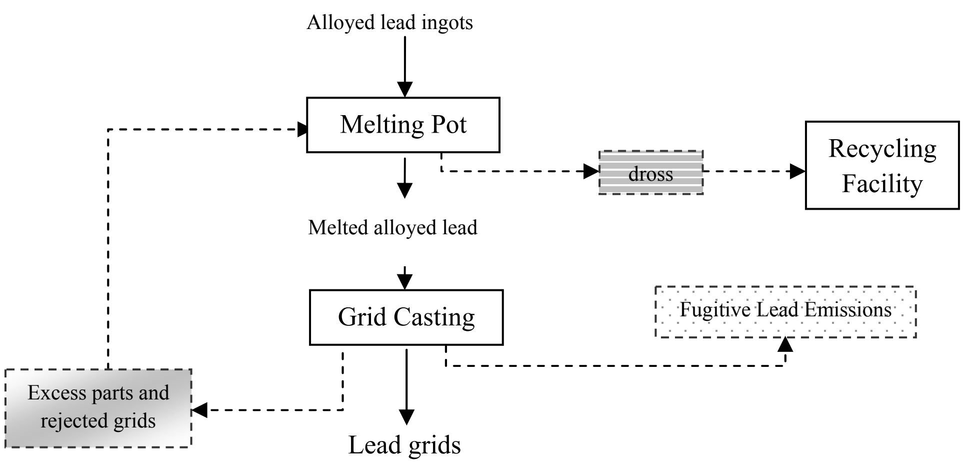


Figure 5.11 On-site Wastes from Grid Casting

a. Excess Parts and Rejected Grids from Grid Casting

The melted alloyed lead that is poured into molds in the grid casting machine generally overflows from the molds and dries as a grid with excess parts. The excess parts of the grids are automatically cut by the grid casting machine and are considered as a waste. In addition, the grid casting machine sometimes produces grids irregular in shape. These grids are rejected and are also considered as waste. Since these wastes are made from lead alloy, it is easy to melt and reuse them in the production process. Excess parts of grids and rejected grids are considered as on-site wastes and are sent back to the melting pot in order to re-melt and use for grid production. The quantity of these wastes is not measured by the company, therefore the cost of these wastes is not known. The company does not collect data about excess parts and rejected grids because these wastes are sent to the pot continuously using the conveyor belt. Quantities of the excess parts and rejected grids are observed in the next sections of this study. After the determination of the quantity of excess parts and rejected plates, this study enables the calculation of costs associated to these wastes.

b. Dross from Grid Casting

Dross is a material formed as a result of the contact of the air with the lead in the melting pot. It is simply the result of lead oxidation in the presence of air, and its formation corresponds to loss of the lead alloy. The cost of using new technologies that prevent dross formation, such as nitrogen blanketing, is so high that accepting dross in the process has become an acceptable issue in the company. Dross is a sponge looking material which captures alloyed lead in its structure. Therefore, there is always a significant amount of recoverable lead alloy in the dross. Since it is not possible to recycle dross in the company, dross is sent to the recycling facility. The formation of dross creates a significant cost to the company. If the dross amount is assumed to be equal to the lead alloy loss, it will be seen that very high quantities of raw materials is lost because of this problem. Since the dross can not be sent to trash because of its hazardous and valuable content, it is sold to a recycling facility. The transportation of dross creates cost for the company. The unit cost of dross is calculated as shown in Table 5.2.

Table 5.2 Unit Cost of Dross

Description	***Worth (YTL/kg)***
Lead Purchasing Cost	3.39
Transportation Cost to Recycling Facility	0.01
Total Cost	3.40
Dross Selling Price	1.50
Unit Cost of Dross (YTL/kg)	1.90

Obviously, as the quantity of dross increases, the total cost of dross will increase. According to the data of year 2006, the quantity of dross formation is 147,599 kg/year in the grid casting department of the company. Therefore, the total cost of dross is:

C_{dross}= 147,599 x 1.9 = 280,438 YTL/year.

c. Fugitive Lead Emissions from Grid Casting

In the grid casting process, the drying of the molten lead alloy that is poured into molds causes generation of fugitive lead emissions. Grid casting is one of the important processes that contaminate the air in the plant with lead particles because of fugitive lead emissions. The ventilation system takes air from the facility and after passing from a filter, discharges the air to the atmosphere. Lead particles are captured by filtration. The filter is changed once a year and is sent to the recycling facility in order to recover the lead from the filter bag.

5.1.4.2 Wastes from Paste Mixing

The wastes obtained from the paste mixing process and waste management practices associated to these wastes are shown in Figure 5.12 and described as follows.

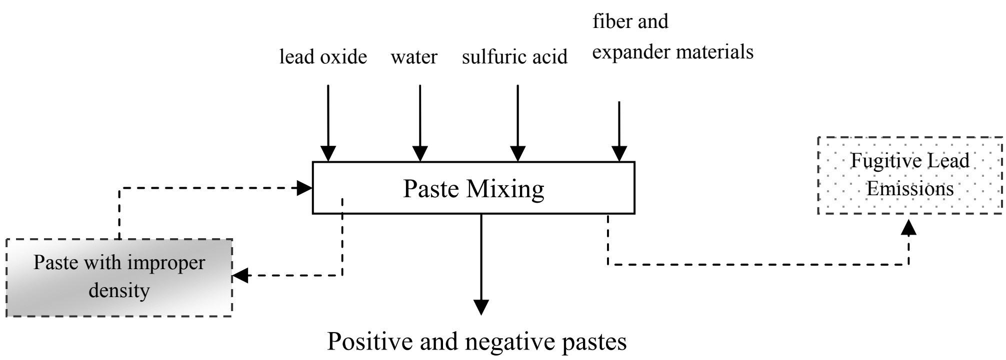


Figure 5.12 Wastes from Paste Mixing

a. Paste with Improper Density from Paste Mixing

The quantity of water and acid and the duration of mixing are the factors affecting the density of paste, which is the property determining the quality of the paste. As the company indicates, the ideal density of a paste is between 4.1 and 4.7 gr/cm^3. The paste produced, however, may sometimes have an improper density. If this is the case, the paste with improper density is set apart and divided into small lots, for example 50 kg. The quantity of the paste with improper density should be small enough so that the quality of paste is not affected. The waste is then included into the subsequent batches of paste as 50 kg, to mix it with normal paste, allowing the waste to be on-site recycled. Table 5.3 shows the content of the paste and the calculation of the unit cost of one kilogram of paste.

Table 5.3 Content of the Paste and Calculation of the Unit cost

Material	Percentage in Paste by Weight (%)	Unit Purchasing Cost (YTL/kg)	Weighted unit Purchasing Cost (YTL/kg)
Lead oxide	80.0	3.3900	2.7120
Acid	4.0	0.2987	0.0119
Water	15.0	0.0035	0.0005
Fiber	0.3	6.0600	0.0181
Expander	0.7	4.3500	0.0304
Unit Cost of the Paste (YTL/Kg)			**2.7729**

In year 2006, it has been recorded that 0.01% of the lead used in paste mixing is wasted associated with the paste having improper density. This corresponds to 752 kg/year. Since the lead corresponds to 80% of the paste, the total weight of the paste with improper density is 940 kg/year. Due to the unit cost of the paste calculated in Table 5.3, the total cost of paste with improper density is calculated as:

$C_{\text{paste with improper density}}$ = 2.77 YTL/kg x 940 kg/year = 2,603 YTL/year.

b. Fugitive Lead Emissions from Paste Mixing

In the paste mixing process, the evaporative losses which contain lead oxide causes generation of fugitive lead emissions. The ventilation system takes air from this department and after passing from a filter, discharges the air to the atmosphere (Dahodwalla and Herat, 2000).

5.1.4.3 Wastes from Grid Pasting

The wastes obtained from the grid pasting process and waste management practices associated to these wastes are shown in Figure 5.13 and described as follows.

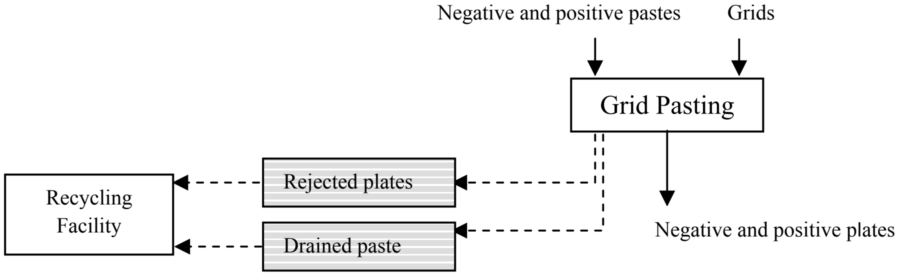


Figure 5.13 Wastes from Grid Pasting

a. Rejected Plates from Grid Pasting

Malfunctioning of machines and improper feeding in machines are the general causes of the plates to be rejected. Improper pasting may occur in grid pasting machine. The company cannot disassemble and recycle the rejected plates deriving from grid pasting in its facility because special equipments would be needed to separate the paste from the grids. Generally, when a plate is rejected, the company's quality management group analyzes the rejected plate and investigates options for using this plate within the facility. For instance, sometimes rejected plates are cut and used in a smaller battery type or are used for testing. If there is no use for the rejected plates, then the demand of the rejected plates, which are indeed by-products with economic value, is investigated by calling potential customers (secondary lead processors). In case there is no demand, the company sends these parts to the recycling facility. Therefore, rejected plates are considered as off-site recycled wastes. The unit cost of the rejected plates is calculated as shown in Table 5.4.

Table 5.4 Calculation of the Unit Cost for Rejected Plates, Lug Wastes, and Lead Dust

Description	***Worth (YTL/kg)***
Lead Purchasing Cost	3.39
Transportation Cost to Recycling Facility	0.01
Total Cost	3.40
Selling Price to the Recycling Facility	2.50
Unit Cost of Rejected Plates, Lug Wastes, and Lead Dust (YTL/Kg)	**0.90**

According to the data of year 2006, since 48,619 kg Pb/year is wasted in the rejected plates of the grid pasting process. Therefore, the total cost of rejected plates is calculated as:

$C_{\text{rejected plates}}$ = 0.90 YTL/kg Pb x 48,619 kg Pb/year = 43,757 YTL/year

b. Drained Paste from Grid Pasting

Drained paste is the paste draining from the grid pasting machine. In the grid pasting machine, the plastered grids are compressed so that the paste enters into the holes of the grids. During compression, there is an overflow of the excess paste applied onto the grids and this paste drains from the pipe attached to the paste mixing machine. The paste also spills to the floor around the machine and it is collected by sweeping into the drainage. Since the drained paste is poor in quality, it cannot be reused in the production line. Therefore, the drained paste is sent to the recycling facility.

Based on the data of year 2006, 0.13% of the lead used in grid pasting is wasted by drained paste. This corresponds to 16,453 kg Pb/year of paste. Since 80% of the paste is lead by weight, it can be said that the total weight of the paste is 20,566 kg/year. The unit raw material cost of the paste is calculated previously in Table 5.3. The calculation of the unit cost of the drained paste is shown in Table 5.5.

Table 5.5 Calculation of the Unit Cost for Drained Paste

Description	*Worth (YTL/kg)*
Raw Material Cost of the Paste	2.77
Transportation Cost to Recycling Facility	0.01
Total Cost	2.78
Selling Price to the Recycling Facility	1.50
Unit Cost of Drained Paste (YTL/Kg)	**1.28**

According to the calculations in Table 5.5, the total cost of the drained paste is calculated as:

$C_{drained\ paste}$ = 1.28 YTL/kg x 20,566 kg/ year = 26.324 YTL/year

5.1.4.4 Wastes from Cutting and Brushing

The wastes obtained from the cutting and brushing process and waste management practices associated to these wastes are shown in Figure 5.14 and described as follows.

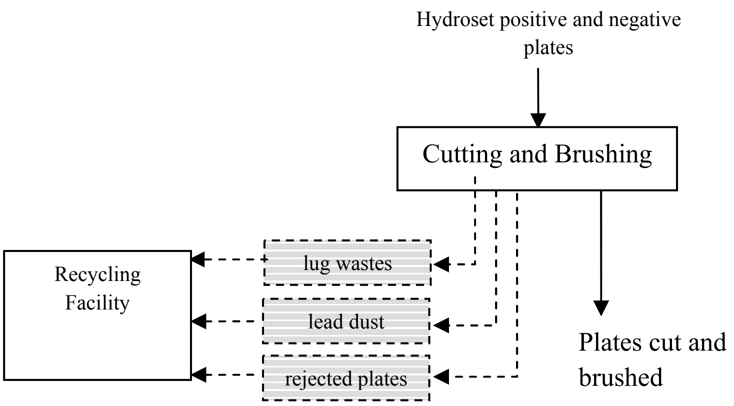


Figure 5.14 Wastes from Cutting and Brushing

a. Lug Wastes from Cutting and Brushing

In the cutting and brushing operation, the lugs are cut from their extremities in order to facilitate the installation of the plates into the battery. Since lug wastes collected from the floor are considered as impure and poor in quality, they cannot be reused in the production line. Lug wastes are considered as off-site recycled waste and are sent to the recycling facility. According to the data of year 2006, 0.58 % of the lead by weight used in cutting and brushing is wasted in the lug wastes. This corresponds to 57,697 kg Pb/year. The unit cost of lug wastes is calculated as previously shown in Table 5.4. Therefore, the total cost of lug wastes is calculated as follows:

$C_{lug\ wastes}$= 0.90 YTL Pb/kg x 57,697 kg Pb/year = 51,927 YTL/year

b. Lead Dust from Cutting and Brushing

Lead dust can be defined as the dust collected from the floor of the working area of cutting and brushing operations. The quality of the lead dust collected on the floor is poor since it is mixed with dirt or other types of foreign materials. Therefore lead dust can not be reused in the production line. As a result, it is necessary to send the lead dust to the recycling facility.

The unit cost of lead dust is calculated as previously shown in Table 5.4. According to the data of 2006, the quantity of lead dust deriving from cutting and brushing is 5,295 kg/year. Therefore, the total cost of lead dust is calculated as follows:

$C_{lead\ dust}$= 0.90 YTL/kg Pb x 5,295 kg Pb/year = 4,765 YTL/year

c. Rejected Plates from Cutting and Brushing

Improper feeding to the cutting machine or the inattention of the operators when brushing parts may be the reasons of rejected plates in cutting and brushing operation. The company cannot disassemble and recycle the rejected plates deriving from cutting and brushing in its facility because rejected plates are composed of grids pasted and cured. For the separation of the components of rejected plates, special equipments would be needed. Therefore, the rejected plates are considered as off-site recycled wastes and are sent to the recycling facility. The unit cost of the rejected plates is calculated as shown in Table 5.4. According to the data of year 2006, 22,309 kg Pb/year is wasted in the rejected plates of the cutting and brushing process. Therefore, the total cost of rejected plates is calculated as:

$C_{rejected\ plates}$ = 0.90 YTL/kg Pb x 22,309 kg Pb/year = 20,078 YTL/year

5.1.4.5 Wastes from Battery Assembly

The wastes obtained from the battery assembly process and waste management practices associated to these wastes are shown in Figure 5.15 and described as follows.

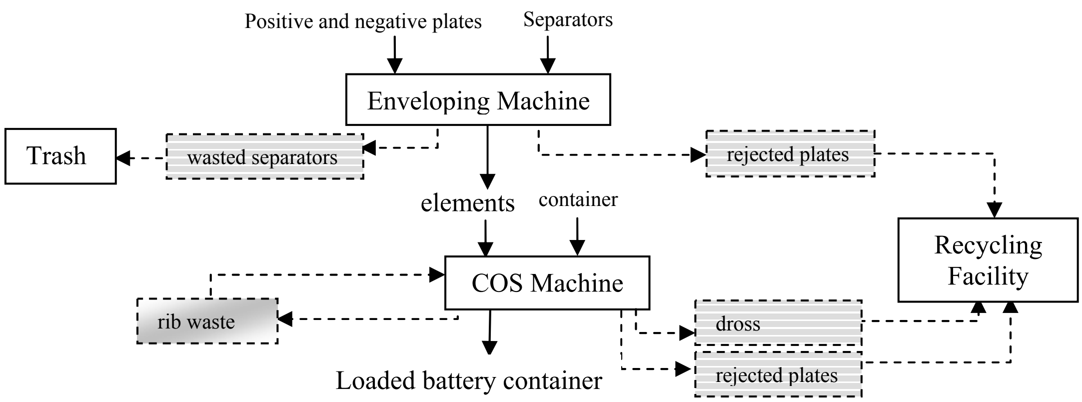


Figure 5.15 Wastes from the Battery Assembly Line

a. Wasted Separators from Battery Assembly

At the beginning of the battery assembly operation, the enveloping machine carves the cylinder of polyethylene and transforms it into a separator, as shown in Figure 5.16. Therefore, one can expect that some separators are misshaped and rejected. Separators are made from polyethylene containing fiber; therefore it is not possible to recycle separators because fiber will burn with flame during melting. As a result, separators cannot be sent to the plastic retailer and are sent to trash. The unit raw material cost of separators calculated in YTL/kg is shown in Table 5.6.

Figure 5.16 An Enveloping Machine

Table 5.6 Calculation of the Unit Raw Material Cost of Wasted Separators

Description	
Purchasing Cost (YTL/m^2)	4.043
Area of one kilogram of separators (m^2)	6.024*
Unit Cost of Wasted Separators (YTL/Kg)	**24.35**

* 1m^2 of the separator weights 0.166 kg.

Based on the data of year 2006, 1,435 kg/year of separators are discarded. Remembering that polyethylene is a thin and light material, this amount refers to a very high volume. When the unit raw material cost calculated in Table 5.6 is taken into account, the total cost of wasted separators is calculated as follows:

$C_{separators}$ = 24.35 YTL/kg x 1435 YTL/year = 34,949 YTL/year.

b. Rib Waste from Battery Assembly

Ribs, which are described in Section 5.1.2.7, are produced in the melting pot of the COS machine in the assembly line. Since ribs are made from lead alloy, it is easy to melt the defective ribs in the pot and reuse them in the assembly line. The company does not have the data about the quantity of the rib wastes produced in this process because these wastes are re-melted instantly.

b. Dross from Battery Assembly

Dross is formed in the melting pot of the COS machine because of the contact of lead alloy in the pot with the air. According to the data of year 2006, the quantity of dross formation is 6,444 kg/year in the COS machines. Based on the total cost calculation of the unit cost of dross described in Table 5.2, the total cost of recycling dross is calculated as 12,243 YTL/year.

c. Rejected Plates from Battery Assembly

Plates rejected in the battery assembly line derives from the enveloping machine and the COS machine. Improper enveloping may be the reason of rejected wastes in the enveloping machine. Improper feeding to the machine or inattention of the operators may be the reasons of rejected plates in the COS machine. The company cannot disassemble and recycle the rejected plates deriving from battery assembly in its facility because rejected plates are composed of grids pasted and cured. For the separation of the components of rejected plates, special equipments would be needed. Therefore, the rejected plates are considered as off-site recycled wastes and are sent to the recycling facility. The calculation of the unit cost of the rejected plates is previously shown in Table 5.4. According to the data of year 2006, total costs of rejected plates are calculated as follows:

- Enveloping Machine:

  $C_{\text{rejected plates}}$= 0.90 YTL/kg Pb x 18, 997 kg Pb/year = 17,097 YTL/year

- COS Machine:

  $C_{\text{rejected plates}}$= 0.90 YTL/kg Pb x 8,667 kg Pb/year = 7,800 YTL/year

5.1.4.6 Wastes from Battery Closing

The wastes obtained from the battery closing process and waste management practices associated to these wastes are shown in Figure 5.17 and described as follows.

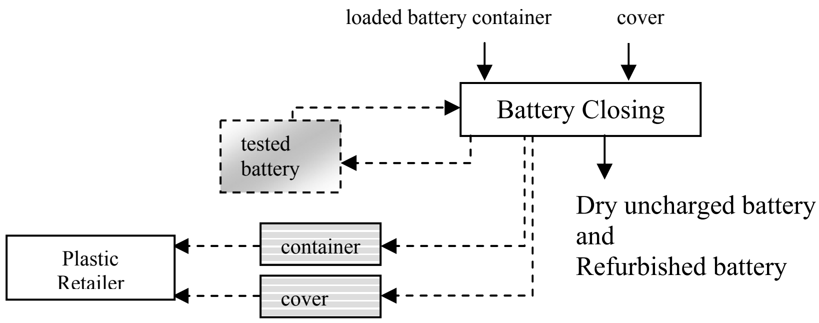


Figure 5.17 Wastes from the Battery Closing Operation

During the battery closing process, the loaded container is closed with the battery cover with the means of heat treatment. For each type of battery, machine adjustments should be made in the covering machine. Two types of setup adjustments are made in this operation.

The first setup adjustment is done with an empty battery container and a cover. The container is melted on the connection nodes and the same operation is done for the cover. Since these two parts are melted separately, they are not attached to each other during tests. After making tests, it is not possible to attach these two parts to each other and reuse them because the minimum necessary height of a battery creates a limitation for this use. In other words, if the connection nodes of the parts are melted again in order to close the battery, the height of the battery will be under the minimum necessary height. Therefore, the empty container and the cover are sent back to the plastic retailer by the company.

The second adjustment is done with a loaded battery container and a cover. The loaded battery container and the cover are both melted on the connection nodes and the tested battery is closed. The quality standard (ISO/TS 16949) notifies that the first battery processed after the machine adjustments should be tested. Therefore, the closed battery is opened by dislodging the cover and the tested battery container is examined to see if there is any error. Since the cover is damaged during opening, it cannot be reused. Therefore, the damaged cover is sold back to the plastic retailer to be recycled. Then, the loaded container is closed with a new cover and sent to the next process. This battery completes the production process but it is not treated like a high quality battery and is considered as a “refurbished battery” by the company. Refurbished batteries are sent to the franchiser, who gives this battery to its customer while the customer’s battery is being repaired (service battery). The company may also send these batteries to its franchisers as a refurbished battery to be sold at a lower price.

a. Battery Cover and Container from Battery Closing

The wasted battery covers and containers are considered as off-site recycled wastes and sent to the plastic retailer. Containers are purchased at 2.37 YTL/unit and covers are purchased at 1.64 YTL/unit. The purchasing costs are transformed to YTL/kg in order to obtain conformity with the selling price to the retailer. The weight of a container is 570 gr and the weight of a cover is 310 gr. The unit cost calculated for a wasted battery container and cover are shown in Table 5.7.

Table 5.7 Calculation of the Unit Cost for Wasted Plastic Materials

Description	**Battery Container**	**Battery Cover**
Purchasing Cost (YTL/kg)	4.15	5.29
Selling Price to the Retailer (YTL/kg)	1.20	1.20
Unit Cost of Wasted Plastic Materials (YTL/Kg)	**2.95**	**4.09**

Quantities and costs of battery containers and covers wasted in the closing operation are shown in Table 5.8.

Table 5.8 Quantities and Calculation of the Unit Cost for Wasted Plastic Materials

Type of Waste	Unit Cost (YTL/kg)	Quantity of Waste (kg/year)	Recycling Cost (YTL/ year)
Battery container	2.95	5,400	15,973
Battery cover	4.09	4,500	18,406
TOTAL		**9,900**	**34,335**

b. Refurbished Battery from Battery Closing

Refurbished batteries are considered as on-site recycled wastes because they are reused in the production as described above. According with the data of year 2006, 0.37 % of the lead used in battery closing is wasted associated to the refurbished battery, which corresponds to 44,177 kg Pb/year. This amount of Pb would be used for the production of 4,854 batteries with 60-Ah, which contains 9.1 kg Pb per battery. Since the refurbished battery can be assumed as a finished battery, its cost is equal to the production cost of a standard battery. The calculations of the total costs of refurbished batteries based on 60-Ah battery production is shown in Table 5.9.

Table 5.9 Calculation of the Total Cost of Refurbished Batteries

Description	
Unit Production Cost (YTL/battery)	51.51*
Quantity of Refurbished Battery (battery/year)	4,854
Total Cost of Refurbished Batteries (YTL/year)	**250,029.54**

* The selling price of a 60-Ah battery is 60.60 YTL/battery. Since the unit production cost is 85% of the selling price, the unit production cost is calculated as 60.60 x 0.85=51.51.

5.1.4.7 Wastewater

In the manufacturing process, water is used not as a raw material that is converted to a product, but as a process instrument. The process that generates the highest wastewater is wet-charging. The use of water and the wastewater obtained from wet-charging process are shown in Figure 5.18. In the wet-charging process, batteries are filled with sulfuric acid, which reacts exothermically with Pb causing temperature increase. This is why cold tap water is added to cooling pools where batteries are charged. After wet-charging, batteries need to be washed in order to clean the containers and the terminals from the corrosion caused by the drainage of the acid. Washing water is used in this phase.

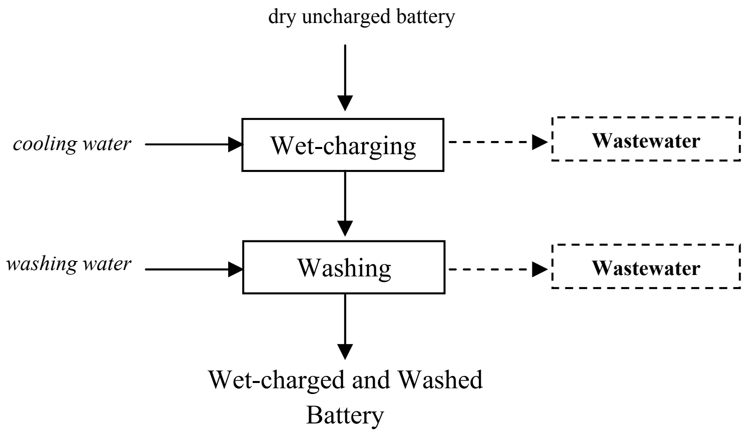


Figure 5.18 Wastes from the Wet-charging Process

In the wet-charging process, batteries are filled with sulfuric acid, which reacts exothermically with Pb causing temperature increase. This is why cold tap water is added to cooling pools where batteries are charged. After wet-charging, batteries need to be washed in order to clean the containers and the terminals from the corrosion caused by the drainage of the acid. Washing water is used in this phase.

The wastewater derived from these operations can not be discharged directly to the sewage system because of low pH and high concentration of lead particles and dissolved Pb. The company treats wastewater in its own wastewater treatment facility. In addition to wastewater from wet-charging and washing operations, the water used for "negative drying" of plates and in cleaning the equipments is transferred to the treatment plant. The wastewater treated in the wastewater treatment facility is not reused in wet-charging or in the cleaning of equipments because of its' high hardness. Therefore, the treated wastewater is only used as lead suppressant on the floor and in the negative drying of plates.

The wastewater derived from the entire facility is 300 m^3 per day. The unit cost of water is 3.54 YTL/m^3. The water usage cost is therefore 1,062 YTL/day for the facility, without taking into account the costs of chemical used in the wastewater treatment facility. Therefore, the total cost of water usage is 331,344 YTL/year, assuming that one year consists of 312 working days for the wet-charging department.

5.1.4.8 Overall View of Production Wastes

Wastes deriving from each manufacturing process are described in previous sections. A summary of the data obtained for the categories of wastes is given in this section (on-site recycled wastes, off-site recycled wastes, wastewater, and discarded wastes). According to the data of year 2006, the quantities of wastes and the waste management costs associated to these wastes are given in Table 5.10.

Table 5.10 Overall View of Production Wastes

Operation	Waste	Percentage of Waste by Weight (%)*	Quantity of Waste (kg/year)	Unit Cost (YTL/kg)	Total Raw Material Cost (YTL/year)
ON-SITE RECYCLED WASTES					
Paste mixing	Paste with improper density	0.01	940	2.77	2,603
Battery Closing	Refurbished battery	0.37	4,854**	51.51***	250,029
Total Cost Of On-Site Recycled Wastes (YTL/year)					**252,632**
OFF-SITE RECYCLED WASTES					
Grid casting	Dross	2.60	147,599	1.9	280,438
Grid pasting	Rejected plates	0.38	48,619	0.9	43,757
	Drained paste	0.13	20,566	1.28	26,324
Cutting and brushing	Lug wastes	0.58	57,697	0.9	51,927
	Lead dust	0.05	5,295	0.9	4,765
	Rejected plates	0.22	22,309	0.9	20,078
Battery Assembly	Dross	0.04	6,444	1.9	12,243
	Rejected plates of enveloping machine	0.14	18,997	0.9	17,097
	Rejected plates of COS machine	0.83	8,667	0.9	7,8
Battery Closing	Battery Container	1.06	5,4	2.95	15,973
	Battery Cover	1.58	4,5	4.09	18,406
Total Cost Of Off-Site Recycled Wastes (YTL/year)					**498,804**
DISCARDED WASTES					
Battery Assembly	Wasted separators	0.72	1,435	24.35	**34,949**
WASTEWATER					
	Wastewater		93,6	3.54	**331,344******
Total Waste Management Cost (YTL/year)					**1,117,729**

* The percentage by weight of the wasted raw material to the total raw material used in the operation.
** The unit quantity is battery/year
*** The unit cost is YTL/battery
**** It is assumed that one year consists of 312 working days for the wet-charging department.

As shown in Table 5.10, the total waste management cost is very high, namely 1,117,729 YTL/year. The dross from grid casting process causes the highest loss of lead and the highest cost of recycling. Additionally, it should be noticed that the company does not collect data about excess parts and rejected grids obtained from grid casting, and rib wastes obtained from battery assembly. Therefore, the data about these wastes can not be given in Table 5.10. However, the needed data are collected and the production of excess parts and rejected grids from grid casting is analyzed in this study.

5.1.5 Environmental Impacts of Materials Used in Production

Lead-acid batteries contain chemicals that have the potential to be hazardous to human health and environment. The batteries contain lead, a highly toxic metal, and sulfuric acid, a corrosive electrolyte solution. Since both of these materials are classified as hazardous (TWGBC, 2002), it is very important to take preventive actions in the entire life cycle of batteries.

5.1.5.1 Lead (Pb)

One of the major pollutants in a lead-acid battery manufacturing industry is Lead (Pb). Lead is a gray-white, soft metal with a low melting point, a high resistance to corrosion, and poor electrical conducting capabilities. It is highly toxic. According to Bishop (2000, p. 42), the primary use of lead is the lead-acid batteries used in vehicles (about 65 percent of all lead used) and lead-acid batteries contribute to the contamination of all environmental media during their production, disposal and incineration (WBG et al., 1998, pp. 215-217).

Lead in the air -detected in the form of particulate- can fall to earth by wet and dry deposition and contribute to lead levels in dusts, water, vegetables and soils. A significant part of lead particles from emissions sources is of submicron size and can be transported over large distances. The World Health Organization (WHO) recommended an air quality standard in 1987 of 0.5-1.0 $\mu g/m^3$. However, elevated levels can be found in some industrial areas. Lead in soil is relatively insoluble and has a low mobility, with a half-life of several hundred years. Once contaminated, soil is liable to remain polluted with lead and this affects soil productiveness. Plants can take up the lead that is present in the soil and this will add to their lead content. Accumulation of lead in grasses is a potential hazard to farm animals. In some researches, it is found that the population living adjacent to industrial areas show elevated levels of lead exposure caused by the higher level of lead in the soil. Lead can be detected in suspended and dissolved form in water. Lead can be carried in water but most of this lead precipitates as a solid at the base of the waterway or ocean. Lead may interact damagingly with aquatic life. Uptake by aquatic species can result in malformations, death, and aquatic ecosystem instability. Lead may enter the human body by inhalation and ingestion of food, water, soil, and airborne dust as shown in Figure 5.19. Ingestion of particles of lead with food is the main source of lead intake to the general adult population. Lead in drinking water is also a source of lead intake and is highly toxic for both children and the fetus of pregnant women. Lead levels in drinking water, sampled at source, are usually below 5 $\mu g/l$ (WBG et al., 1998, pp. 215-217; Dahodwalla and Herat, 2000; Allen and Shonnard, 2001, p. 19; Thornton et al., 2001, pp. 113-142).

As Bishop (2000, p. 42) indicates, lead is a general metabolic poison at high levels for the human body. It is stated in Dahodwalla and Herat (2000) that if absorption of lead is not controlled, the body will accumulate the lead in target organs and tissue, such as brain, faster than it can be eliminated. Lead affects the nervous system, the blood-forming system, the kidneys, and the cardiovascular and reproductive systems. High levels of exposure to lead may cause lead poisoning. The most profound effects of lead poisoning are undoubtedly those associated with severe damage to the central nervous system. As a result, brain damage may cause stupor, convulsions and/or coma and may progress to death. People exposed to lead fume at work can absorb significant amounts by inhalation if protective equipment is not worn. Additionally, there is a direct correlation between elevated levels of lead in the blood and decreased IQ, especially in the urban areas of countries that have yet to ban lead as a gasoline additive. Lead has important effects on the nervous system of young children: reducing intelligence and causing attention deficit, hyperactivity, and behavioral abnormalities. Chronic exposure to lead has significant effect on intelligence and neuropsychological performance of children. It is also proved that preschool lead exposure affects the risk of criminal behavior later in life (Nevin, 2007). The human fetus is seen to be affected by prenatal exposure to lead which may cause reduced birth weight, disturbed mental development, spontaneous abortion, and premature birth (WBG et al., 1998, pp. 215-217; Allen and Shonnard, 2001, p. 19; Thornton et al., 2001, pp. 113-142).

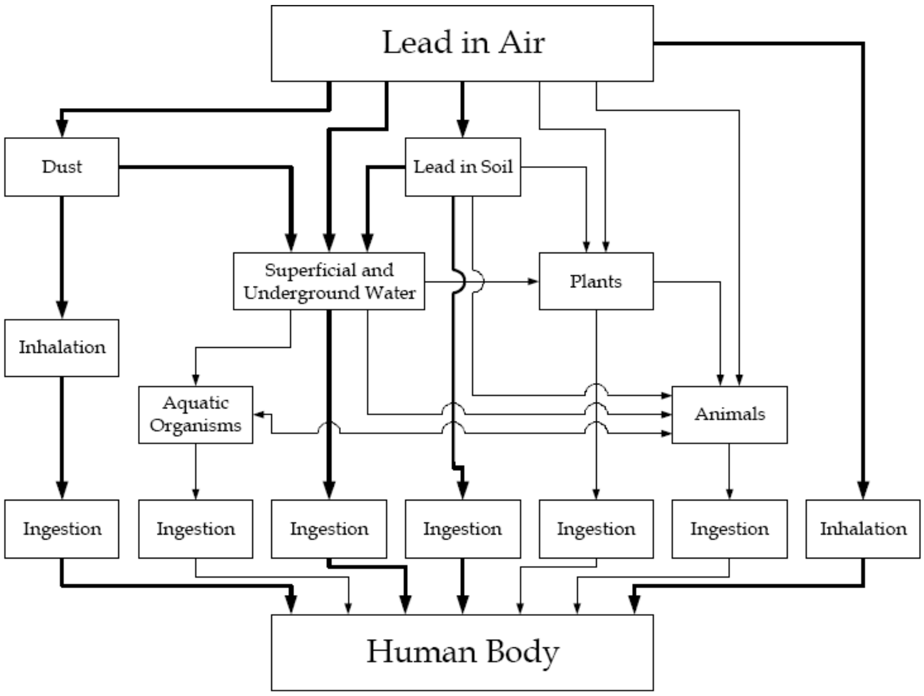


Figure 5.19 Major Pathways of Human Lead Intake (Source: TWGBC, 2002, p. 20)

5.1.5.2 Sulfuric Acid

Sulfuric acid is used in the electrolyte solution of the battery. Contact with the sulfuric acid solution may result in irritation or chemical burns to the skin, or irritation to the mucous membranes of the eyes or the upper respiratory system. Direct contact of sulfuric acid electrolyte with eyes may cause severe burns or blindness. Likewise, direct contact of sulfuric acid electrolyte with the skin may cause skin irritation or damaging burns. Short term liquid or vapor contact with sulfuric acid electrolyte may result in irritation and acid burns to the exposed area. Ingestion of electrolyte may cause severe injury and vomiting.

5.2 Identification of Alternative Waste Management Solutions

In this phase of the methodology, the alternative waste management solutions are identified by investigating waste management technologies and alternative waste management solutions.

5.2.1 Investigation of Waste Management Technologies

The possible waste management technologies in the battery manufacturing plant are identified and the benefits of implementing pollution prevention techniques in the considered sector are investigated. The best available technologies aiming the decrease of particular types of wastes are described in detail in the evaluation of alternative waste management solutions investigated for the considered wastes. Additionally, two case studies concerning a general pollution prevention study in the car battery manufacturing industry are examined.

A Tunisian car battery manufacturer has made many improvements in the overall of the manufacturing process and developed its operational efficiency and product quality. Detected alternatives required investment about $ 522,500 and a financial benefit of $ 1,531,206 per year is achieved. Benefits gained from the project are reduction of employee exposure to lead dust, reduction in energy usage, reduction of amount of lead purchased, and reduction in the quantity of wastewater. This case study is also an important example showing that it is possible to gain big financial benefits by decreasing the dross formation in the grid casting operation (RCP/RAC, 2008). However, the case study does not indicate the methods used for decreasing dross. Therefore, investigations are made in order to discover alternative waste management solutions for minimizing the dross formation and decreasing dross, which is considered as one of the most important alternatives. Another Turkish car battery manufacturer has decreased its water usage by 366,000 tons/year by constructing a wastewater recycling system. Additionally, the wastewater discharged from the wastewater treatment plant to sewage system is diminished to 1% and the pollution caused by sulfate has been removed. An investment of $ 8,450 is made and a financial benefit of $ 1,160,000 is achieved (DELTA, 2003). This case study is an important motivation showing that it is possible to considerably decrease the water usage and associated costs in battery manufacturing.

5.2.2 Investigation of Alternative Waste Management Solutions

Alternative waste management solutions are investigated for the production wastes described in Section 5.1.4. Alternatives summarized in Table 5.11 are described in detail in the following sections.

Table 5.11 Investigated Alternative Waste Management Solutions

Waste Type	**Manufacturing Process**	**Solutions**
Dross, excess parts and rejected grids	Grid casting	Addition of Excess Parts and Rejected Grids in Batch Mode
		Separate Pure Lead From Dross With Vitaflux
Dross	Battery Assembly (COS machine)	Separate Pure Lead From Dross With Vitaflux
Wasted Battery Covers and Containers	Battery Closing	Change the Production Schedule
Treated wastewater	Wastewater treatment	Use Caustic Instead of Lime
		Adjust the Hardness by Dilution Using Fresh Water
Drained paste	Grid pasting	Collect The Drained Paste in a Container
Wasted separators	Enveloping	Increase the Consciousness of Operators
Rejected plates	Grid pasting	Use Water Jet Technologies
Lug wastes, lead dust, rejected plates	Cutting and brushing	Use Automated Closed Machines
Fugitive lead emissions	Grid casting and paste mixing	Use Face Masks

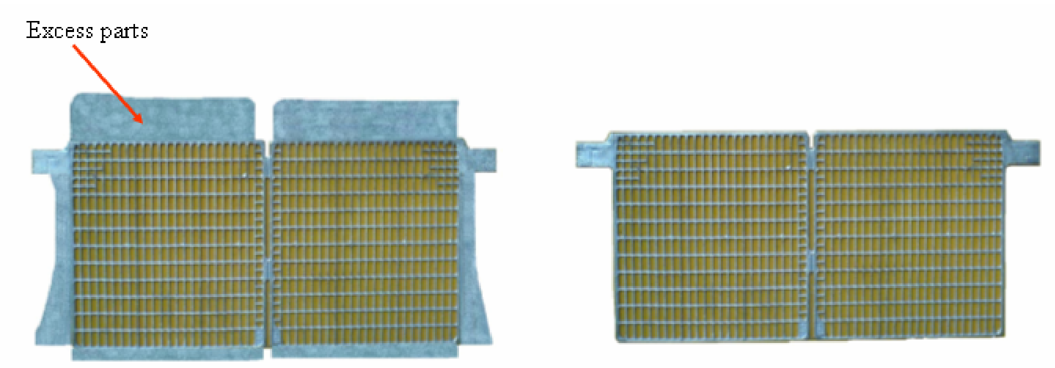
5.3 Evaluation of the Alternative Waste Management Solutions

The alternative waste management solutions investigated in Section 5.2.2 are evaluated from operational, technical and economical point of views. The studies made during the evaluation of the alternatives and results of operational, technical and economical analyses are summarized in the following sections.

5.3.1 Alternative Waste Management Solutions for Waste Generated From Grid Casting

Dross obtained from the grid casting process is the waste that causes the highest lead loss in the company as reported before (Table 5.10). Therefore, it is critical to generate alternatives solving the problem of dross formation either by preventing its formation or decreasing the rate of formation. In the grid casting process, the excess parts of each grid are cut automatically (Figure 5.20) and transferred to the melting pot by a conveyor belt located behind grid casting machines, as shown in Figure 5.21.

Moreover, the rejected grids detected by operators are added to the melting pot immediately after their detection. Therefore, the grid casting process involves continuous addition of wastes into the melting pot. The formation of dross is the result of contact of molten lead alloy with air. It is simply the oxidation of lead alloy. Therefore the formation of dross is inevitable on the surface of the molten lead alloy in the pot that is open to atmosphere. In fact, the dross may act as a protective passive film preventing further dross formation if it is not disturbed. But, when wastes deriving from the grid casting machine are added to the melting pot continuously, the surface covered by dross collapses, and this results in an increase in contact time and contact area of lead alloy with air. As a result, the amount of dross increases continuously when wastes are added to the pot.



a. Grids before excess parts are cut b. Grids after excess parts are cut

Figure 5.20 A Grid Before and After the Cutting Process

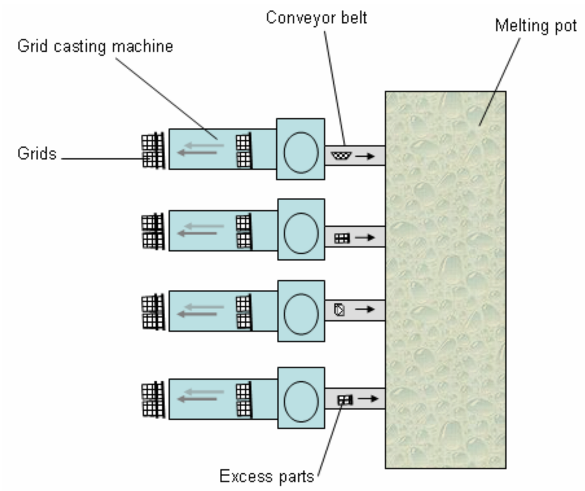


Figure 5.21 Top View of Grid Casting Department

The unit cost calculation of dross is given previously in Table 5.2. For example, if the dross is decreased by 20%, the decrease in dross will be 29,520 kg/year and the associated cost decrease will be 56,088 YTL/year. As seen from this example, it is highly profitable to decrease the amount of dross. Therefore, it is decided to investigate methods involving the decrease of the rate of dross formation or the prevention of formation.

Dross formation can be minimized by stopping the practice of adding excess parts and rejected grids into the pot. This alternative has been evaluated by he company. The rejected grids have not been added to the melting pot during a week and the amount of dross in the cauldron has been reduced by 70% for calcium alloyed lead and 20% for antimony alloyed lead. However, the company has experienced that the storage of these wastes during one week period was very difficult. Furthermore, in order to reuse these wastes in the production, they have melted them in a small melting pot, which resulted in lead dust and fume formation. The company has not considered transporting the excess parts and rejected grids to the recycling facility, because these rejects have the quality of a raw material and are not contaminated.

The amount of dross and its formation rate grows with the increase of the contact surface area between the molten lead and air. The duration of contact is also a factor increasing the amount of dross and its formation rate. For these purposes, there may be some engineering controls over the problem aiming at reducing dross amount or slowing down the rate of formation. This can be done either by changing the design of the melting pot or by changing work practices. The excess parts and rejected grids can be melted in a separate pot as shown in Figure 5.22. This type of procedure is expected to lower the amount and rate of dross formation considerably while decreasing lead exposure from lead fumes and powdery dross which may become airborne easily.

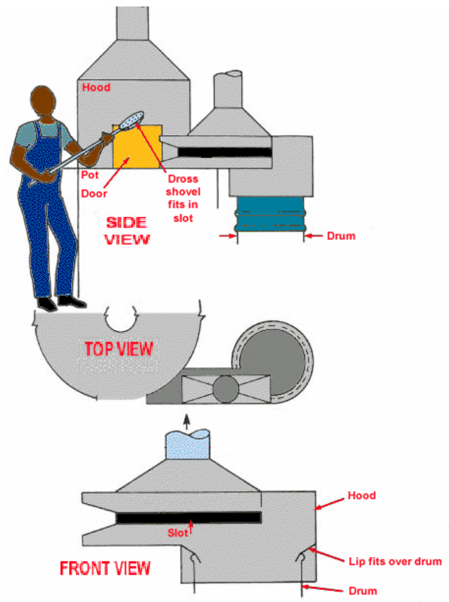


Figure 5.22 Scrap Pot and Dross Hood (Source: OSHA, n.d., n.p.)

Another technique may be the continuous ventilation of the melting pot with a gas, which is inert and not ignitable. Nitrogen (N_2) gas can be used for this application; however, the application is high in cost.

In addition to the techniques mentioned, the practice of adding excess parts and rejected grids may be changed from continuous to batch. In other words, the parts and grids may be collected and then added at specific time intervals, so that the contact time of the molten lead alloy with air can be decreased. This practice is experimented in the grid casting procedure in this study to observe the change of dross formation rate. On the other hand, it is also possible to use drossing-off fluxes for extracting the pure lead from dross in the melting pot. This practice is also analyzed in this study to observe the recovery of pure lead from dross in grid casting operation.

5.3.1.1 Alternative Waste Management Solution 1: Addition of Excess Parts and Rejected Grids in Batch Mode

The suggested application involves short-term collection of excess parts and rejected grids. As shown in Figure 5.23, the wastes can be stored next to the grid casting machine and they can all be added at the same moment to the melting pot at the end of a period of time. This alternative may bring in the possibility of mitigating the amount of dross produced at source and may also decrease the disadvantages of storing wastes for a long time.

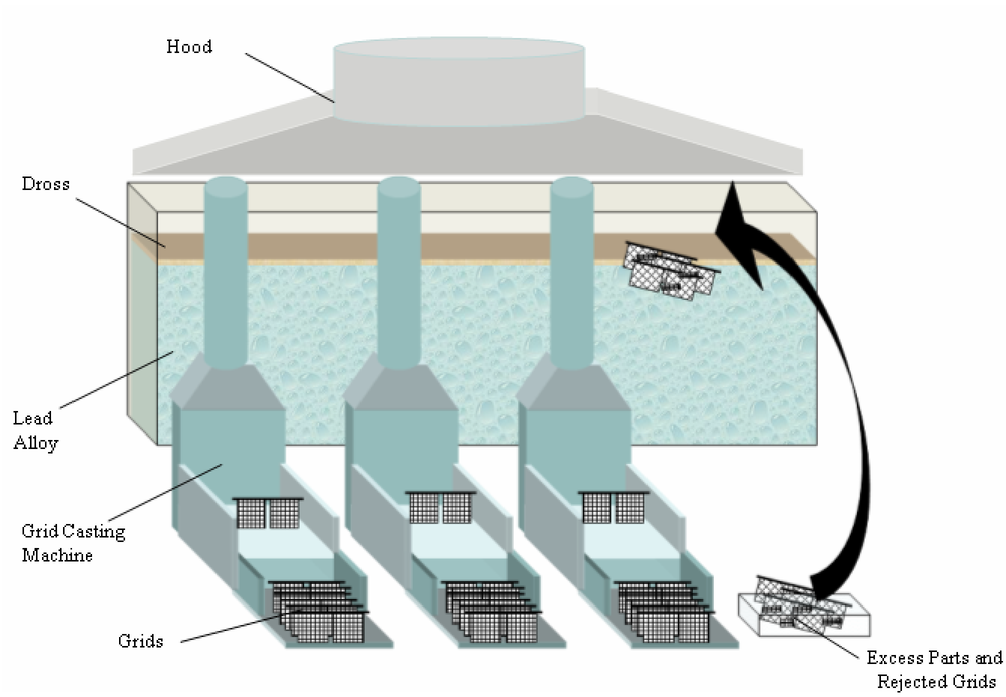


Figure 5.23 Representation of Batch Addition of Excess Parts and Rejects

Two experiments are made for observing the relationship between dross formation and time interval adopted for collection of rejected parts and grids. Two different time intervals were tested as 1.5 and 3 hour. The current grid casting procedure was also observed for comparison. At the time of the experiment, the grid casting machines were in use for producing antimony alloyed lead grids.

Before the experiment, the dross layer from the surface of the molten lead alloy was completely removed from the melting pot by the use of a ladle with holes in it. The amount of dross formed in the melting pot during 1.5 and 3 hour periods was observed under the conditions in which the excess parts and rejected grids were collected (Figure 5.24). At the end of the collection period, the production of grids was stopped and the dross formed on the surface was removed and weighed. Following this, the collected excess parts and rejected grids were weighed and added to the melting pot. Since the excess parts and rejected grids weighed about 700 kg, the manual addition of the rejects to the pot took approximately 25 minutes. Then, the formation of dross for an hour was allowed under the conditions of no production. Finally, the dross formed in an hour was collected and weighed. The summation of the dross collected before and after the addition of rejects is considered as the total weight of dross obtained from the experiment with the considered time interval.

Figure 5.24 Excess Parts and Rejected Grids Collected

Following up these steps, the current grid casting procedure was observed for the same time intervals; specifically 1.5 and 3 hours time periods. Accordingly, the production of grids was started with continuous feeding of the melting pot with the excess parts and rejected grids by conveyor belt. The amount of dross formed at the end of the time interval was measured by collecting and then weighing the dross. During this step, the amount of excess parts and rejected grids could not be measured since they are automatically added to the melting pot. However, results of the previous experiment show that the ratio of rejects to the ratio of product produced is about 58-60%, which is considerably high.

The current grid casting procedure and the experiment in which rejects are collected in a time interval are compared. Table 5.12 shows the comparison for 1.5 and 3 hour time interval.

Table 5.12 Results of Experiments

	Experiment 1		**Experiment 2**	
	Experiment 1.1: Collection of Rejects During 1.5 Hour	**Experiment 1.2:** Current Grid Casting Procedure During 1.5 hour	**Experiment 2.1:** Collection of Rejects During 3 Hours	**Experiment 2.2:** Current Grid Casting Procedure During 3 Hours
Excess Parts and Rejected Grids Measured (kg)	625	-	795	-
Dross Measured (kg)	44.6	51.0	16.5	41.0
Product Produced (kg)	1,073.4	1,132	1,318	1,716
Percentage of Dross in Weight (%)	4.15	4.50	1.25	2.40
Total Cost (YTL)*	**84.75**	**96.90**	**31.35**	**77.90**

* The unit cost of dross evaluated in Table 5.2 is calculated as 1.90 YTL/kg. Total cost is computed by multiplying the dross measured by the unit cost of dross.

The percentage of dross is an important indicator showing the efficiency of the experiment. The percentage of dross is calculated by dividing the amount of dross formed to the amount of product produced. As it is seen in Table 5.12, the percentage of dross is less in the experiments in which rejects are collected during a specific time interval compared to the percentage of dross of the current grid casting procedure. Specifically, Experiment 2 shows that the dross is reduced by 48% when rejects are not added to the melting pot during a 3 hour time interval. The difference between the dross measured in Experiment 2.1 and Experiment 2.2 is 24.5 kg as it can be seen in Table 5.12. If the dross amount is assumed to be equal to the amount of lead alloy loss, then 24.5 kg of lead alloy may be considered as recovered lead alloy using this alternative during 3 hours. It can be seen in Table 5.12 that the total cost is less in the experiments in which rejects are collected during a specific time interval compared to the total cost of the current grid casting procedure. When costs of Experiment 2.1 and Experiment 2.2 are compared, it can be seen that Experiment 2.1 is 46.55 YTL more profitable for 3 hours.

According to the results obtained from the two experiments with different time intervals, it is proved that the suggested work practice reduces the amount of dross significantly. It has been also shown that decreasing contact time decreased the amount of dross formed. Therefore the longest possible time period for collection is expected to decrease the dross amount most. However, the storage of the wastes is difficult and time consuming. To overcome this difficulty in application, a new conveyor belt collecting the rejects of all of the grid casting machine should be installed so that the collection is automatically done. As shown in Figure 5.25, the conveyor belt may carry excess parts into a storage box. At the end of a time period, the loaded storage box can be moved next to the melting pot and the excess parts and rejected grids can be emptied to the pot. Emptying the storage box takes about 25 minutes. Since the production should not be interrupted while the box is emptied, it is needed to locate a new storage box at the end of the conveyor belt. This system will prevent the interruption of the manufacturing operations and the collection of excess parts and rejected grids while the loaded storage box is emptied into the melting pot. Two storage boxes can be used alternately when emptying the collected parts to the pot. Additionally, the best time period should be chosen considering the addition of the wastes into the melting pot.

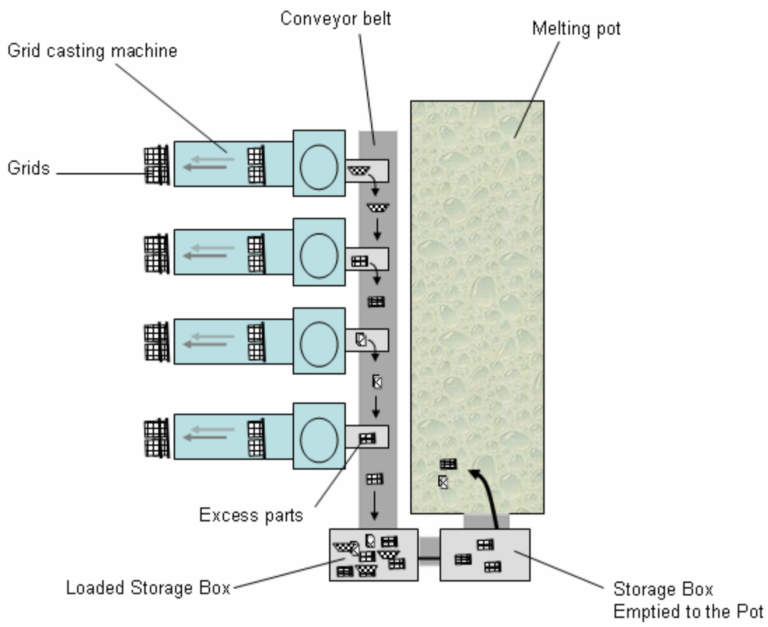


Figure 5.25 Top View of Grid Casting Department with Conveyor Belt

When analyzing Tables 5.12, it can be seen that the decrease in the percentage of dross is higher in the 3 hour experiments compared to 1.5 hour experiments. There are different aspects affecting the difference between the two sets of experiments other than their different time interval. One aspect is the attention and concern of operators. It is observed that some operators added the rejects to the melting pot during Experiment 1.1, where no addition to the pot should be done. Undoubtedly, this is the reason why the percentage of dross formed in Experiment 1.1 is higher than Experiment 2.1. On the other hand, due to the production schedules, 4 grid casting machines have worked in 1.5 hour experiments, while 3 machines have worked in 3 hour experiments. This fact is also one of the reason why the dross formed in Experiment 1.1 is much higher than Experiment 2.1. Additionally, the dross collected at the end of experiments also depends on the operator who collects the dross. When one operator can collect more carefully, another may collect dross quickly. This fact causes differences in the quantity of dross collected. Finally, values obtained in these experiments depend also on the workloads of the operators since the experiments are done manually. For instance, when an operator is transporting the wastes to the storage area, the grid casting machine may make an error and the quantity of rejected grids may increase until the operator come back next to the machine. In the 1.5 hour experiments, the production schedule was more loaded than the 3 hours experiments, therefore operators had difficulties in carrying on the experimental plan. In order to prevent the failures caused by the heavy workload of operators, it is recommended to install a conveyor belt as shown in Figure 5.25.

Benefits: The cash flow analysis of the batch mode and the current system are compared in Table 5.13.

Table 5.13 Comparison of Cash Flow Analyses of the Current System and the Batch Mode

	Current System	**Batch Mode**
Quantity of dross (kg/month)	12,299	6,396
Cost of raw material loss (YTL/month)	23,368	12,150
Direct labor cost associated to dross (YTL/month)	2,337	1,215
Overhead cost associated to dross (YTL/month)	4,340	2,256
Labor cost associated to the collection of parts (YTL/month)	-	456
Net Present Value (YTL/year)	**325,684**	**174,273**

The calculations in Table 5.13 take into basis the results of Experiment 2, implicating that dross is reduced by 48% with the use of the batch mode alternative. The cost of raw material loss is calculated based on the unit cost of dross calculated in Table 5.2. Since it took 3 hours to obtain 41 kg of dross in Experiment 2, the production of dross is assumed to be 13.6 kg/hour. Additionally, the unit labor cost for the company is calculated to be 2.62 YTL/hour, based on the base wage rate. Given the unit labor cost and unit production rate of dross, it can be concluded that the unit direct labor cost of dross is 0.19 YTL/kg. Based on the monthly quantity of dross, the direct labor cost associated to dross in the current system is:

$$C_{\text{Direct Labor Cost of Current System}} = 0.19 \text{ YTL/kg} \times 12{,}299 \text{ kg/month} = 2{,}337 \text{ YTL/month}.$$

In the production cost of a battery, it is known that the direct labor occupies a percentage of 14%, and the overhead occupies a percentage of 26%. The overhead cost associated to dross can be calculated by using these ratios and the direct labor cost calculated above. Since the 14% of the production cost is 2,337 YTL/month, the 26% is 4,340 YTL/month, which corresponds to the overhead cost associated to dross, as shown in Table 5.13.

The direct labor and overhead costs of the batch mode are calculated similarly. In addition to the current system, in the batch mode there is a need of labor when collecting excess parts and rejected grids. In the experiment, it is seen that a total of 45 minutes is spent for a production of 3 hours. Taken into basis that the company works 24 hours during 29 days/month, it is calculated that the monthly labor spent for this alternative is 174 hours. Since the unit labor cost is 2.62 YTL/hour, the labor cost associated to the collection of parts is:

$$C_{\text{Labor Cost of Collecting Parts}} = 2.62 \text{ YTL/hour} \times 174 \text{ hours/month} = 456 \text{ YTL/month.}$$

The net present values of the current system and the batch mode are calculated for one year, as seen in Table 5.13. The costs are assumed to derive at the end of each month and the monthly interest rate is taken as 1.6%. When comparing net present values, it can be seen that the batch mode decreases costs by 46% compared to the current system.

This alternative obviously will reduce the quantity of lead alloy required to produce the same amount of grid since the raw material loss in dross will be minimized. Therefore, it will clearly improve the productivity by reducing raw material consumption. This alternative is also advantageous because the waste is reduced at source. As a result, the environmental impact of the company can be considerably reduced by using this alternative.

Limitations: As explained before, it is necessary to install automated machines in order to collect excess parts. A simple conveyor belt and two storage boxes will be sufficient as shown in Figure 5.26. The storage of wastes should not interrupt operators. On the other hand, if the optimal time interval is aimed for decreasing dross, several experiments should be made with the same procedure. The time interval should be changed and the quantity of dross measured and the decrease in percentage of dross should be watched. The volume of the storage area and the participation of the operators should also be taken into account while making new experiments.

5.3.1.2 Alternative Waste Management Solution 2: Separate Pure Lead from Dross with Vitaflux

The dross collected from the melting pot is high in its lead (Pb) content. It is observed that dross formed in the current system contains a quantity of 41% of lead in a purity of 99.92%. As mentioned before, the dross is collected and sent to the recycling facility. However, if the pure lead can be extracted from the dross inside the facility, it will be a very beneficiary practice. Drossing-off fluxes are used for this purpose in order to accumulate the oxides and allow easy removal from the surface of the molten lead (Brown, 1999, pp. 56-62). Specifically, there is a material called Vitaflux™, which is used to recover the lead from dross at source (NA Graphics, n.d.). Application of the material is very simple. Vitaflux™ is added on the surface of the melting pot before dross is collected. The lead alloy begins to burn with the addition of Vitaflux™ and the pot is mixed until dross becomes fine powder. At the end of the reaction, the dross in fine powder form is accumulated on the surface of the molten metal. Vitaflux™ has been tested in the company previously and lead was recovered from the dross successfully. The grid casting department consists of two melting pots. Due to the lead alloy load of the pots, six tubes of Vitaflux™ is needed for each melting pot every time dross is collected. Since dross is collected once a day in the grid casting department, one box containing a dozen of Vitaflux™ tubes is needed every day. In the calculations, it is assumed that one year consists of 350 working days. Therefore, the need of Vitaflux™ is 350 boxes per year.

In the tests made in the company, it is analyzed that the use of Vitaflux™ do not influences the composition of the lead alloy in the melting pot. Besides, when the dross collected after the use of Vitaflux™ is analyzed, it is observed that the pure lead is totally removed from the dross. Therefore, it can be concluded that the use of Vitaflux™ creates the maximum recovery of lead from the dross.

Benefits: Experiments conducted in the company for recovering lead from dross show that the quantity of the dross decreases by 30% when pure lead is separated from dross with the help of Vitaflux™. In other words, this alternative involves 30% of reduction of dross at source. Therefore, even if the impact to the environment can not be quantified, the company's damage to the environment is certainly decreased on a large scale since the dross deriving from grid casting is the highest amount of waste in the company. In addition and more importantly, a significant quantity of pure lead is going to be saved and will be used in production. As a result, this alternative allows a more efficient use of raw materials and a decrease in total recycling costs. The cash flow analysis of the Vitaflux alternative and the current application are compared in Table 5.14.

Table 5.14 Comparison of Cash Flow Analyses of the Current System and the Vitaflux Alternative

	Current System	**Vitaflux Alternative**
Quantity of dross (kg/month)	12,299	8,609
Cost of raw material loss (YTL/month)	23,368	16,359
Labor cost associated to the collection of dross (YTL/month)	26	52
NPV of Vitaflux for 1 month purchasing period*	-	31,295
NPV of Vitaflux for 3 months purchasing period*	-	31,145**
NPV of Vitaflux for 6 months purchasing period*	-	32,074
NPV of Vitaflux for 12 months purchasing period*	-	33,600
Net Present Value (YTL/year)	**253,588**	**209,038****

* Calculated due to data of NA Graphics (n.d., n.p.)
** The total cost is calculated based on the 3 month purchasing period.

The calculations in Table 5.14 take into basis that dross is reduced by 30% with the use of Vitaflux. The cost of raw material loss is calculated based on the unit cost of dross calculated in Table 5.2. However, it should also be taken into account that the dross selling price may be reduced since the dross does not contain pure lead in it.

In addition to the current system, in the Vitaflux alternative there is a need of extra labor time when mixing the pot and collecting the dross after the addition of Vitaflux. Dross is collected once in 24 hours from 2 melting pots. In the current system, the collection of dross from one pot takes 10 minutes. Taken into basis that the company works 24 hours during 29 days/month, it is calculated that the monthly labor spent for in the current case is 10 hours. Since the unit labor cost is 2.62 YTL/hour, the labor cost associated to this alternative is:

$$C_{\text{Labor Cost of Current System}} = 2.62 \text{ YTL/hour x } 10 \text{ hours/month} = 26 \text{ YTL/month.}$$

The same calculation is made for the Vitaflux alternative taking into basis that the collection of dross from one pot takes 20 minutes.

On the other hand, it is possible to obtain lower unit transshipment costs when buying in big quantities. In other words, the period in which Vitaflux™ is bought and the quantity of Vitaflux™ needed in this time period is important. As shown in Table 5.14, when comparing the net present values (NPV) of different purchasing periods, it is seen that 3 month purchasing period gives the minimum net present value. The net present values of the current system and the Vitaflux alternative are calculated for one year, as shown in Table 5.14. The monthly interest rate is taken as 1.6%. When comparing net present values, it can be seen that the Vitaflux alternative decreases costs by 17% compared to the current system.

Since the amount of dross is assumed to be equal to the lead alloy loss, it can be concluded that 3,690 kg/month of lead can be recovered and used in production with the Vitaflux™ application. The recovery of raw material is an important opportunity in increasing the productivity of the company.

Limitations: The transshipment cost is an important factor affecting the lot-size decision because Vitaflux™ is imported. It is possible to buy smaller quantities of Vitaflux™ in order to decrease the investment made in short term period. But this fact may increase the total cost of one year, as shown in Table 5.14. Even if short ordering time periods may generally increase the total cost, evaluation of costs should be made for several time periods in order to provide a realistic comparison. As it is seen in Table 5.14, the minimum cost for one year duration is achieved when a purchasing period of 3 months is chosen. Even though the net present values of different purchasing periods are close to each other, it is important to notice that this type of lot size decisions should also be taken into account.

5.3.2 Alternative Waste Management Solution for Dross Generated From the COS Machine

The dross derived from the COS machine in the battery assembly department is considerably less than the grid casting machine because there is a small contact surface area between the molten lead and air in the COS machine. In order to reduce the amount of dross formed, the possibility of adding Vitaflux™ to the melting pot of the COS machines is investigated.

Benefits: The Vitaflux™ application involves 30% of reduction of dross at source as well as separation of free lead captured within the structure of dross. With the use of Vitaflux in COS machines, the amount of lead recovered at source can be about 1,933.2 kg/year and will be used in production directly. As a result, this alternative allows a more efficient use of raw materials.

Limitations: The cash flow analysis of using Vitaflux in the COS machine and the current system are compared in Table 5.15.

Table 5.15 Comparison of Cash Flow Analyses for the Vitaflux Alternative in COS Machine

	Current System	**Vitaflux Alternative**
Quantity of dross (kg/month)	537	375
Cost of raw material loss (YTL/month)	1,020	712
Labor cost associated to the collection of dross (YTL/month)	76	152
NPV of Vitaflux for 1 month purchasing period*	-	31,295
NPV of Vitaflux for 3 months purchasing period*	-	31,145**
NPV of Vitaflux for 6 months purchasing period*	-	32,074
NPV of Vitaflux for 12 months purchasing period*	-	33,600
Net Present Value (YTL/year)	**11,880**	**40,511****

* Calculated due to data of NA Graphics (n.d., n.p.)
** The total cost is calculated based on the 3 month purchasing period.

The calculations in Table 5.15 take into basis that dross is reduced by 30% with the use of Vitaflux. The cost of raw material loss is calculated based on the unit cost of dross calculated in Table 5.2. In the Vitaflux alternative, there is a need of extra labor time when mixing the pot and collecting the dross after the addition of Vitaflux into the COS machines. Dross is collected 3 times in 24 hours from 4 melting pots. In the current case, the collection of dross from one pot takes 5 minutes. Taken into basis that the company works 24 hours during 29 days/month, it is calculated that the monthly labor spent for in the current case is 29 hours. Since the unit labor cost is 2.62 YTL/hour, the labor cost associated to this alternative is:

$$C_{\text{Labor Cost of Current System}} = 2.62 \text{ YTL/hour} \times 29 \text{ hours/month} = 76 \text{ YTL/month.}$$

The same calculation is made for the Vitaflux alternative taking into basis that the collection of dross from one pot takes 10 minutes.

As in Alternative 5.3.1.2, the possibility of obtaining lower unit transshipment costs when buying in big quantities is investigated for this alternative. It can be seen in the Table 5.15 that the use of Vitaflux™ in the melting pot of the COS machine is not cost effective. The reason is the high amount of Vitaflux™ needed. The battery assembly line consists of 4 COS machines having a melting pot each. Since dross is collected three times a day in the battery assembly department, one box containing a dozen of Vitaflux™ tubes is needed every day. In the calculations, it is assumed that one year consists of 350 working days. Therefore, the need of Vitaflux™ is 350 boxes per year. Since a small quantity of dross is formed in the COS machines, the improvement in the material recovery does not afford the price of Vitaflux™ for this alternative.

5.3.3 Alternative Waste Management Solutions for Setup Wastes Generated From Battery Closing Operation

The adjustment of setup times of the manufacturing line is important in production planning and it is usually tried to be minimised (Pinedo, 2005, pp. 407-413). Minimisation of setup time may correspond to reduction of setup wastes for the industries producing sequential products requiring similar production techniques. In that case where setup costs are sequence dependent, it is possible to decrease the number of waste produced.

One way of decreasing setup waste may be to decrease the number of machine adjustments in the productions where the number of setup waste is constant according to quality regulations. The production scheduling policy used in most of the industries is based on a system where monthly demands are divided into short sub-periods in order to increase the flexibility of the production. However this may cause production of abundant numbers of setup waste as a result of inverse proportionality between the length of the sub-period of scheduling plan and the number of machine adjustments. If longer scheduling sub-periods are chosen, then the production of setup wastes and the inventory holding costs will be decreased but the flexibility of the scheduling will be lost. On the other hand, if the scheduling sub-period is shortened, then the scheduling will be more flexible but the number of setup waste will increase. For this reason, there is a need to find out an optimum scheduling plan taking into account the production of setup wastes.

When adjusting the production schedule with the aim of minimizing setup wastes, the primary concern is the demand level of products. Products with low demands (products whose monthly demands are approximately equal to the production capacity of one shift) are produced in one or two shifts. Products with high demands (products whose monthly demand highly exceeds the production capacity of one shift) are produced on a weekly basis and are sent to customers each week. Namely, the monthly demand is divided to weekly demands. Since these highly demanded products are not produced continuously, a setup adjustment on the closing machine is needed each time the production of this product starts (each week). The number of setup adjustment will be high, as well as the setup waste generated.

An alternative waste management solution is to schedule products so that high-demanded products are produced continuously like the low-demanded products. By this one-month-scheduling method, the monthly demand of high-demanded products will not be divided by four; the monthly demand will be produced in one batch. Namely, the production of these products will continue until the monthly demand is reached. The setup wastes obtained from the battery closing machine are the refurbished batteries, and the plastic container and covers. The next sections describe the alternative waste management solutions for refurbished batteries and wasted battery containers and covers.

5.3.3.1 Alternative Waste Management Solution for Refurbished Batteries Generated From Battery Closing Operation

It is necessary to produce one setup waste while making machine adjustments in the battery closing operation. This setup waste is considered as a refurbished battery and can not be sold to customers. Therefore, the production cost of the battery is considered as the on-site waste management cost of the refurbished battery, as described in Section 5.1.4.2. One way to establish a pollution prevention approach may be to change the production scheduling policy to decrease the number of refurbished batteries (setup wastes). The relation between the length of the scheduling sub-period and setup waste amount is established to find out the existence of an option to obtain minimum waste. The scheduling sub-period (one week, two week, or four week) in a month affects the number of setup waste generated. Therefore, one of the ways of reducing the setup waste is to determine the sub-period with minimum inventory holding and waste removal cost between different scheduling sub-periods. For this reason, different scheduling sub-periods are analysed, such as one week, two week and four week. The company is currently using a production scheduling based on one-week sub-period.

A binary integer programming model is developed to determine the sub-period giving the minimum total cost comprising inventory holding and waste management costs. Inventory carrying within the considered sub-period is ignored. The model is demonstrated below.

Parameters:

D_i = The demand of product i

$W_{i,k}$ = Setup waste of product i derived with alternative k

R_i = Waste management cost of product i

h_i = Weekly inventory holding cost of product i

Decision Variables:

$$X_k = \begin{cases} 1, \text{ if alternative k is used} \\ 0, \text{ otherwise} \end{cases} \quad \text{k = 1,2,4}$$

The Model:

Minimize

$$\sum_{i=1}^{m} \left(W_1 R_i X_1 + W_2 R_i X_2 + W_4 R_i X_4 + \frac{3}{2} h_i X_1 D_i + h_i X_2 D_i \right)$$

Subject to

$$X_1 + X_2 + X_4 = 1$$

$$X_k \in \{0,1\} \quad , \text{k} = 1,2,4$$

The model is solved for the given data. Different types of products with varying demands (5 of them are low-demanded and 12 of them are high-demanded) are taken into basis and the forecasts of year 2006 are considered as the monthly demands of each product. The battery production cost associated to the refurbished batteries is considered as the waste management cost of the refurbished battery. The weekly inventory cost of a product is considered as the selling price of the product multiplied by the weekly interest rate which is taken as 0.4%. The number of setup wastes changes according to the sub-period chosen. The one-week sub-period produces 4 setup wastes, the two-week sub-period produces 2 setup wastes and the four-week sub-period produces 1 setup waste per month.

The model is solved in Excel Solver for the demands of each month. The option giving the minimum cost is found as the four-week sub-period for each run (In the optimal solution, X_4 is 1 while X_1 and X_2 are 0)

Benefits: The cash flow analysis of the optimal solution of the mathematical model and the current system are compared in Table 5.16.

Table 5.16 Comparison of Cash Flow Analyses of the Current System and the Mathematical Model

Costs (YTL/month)	Current Case	Optimal Solution of the Mathematical Model
January	29,451	1,550
February	29,451	1,550
March	30,887	1,462
April	30,887	1,462
May	25,340	1,417
June	24,895	1,417
July	24,324	1,338
August	23,286	1,338
September	37,032	1,550
October	37,476	1,550
November	38,415	1,550
December	37,476	1,550
Net Present Value (YTL/year)	**331,585**	**16,015**

As shown in Table 5.16, the optimal solution of the mathematical model for each month corresponds to the cost associated to the sub-period giving the optimal solution, the four-week sub-period. When comparing net present values, it can be seen that the four-week sub-period decreases costs by 95% compared to the current system. The wastage of the semi-finished products and the according waste management costs can be significantly decreased with the four-week sub-period. This alternative is an important example showing how the operational decisions can improve environmental problems in a company.

Limitations: The production of a high-demanded product in one batch may not be possible in certain cases because of the lead-time of the demands. The operation time of a product may have a long duration, especially when all of the monthly demand is to be produced in one batch. Therefore, the lead time of the other products waiting on the queue will be an important constraint. In addition, production plans must be flexible enough to meet the unexpected demands coming from the competitive environment. The scheduling of this type of environmentally integrated production plan may be difficult and sometimes infeasible for companies that have to deliver products every week.

5.3.3.2 Alternative Waste Management Solution for Wasted Battery Covers and Containers Generated From Battery Closing Operation

Battery covers and containers are wasted in the setup operations of the closing machine. The company sends the polypropylene cover and containers to the plastic retailer to recycle them. However there is a possibility to prevent the wastage of these plastic parts by changing the production schedule. Each time the closing machine operates a new type of product, setup adjustments have to be made as explained before in section 5.1.4.6. As a result, each time a setup adjustment is made, 2 battery covers and 1 container are wasted.

An example will be given using one of the most demanded products, “60-Ah”. In January 2005, the monthly demand for this product was forecasted to be 18,885 units. The production capacity for 60-Ah is 800 units for an 8 hours shift. The monthly demand of 60-Ah battery can be divided by four and a setup adjustment will be needed each week. Since 2 covers and 1 container are spent in each setup adjustment, 8 covers and 4 containers will be wasted in order to complete the monthly demand of 60-Ah.

The calculations in Table 5.17 are made using the data of January 2006. Products with varying demands (5 of them are low-demanded and 12 of them are high-demanded) are taken into basis and the total monthly waste of plastic material is calculated. As shown in Table 5.17, the total number of plastic material spent in the proposed policy is very small compared to the actual four-week-scheduling policy. The unit cost for the container and cover used for producing a 60-Ah battery is calculated by the following method:

- **For a container:** Containers are purchased from 2.37 YTL/unit and wasted containers are sold at the plastic retailer at 1.20 YTL/kg. One container is 570 gr. Therefore, the cost of wasting one plastic container is:
    - 2.37 – (0.570 x 1.20)= 1.686 YTL/unit

- **For a cover:** Covers are purchased from 1.64 YTL/unit and sold at the plastic retailer at 1.20 YTL/kg. One cover is 310 gr. Therefore, the cost of wasting one plastic cover is:
    - 1.64 – (0.310 x 1.20)= 1.268 YTL/unit

Table 5.17 Plastic Material Spent and Cost for Two Policies

Unit/month	**Low-demanded products (5 products)**		**High-demanded products (12 products)**		**Total plastic material spent for all products in One month**	**Total cost for all products (YTL/month)**
	setup adjustment	plastic material spent	setup adjustment	plastic material spent		
Weekly scheduling policy	1	1 container 2 cover	4	4 container 8 cover	**53 container** **106 cover**	**89.36** **134.41**
Total Cost (YTL/month)						**223.77**
One-month scheduling policy	1	1 container 2 cover	1	1 container 2 cover	**17 container** **34 cover**	**28.66** **43.12**
Total Cost (YTL/month)						**71.78**

Benefits: As it is seen from Table 5.17, the proposed alternative lowers the wastage of plastic materials significantly. 36 containers and 72 covers can be recovered in a month. Since the wasted container and covers are actually sent to off-site recycling, it is important to mention that the proposed alternative reduces the waste at source. This alternative is an important example showing how the operational decisions can improve environmental problems in a company.

The cash flow analysis of the changed production schedule and the current application are compared in Table 5.18 taking into basis the total costs calculated in Table 5.17.

Table 5.18 Comparison of Cash Flow Analysis of the Current System and the Changed Production Schedule

COST	**Current System**	**Changed Production Schedule**
Waste Management Cost (YTL/month)	224	72
Net Present Value (YTL/year)	**2,428**	**780**

The costs are assumed to derive at the end of each month and the monthly interest rate is taken as 1.6% in the calculations made in Table 5.22. When comparing net present values, it can be seen that the suggested alternative decreases costs by 67% compared to the current system.

Limitations: The production of a high-demanded product in one batch may not be possible in cases where lead-time of the demands is critical. The operation time of a product may be an important constraint for regulating the lead time of the other products waiting on the queue. Additionally, production plans must be flexible enough to meet the unexpected demands coming from the competitive environment. The scheduling of this type of environmentally integrated production plan may be difficult and sometimes infeasible for companies that have to deliver products every week.

5.3.4 Alternative Waste Management Solutions for Using the Water Treated in the Wastewater Treatment Facility

The cooling and washing water coming from wet-charging process, the charging water of plates and the water used in cleaning equipments are collected and then treated in the wastewater treatment facility operated by the company. Figure 5.26 shows the unit operations and processes in the wastewater treatment facility of the company.

As shown in Figure 5.26, the collected wastewater from the resources mentioned above, with a discharge of 300 m^3/day, is first transferred to sedimentation tank to remove particles, which have high amount of Pb. The sludge formed in this process is sent to the tank used for the collection of sludge. The cleared wastewater (supernatant) is then transferred to pH adjustment unit in which lime (CaO) is added (413 kg/day) to raise pH value of the wastewater from 1.3 to 8.5-9.0. The addition of polyelectrolyte, which is a polymer used to stabilize the sludge, is also accomplished in this unit (900 kg/day). Following up the pH adjustment, aluminum sulfate ($Al_2(SO_4)_3$) is added as precipitant for the removal of Pb dissolved in wastewater in coagulation and flocculation unit. The sludge formed in this reactor is sent to sludge collection tank and then to filter press to become thicker. The wastewater from the filter press unit is recycled back to mixing process. The sludge is sent to the recycling facility since it contains considerable amount of lead. The wastewater from flocculation unit is discharged to sewage while about $1/6^{th}$ of the volumetric flow is reused as lead suppressant and in negative drying purposes.

Since the hardness of the treated wastewater is high enough to stain the containers, it is not possible using it as cooling water or cleaning water for equipments. The amount of water reuse can be increased by using a chemical which does not increase the hardness as much as CaO or by adjusting the hardness via dilution using fresh water.

5.3.4.1 Alternative Waste Management Solution 1: Using Caustic Instead of Lime

As mentioned before, the treated wastewater cannot be used in wet-charging or in equipment cleaning because of high levels of hardness. In cases it is used in wet-charging, white traces will be left on the surface of containers. Hard water is not preferred for cleaning the equipments since it reduces the performance of detergents used. Therefore, using another chemical to adjust pH instead of CaO, for example NaOH, may decrease the water consumption.

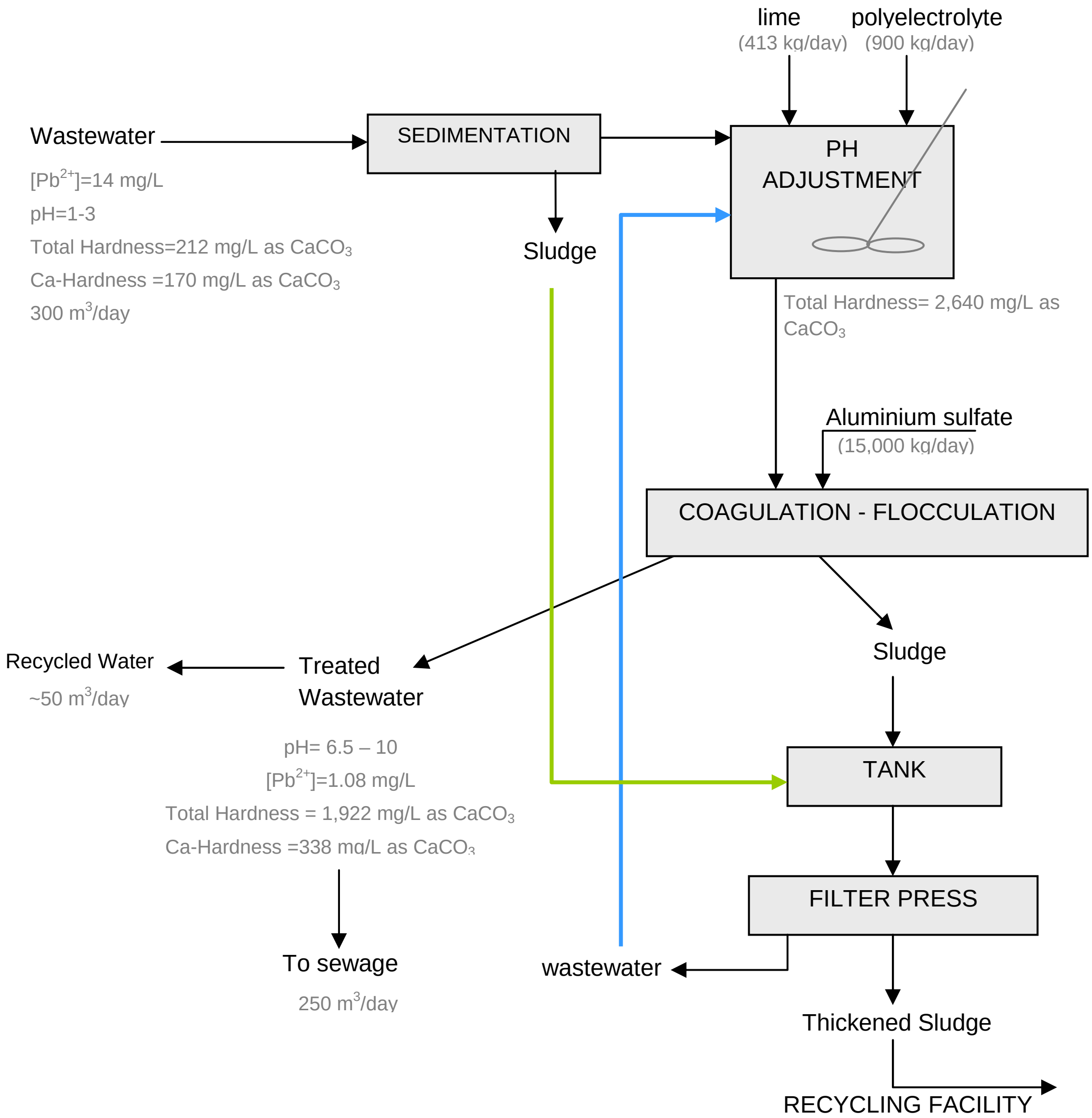


Figure 5.26 Operations in the Wastewater Treatment Facility

The hardness of water is mainly caused by divalent or trivalent ions, Mg^{2+} and Ca^{2+}, and water can be softened by chemical precipitation technique (Patterson, 1985, 220-226). If the chemical (CaO) used for pH adjustment is replaced by another chemical containing an ion, which does not cause any additional hardness, then the treated wastewater can be recycled back to the production system to be used in wet-charging, equipment cleaning, etc. This change is expected to decrease the water consumption of the company significantly. To be able to compare the benefits of using NaOH instead of CaO, there is a need to find out the amount of NaOH required to neutralize the wastewater containing H_2SO_4 and to raise its pH to 8.5.

Calculation of CaO and NaOH Amounts:

The theoretical calculation of the amounts of CaO and NaOH to be added to neutralize the wastewater containing 496 mg SO_4^{2-}/L (5.2×10^{-3} mol SO_4^{2-}) and to adjust the pH to 8.5 requires the following assumptions:

1) The ionic strength of the wastewater is very low, so that the influence of other ions in concentration estimations can be ignored.
2) The temperature of the wastewater is 25°C.
3) Dissociation of $Ca(OH)_2$, which is the product of a reaction between CaO and H_2O is complete.

   $CaO\ (s) + H_2O \rightarrow Ca(OH)_2\ (aq)$ ……………………(Reaction 1)

   $Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$……………………………(Reaction 2)
4) The dissociation of NaOH in H_2O is complete.

   $NaOH \rightarrow Na^+ + OH^-$………………………………...(Equation 1)
5) The CaO and NaOH used are 100% pure.

Dissociation of H_2O:

$$K_w = [H^+]\,[OH^-] = 10^{-14} \qquad (5.1)$$

$$\left[OH^-\right] = \frac{10^{-14}}{[H^+]} \qquad (5.2)$$

Mass balance on Ca^{2+} and SO_4^{2-}:

$$C_{T,Ca^{2+}} = [Ca^{2+}] = \frac{\text{number of moles}}{\text{total volume}} \qquad (5.3)$$

$$C_{T,SO_4^{2-}} = [SO_4^{2-}] = \frac{\text{number of moles}}{\text{total volume}} \qquad (5.4)$$

Charge Balance:

$$2[Ca^{2+}] + [H^+] = 2[SO_4^{2-}] + [OH^-]$$

$$2[Ca^{2+}] + [H^+] = 2[SO_4^{2-}] + \frac{10^{-14}}{[H^+]}$$

$$pH = 8.5 = -\log[H^+]$$

$$[H^+] = 10^{-8.5}\ M$$

$$[Ca^{2+}] = 5.20 \times 10^{-3}\ M$$

Therefore, Ca^{2+} to be added:

$$= 5.20 \times 10^{-3}\ \frac{\text{mol}}{L} \times 300\,\frac{m^3}{\text{day}} \times 1000\,\frac{L}{m^3} \times \frac{1\ \text{mol CaO}}{1\ \text{mol Ca}^{2+}} \times \frac{(40+16)\ \text{gr}}{1\ \text{mol CaO}} \times \frac{1\ \text{kg}}{1000\ \text{gr}} = 87.36\ \text{kg}/day$$

The calculated amount of CaO is much lower than the amount added into the pH adjustment tank in the wastewater treatment plant, which is 413 kg/day. The difference is huge, but it could be due to the assumptions made in theoretical calculations especially the grade of the CaO used in the plant, which may be very low. Moreover, the dissociation of CaO and $Ca(OH)_2$ may not be completed in the pH adjustment unit as a result of poor mixing conditions.

Mass Balance on Na^+ and SO_4^{2-}:

$$C_{T,Na^+} = \left[Na^+\right] \frac{\text{number of moles}}{\text{total volume}} \tag{5.5}$$

$$C_{T,SO_4^{2-}} = [SO_4^{2-}] = \frac{\text{number of moles}}{\text{total volume}} \tag{5.6}$$

Charge Balance:

$$[Na^+]+[H^+]=2[SO_4^{2-}]+[OH^-]$$

The equation was similarly solved and the amount of $[Na^+]$ was found to be 0.01037 M which corresponds to 124.46 kg/day. The reason for adding more NaOH than CaO is the number of hydroxyl ions in the compositions of the chemicals. It should be noted here that there is a significant difference in the solubility of NaOH (1,080 gr/L) and CaO (1.39 gr/L) (Dean, 1992). The NaOH can be dissolved in the water in almost instantly requiring mixing enough to sustain the homogeneity of the wastewater. On the other hand, the solubility of CaO is lower than NaOH.

Benefits: In the experiments made in the wet-charging operation, it is seen that caustic does not leave white traces in the surface of containers. Therefore it is feasible to use caustic instead of lime. In addition, with the use of lime, it will be possible to treat and reuse the same water for several days. The wet-charging operation uses 150 tones of water every day; so the reuse of the treated water in wet-charging will remarkably reduce the water consumption. The remaining 150 m^3 of refined water may be used in the cleaning of equipments, in the negative drying of plates and as lead suppressant.

Table 5.22 shows the comparison of lime and caustic. Since 100 tones of treated wastewater will be used in equipment cleaning once a day, this amount of wastewater can not be recycled back to production system. Otherwise, there would be a need for tank with capacity of at least 100 tones. Since the water needed in the facility is 300 tones/day, the company will have to use tap water of 100 m^3 to clean the equipments each day. In the calculations, it is assumed that 300 m^3 of tap water is captured in the first day of the week and 100 m^3 of water in each of the remaining 5 working days of the week. Therefore, the weekly water consumption is:
Water consumption = 300 + 5 x 100 = 800 m^3/week.

In addition, as calculated previously, it is also known that 124.46 kg/day of caustic will be used instead of 87.35 kg/day CaO. Since no experiment could have been performed using real wastewater to find out the amount of NaOH for adjusting the pH to about 8.5, the comparison of costs of lime and caustic was made based on theoretical calculation of the amounts of chemicals with the assumptions made. The prices of the pure CaO and NaOH are 122 YTL/tone and 900 YTL/tone, respectively. The unit cost of water is 3.54 YTL/tone. The cash flow analysis of the using caustic instead of lime is compared with the current system in Table 5.19.

Table 5.19 Comparison of Cash Flow Analyses of the Current System and Lime Alternative

	Current System	**Lime Alternative**
Water Usage (m^3 /month)	7,200	3,200
Total Cost of Water (YTL/ month)	25,488	11,328
Chemical Usage (tone/month)	2.1 (0.08735 x 6 x 4)	2.9 (0.124460 x 6 x 4)
Unit Cost of Chemical (YTL/tone)	122.00	900.00
Total Cost of Chemical (YTL/month)	256	2,688
Net Present Value (YTL/year)	**279,062**	**151,932**

As it is seen from Table 5.19, even though the unit cost of caustic is greatly higher than lime, this alternative gives lower costs because it significantly reduces the water consumption by allowing the reuse of the refined wastewater. A high cost saving is obtained with the use of this alternative. The net present values of the current system and the suggested alternative are calculated for one year, as seen in Table 5.19. The costs are assumed to derive at the end of each month and the monthly interest rate is taken as 1.6%. When comparing net present values, it can be seen that the suggested alternative decreases costs by 45% compared to the current system.

Limitations: As previously described, the theoretical amount of CaO is much lower than the amount currently added into the pH adjustment tank in the wastewater treatment plant. The big difference in amounts may be due to the assumptions made in theoretical calculations. Even there is a difference between theoretical calculations and current applications; the suggested alternative proves that the usage of caustic is more profitable than lime in a certain ratio, namely 45 %.

5.3.4.2 Alternative Waste Management Solution 2: Adjust the Hardness by Dilution Using Fresh Water

As previously told, it is not possible to use the treated wastewater as cooling water or cleaning water for equipments because the hardness of the treated wastewater is high. An alternative may be to adjust the hardness of the wastewater by dilution using fresh water. The ratio of wastewater to the fresh water is an important data influencing this alternative. The Source and Sink Mapping method (Rosselot and Allen, 2002) is utilized for calculating this ratio.

As the first step in creating a source-sink diagram, the sources and sinks of the wastewater are identified. Table 5.20 shows the stream data for source and sink diagram.

Table 5.20 Stream Data for Source and Sink Diagram

Source			**Sinks**				
Type	**Flow rate (m^3/day)**	**Hardness (mg/L as $CaCO_3$)**	**Type**	**Flow (m^3/day)**		**Hardness (mg/L as $CaCO_3$)**	
				Max*	**Min**	**Max**	**Min****
Treated Wastewater	300	1922	(1) Wet-Charging	172.5	150	212	75
			(2) Equipment Cleaning	115	100	212	75
			(3) Negative Drying and lead suppressant	57.5	50	1922	75

* The rate of evaporation is assumed to be 15%
** The hardness of the tap water

Samples are taken from the wastewater treatment plant of the company and data such as the hardness of the wastewater at specific points was measured in the laboratory. The minimum flow rates of sinks are given by the company. For calculating the maximum flow rate of sinks, the rate of evaporation is assumed to be 15%. The source and sink diagram for streams described in Table 5.20 is shown in Figure 5.27.

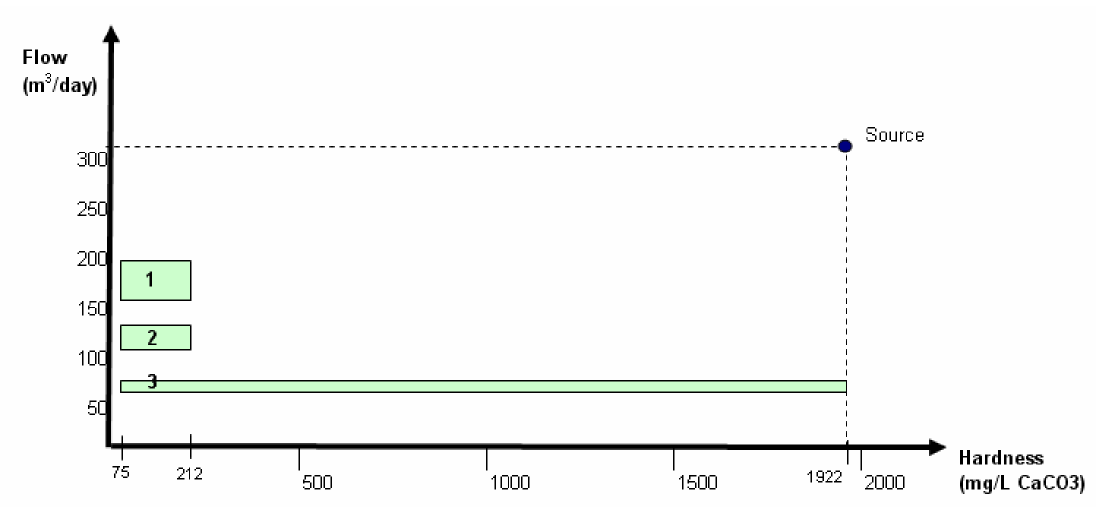


Figure 5.27 The Source and Sink Diagram

The direct use of wastewater for sink 3 is possible as it can be seen from Figure 5.28. Likewise, the use of treated wastewater as lead suppressant and in negative drying is the current application in the facility. Since there is a single source of water with high hardness, the tap water with approximately 75 mg/L $CaCO_3$ hardness can be used for dilution purposes. The volumetric flow rate of the tap water ($\forall_{TW}$) and volumetric flow rate of the wastewater ($\forall_{WW}$) are found in the following equations:

$$\frac{\forall_{WW} \times (1922 \text{ mg/L CaCO}_3) + \forall_{TW} \times (75 \text{ mg/L CaCO}_3)}{250 \text{ m}^3 / \text{day}} = 212 \text{ mg/L CaCO}_3$$

$$\forall_{WW} + \forall_{TW} = 250 \text{ m}^3 / \text{day}$$

The following results are obtained by solving these equations:

$$\forall_{WW} = 19 \text{ m}^3 / \text{day}$$

$$\forall_{TW} = 231 \text{ m}^3 / \text{day}$$

The results indicate that, in order to adjust the hardness of the treated wastewater by dilution, 231 m^3 of tap water should be added to 19 m^3 of wastewater. Therefore, the saving in water consumption will be 19 m^3/day.

Benefits: In the cost calculations shown in Table 5.21, it is assumed that 300 m^3 of tap water is captured in the first day of the week and 231 m^3 of water in each of the remaining 5 working days of the week. Therefore, the weekly water consumption is:

Water consumption = 300 + 5 x 231 = 1,455 m^3/week.

The cash flow analysis of adjusting the hardness is compared with the current application in Table 5.21.

Table 5.21 Comparison of Cash Flow Analyses of the Current System and Adjusting Hardness

	Current System	**Adjusting Hardness**
Water Usage (m^3/month)*	7,200	5,820
Total Cost of Water (YTL/ month)	25,488	20,600
Net Present Value (YTL/year)	**276,287**	**223,301**

* Weekly water usages are converted into monthly basis by assuming that one month consists of 4 weeks.

The net present values of the current system and the suggested alternative are calculated for one year, as seen in Table 5.21. The costs are assumed to derive at the end of each month and the monthly interest rate is taken as 1.6%. When comparing net present values, it can be seen that the suggested alternative decreases costs by 19% compared to the current system. As shown in Table 5.21, this alternative is decreasing the water consumption by 1380 m^3/month and therefore provides an efficient use of water. When costs of this alternative are analyzed, it can be noticed that adjusting the hardness of the treated wastewater can decrease costs by 52,986 YTL/year. As a result, this alternative is considered as economically and environmentally profitable.

Limitations: With the implementation of this alternative, the wastewater that will be recycled in the wastewater treatment facility is 19 m^3/day. This quantity is considerably small compared to the daily usage of water in the company (300 m^3/day).

5.3.5 Alternative Waste Management Solution for Drained Paste Generated From Grid Pasting

The paste spilled on the floor around the grid pasting area is collected by washing off paste into drainage and the volume of the drained paste increases when it is mixed with water. Since the collected paste become impure while being collected, it cannot be reused in the production line and is sent to the recycling facility. An alternative is to collect the drained paste in a container and to recycle it in the paste mixer.

Benefits: Due to this alternative, it will be possible to collect the drained paste and use it in the paste mixer as a raw material. The quantity of drained paste is 20,566 kg/year according to the data of year 2006. Clearly, the reuse of this big quantity of paste will considerably increase the productivity by reducing the raw material consumption. Moreover, since the drained paste will be reused in the production, additional raw material and waste treatment costs, which costs 26,324 YTL/year as calculated in Section 5.1.4.3-b, will be totally eliminated. The cash flow analysis of the suggested alternative is compared with the current system in Table 5.22.

Table 5.22: Comparison of Cash Flow Analyses of the Current System and Container Alternative

	Current System	**Container Alternative**
Quantity of drained paste (kg/month)	1,714	-
Cost of raw material loss (YTL/month)	2,193	-
Labor cost associated to emptying the container (YTL/month)	-	37
Net Present Value (YTL/year)	**23,772**	**401**

There is a need of extra labor when emptying the container to the mixer in the suggested alternative. It is assumed that emptying the container would take 10 minutes each shift. Taken into basis that the company works 24 hours during 29 days/month, it is calculated that the monthly labor spent for this alternative is 14 hours. Since the unit labor cost is 2.62 YTL/hour, the labor cost associated to the collection of parts is:

$$C_{\text{Labor Cost of Collecting Parts}} = 2.62 \text{ YTL/hour} \times 14 \text{ hours/month} = 37 \text{ YTL/month.}$$

The net present values of the current system and the suggested alternative are calculated for one year, as seen in Table 5.22. The costs are assumed to derive at the end of each month and the monthly interest rate is taken as 1.6%. When comparing net present values, it can be seen that the suggested alternative decreases costs by 98% compared to the current system.

Limitations: There exists a limit to the amount of recycled paste that can be added into the paste mixing machine. Therefore, to find the right ratio of recycled paste to the new paste, experiments must be made before applying this alternative.

5.3.6 Alternative Waste Management Solutions Needing Further Evaluations

The sections above have identified alternative waste management solutions which are worthwhile without further evaluation. Some alternative waste management solutions, however, require further evaluation to consider whether they are feasible. These alternative solutions should be evaluated by examining the availability and prices of equipments and materials needed. It should be investigated if controls, maintenance and operator trainings are required. The results of these alternative waste management solutions should be clarified to determine their ability of reducing wastes and costs.

5.3.6.1 Alternative Waste Management Solution for Wasted Separators Generated From the Enveloping Machine

As discussed before, it is not possible to recycle separators made from polyethylene and fiber because fiber can not endure at high temperatures. As a result, it is not possible to recycle them and separators are sent to trash. The reason of the separators to be wasted in the enveloping machine may be the inattention of the operators while feeding the cylinder of polyethylene into the machine. Even if it is not as high as lead, plastic is also a raw material creating a cost to the facility. By training the operators to be conscious about the effects and the costs of the waste of separators, this pollution may be reduced at the source.

Benefits: By increasing the consciousness of the operators, the quantity of wasted separators can be considerably decreased. Decreasing the quantity of plastic materials to be sent to trash will make a big difference in the effects to the environment since it is the only material discarded by the company. The raw material cost of separators wasted, which costs 34,949 YTL/year, can be importantly diminished due to the performance of operators.

Limitations: When applying this alternative in the company, it is important to make serious controls in the production line in order to control the manner of work of operators. Inspections must be made in order to maintain the careful use of separators in the production. This alternative has no cost.

5.3.6.2 Alternative Waste Management Solution for Rejected Plates

The company can not reuse the rejected plates because rejected plates need to be disassembled in order to be used. In grid pasting, there is a chance to decompose the rejected plates because the plates are not yet sent to curing rooms. In other words, the paste is not completely solidified and it is possible to remove the paste on the grids by using water jet technologies.

Due to this alternative, the rejected plates must be collected in a tank. The collected rejected plates can be washed using water jet. After the operation:

- The paste will settle and can be reused in paste mixing operation in a fixed ratio with the virgin paste.
- The clear water from the top of the tank can be used for cleaning purposes depending on its quality.
- The cleaned and dried grids can be melted in melting pots in the grid casting or assembly section.

Benefits: If all rejected plates of grid pasting operation are recycled, implementation of this alternative will save 48,619 kg/year of lead. This will allow the reuse of the raw material; therefore will improve the productivity by reducing raw material consumption. Additionally, since the rejected plates will be reused in the production, waste management costs, which are 43,757 YTL/year, will be decreased.

Limitations: The feasibility of recycling of paste removed from the plates needs to be investigated since the moisture content of the paste will be a critical parameter. It is also important to dry the recycled grids with care in order to prevent the entrance of water into the melting pots.

5.3.6.3 Alternative Waste Management Solution for Lug Wastes, Lead Dust and Rejected Plates Generated from Cutting and Brushing

The major cause of the wastes derived in cutting and brushing line is that most of the operations are performed manually and the system of collecting wastes is poor. The lugs cut by the operators fall to the floor area, where they are contaminated with dust generated from vehicle and operators movements and because of this, the lug waste collected from the floor cannot be reused in the company. Therefore, the lugs are sent to the recycling facility.

Another problem of this process is the lead dust caused by cutting and brushing the plates. Similar to lugs, lead dust is also collected on the floor. Working inside the lead dust is dangerous for the operators working in cutting and brushing section, as well as the whole company because lead particles are released in the air. Both of the wastes are collected and sent to recycling facility. Automated and closed machines are a good opportunity to prevent both of the problems.

Benefits: Automated machines offer closed systems in which lead dust and lug wastes are separated in different compartments. The segregation and collection of wastes ensure that these wastes can be reused within the facility. Lugs and collected dusts can be melted in the melting pot of grid casting or the assembly line. Automated machines also reduce the number of rejected plates because errors are minimized. Examples of automated cutting machines are shown in Figure 5.28 and Figure 5.29.

Limitations: As a result of the pasting operation, the paste on the grids may contact with the lug that will be cut. Therefore, the lug waste and lead dust generally do not consist of pure alloyed lead; expanders in the pastes and lead oxide may be mixed into these wastes. Therefore, it may not be possible to reuse these wastes within the facility. The automated machine may minimize the contact of the paste with the lugs and lead dust, but still, a small contact may obstruct the on-site recyclability of the waste collected. Even if it is the case, it is worth to install an automated machine in this line because rejected plates will be minimized and better working conditions for the facility will be provided.

Figure 5.28 Automatic Pneumatic Plate-Cutting Machine (Source: Gang Lih, n.d., n.p.)

Figure 5.29 Plate Cutting and Lug Cleaning Machine (Source: TBS, n.d., n.p.)

5.3.6.4 Alternative Waste Management Solution for Fugitive Lead Emissions

Even though the ventilation system in the facility is performing successfully, it is important to notice that fugitive lead emissions may be very dangerous for operators working in grid casting and paste mixing processes. Operators must continuously use face masks in order to decrease the entrance of lead into their body by inhalation. The maintenance of the ventilation system must be made carefully and controlled in order to prevent employee exposure to lead. As recommended in Alternative 4.2.3, machines with closed systems must be used in order to decrease the release of lead in the air.

Benefits: The use of face mask and the maintenance of ventilation system are easily applicable precautions ensuring the minimization of the effects of lead emissions.

Limitations: The purchase of closed machines may need high investments and changes in the production line. In addition, it is needed to train the operators about the continuous use of face masks.

5.4 Comparison of Alternative Waste Management Solutions

As it is seen in Section 5.3, each problem may be solved by investigating an alternative waste management solution. On the other hand, it can be seen that multiple alternative waste management solutions are determined for the dross formed in grid casting operation and for the water treated in the wastewater treatment facility. The company has to compare these alternative waste management solutions in order to choose which one will be applied. The comparison of alternative waste management solutions should be made by taking charge of the working condition and criteria of the company. As told before, the operational, technical and economic information should be reviewed in order to decide which alternative waste management solution is appropriate for the company.

Let's consider the problem of dross formation in the grid casting machine as an example. The company has two alternative waste management solutions to compare: addition of excess parts and rejected grids in batch mode (Alternative 5.3.1.1) and separating pure lead from dross with Vitaflux (Alternative 5.3.1.2). A general comparison involving the environmental, operational and economical aspects can be made between these alternatives. Obviously, Alternative 5.3.1.2 is much more environmentally friendly because the waste is prevented and reduced at source. By this way, the raw material consumption is less to produce the same number of batteries and waste management costs are significantly decreased. Alternative 5.3.1.2 does not need new equipment, only a new material is going to be used. Alternative 5.3.1.1 needs a new conveyor belt in order to operate efficiently. Otherwise, the workload of operators will increase and inefficiencies in working practices may occur for that reason. However, there may be other aspects affecting the decision of the company. The area for installing a conveyor belt may be a problem for the application of Alternative 5.3.1.1. In addition, the investment of using Vitaflux may be too high for the company. Even if the benefits gained with this alternative are very high, the company may reject to use it because of high investments.

It is important to make further experiments in the company in order to see the effects of these alternatives. Feedback information should be continually used for adjusting the mix of inputs and outputs affected by the alternative waste management solutions implemented. Information derived from environmentally integrated manufacturing system analysis will constantly change production planning decisions such as demand, production scheduling, and inventory control, forecasting, and purchasing. To observe the relation between demand levels and waste quantities, a sensitivity analysis should be carried out. However, the sensitivity analysis can not be performed because of the given data covers a duration of only one year. In order to examine the correlation between demand levels and wastes, the data for several years should be gathered.

CHAPTER 6

CONCLUSION

This chapter gives a summary of the studies accomplished in this thesis and the results obtained. Further research areas that may be investigated in the future studies are also stated in this chapter.

This thesis has introduced an environmentally integrated manufacturing system analysis for companies willing to be a part of the sustainable development by efficiently using the principles of "cleaner" production techniques in obtaining high productivity levels. The wastes obtained from the manufacturing process should be minimized in order to reduce the amount of raw materials used and decrease the need for wastes' recycling. The problem considered is the generation of a systematic methodology decreasing the waste derived from the manufacturing process while simultaneously improving the overall performance of the company. This methodology is important in being a roadmap for the evaluation of environmentally friendly and economically favorable manufacturing alternatives. By using this methodology, the operations management system and waste management system of a company can be analyzed, alternatives for decreasing wastes can be investigated, evaluated and compared.

The implementation of the methodology has been realized in a car battery manufacturing company. Alternative waste management solutions were investigated for reusing off-site recycled wastes and discarded wastes in the facility or reducing them at the source. Alternative waste management solutions were investigated for on-site recycled wastes in order to achieve a better use of raw material and energy. Alternative waste management solutions for improving the water usage of the company were also investigated to allow the reuse of the refined water within the facility.

After the evaluation of alternative waste management solutions, the applicability of each alternative was considered in order to show the type of problems that could derive from their applications. By making an operational, technical and economical analysis for each of the alternatives, it was possible to present realistic propositions. Therefore, the possible benefits and limitations were identified for each alternative. The alternatives that were found to be infeasible in the battery manufacturing company were also described in this project with an idea of offering alternative solutions to other companies with different problem patterns that would wish to implement such a methodology.

Experiments were made in the battery manufacturing company for some of the alternatives. These experiments demonstrated the applicability of the alternatives or helped to obtain inputs for evaluating these alternatives. Experiments made in the company presented a realistic standpoint to the alternatives by showing problems that might occur and exact benefits that could be achieved. Financial and operational data were utilized to calculate costs. Costs calculations were achieved in order to compare the current system with the system proposed. Costs of the alternatives generally included raw material costs, recycling and transportation costs, equipment and material purchasing costs. After the evaluation of alternatives in the battery manufacturing company, the most beneficial alternatives from economical and environmental point of views were determined: the decrease of dross in the grid casting department and the reuse of the treated wastewater in the company. Table 6.1 shows the suggested alternatives and the environmental and economical benefits that can be obtained by using them in the production.

Table 6.1 Suggested Alternatives and Advantages

Wastes	Alternative	Environmental Advantages	Economic Advantages
Dross, excess parts and rejected grids from grid casting	Addition of Excess Parts and Rejected Grids in Batch Mode	Waste reduction at source	Cost Reduction: 151,411 YTL/year
		Recovery of 70,848 kg Pb/year	
	Separate Pure Lead From Dross With Vitaflux	Waste reduction at source. Recovery of raw material from the waste at source	Cost Reduction: 44,550 YTL/year
		Recovery of 44,280 kg Pb/year	
Dross from battery assembly	Separate Pure Lead From Dross With Vitaflux	Waste reduction at source. Recovery of raw material from the waste at source	No economic advantage
		Recovery of 1,934 kg Pb/year	
Refurbished battery from battery closing	Change the Production Schedule	Waste reduction at source	Cost Reduction: 315,570 YTL/year
Wasted battery covers and containers from battery closing	Change the Production Schedule	Waste reduction at source	Cost Reduction: 1,648 YTL/year
		Recovery of 514 kg plastic material per year	
Treated wastewater from the wastewater treatment facility	Use Caustic Instead of Lime	Usage of water decreased by 52,000 m3/year	Cost Reduction: 127,130 YTL/year
	Adjust the Hardness by Dilution Using Fresh Water	Usage of water decreased by 17,940 m3/year	Cost Reduction: 52,986 YTL/year
Drained paste from grid pasting	Collect the Drained Paste in a Container	Reuse of waste	Cost Reduction: 23,371 YTL/year
		Recovery of 20,563 kg paste/year	
Wasted separators from enveloping machine	Increase the Consciousness of Operators	Waste reduction at source	Better usage of raw material
Rejected plates from grid pasting	Use Water Jet Technologies	On-site recycling and reuse of waste	Better usage of raw material: decrease in raw material costs
Lug wastes, lead dust, rejected plates from cutting and brushing	Use Automated Closed Machines	Reuse of wastes, minimized exposure to lead	Decrease in raw material costs
Fugitive lead emissions from grid casting and paste mixing	Use Face Masks	Minimized exposure to lead	No economic advantage

As seen in Table 6.1, it was demonstrated that the formation of dross which is the biggest waste problem of the company could be decreased by 30% by using a flux during dross collection (Alternative 5.3.1.2). Since the waste was reduced at the source, the waste and recycling costs could be significantly decreased, and most importantly, a very big quantity of lead (Pb) raw material could be recovered consequently. The reuse of the treated wastewater was also a good alternative for the company since a very high quantity of water is used and wasted every day due to production requirements. By using caustic instead of lime (Alternative 5.3.4.1), the company could reduce its weekly water usage up to 44 %, which would make a considerable decrease in environmental impacts and operating costs. Economic advantages are calculated based on the difference between net present values of current and suggested waste management costs, as explained in the previous sections.

After the evaluation of alternatives, the company using the proposed methodology will have to decide which alternatives should be implemented. Since every company has its own working conditions, goals and legal restrictions, the decision process is left to the company. However, general environmental operations management criteria such as dependability, efficiency, flexibility and quality of alternatives can be used in the decision making process. A company aiming at a successful environmentally integrated manufacturing system analysis should not base its decisions barely on just the economic performance of the alternative, but also on the environmental performance. The trade-offs and the steady-states should be carefully analyzed.

Sensitivity analysis allows manufacturing planners to identify the parameters that are most critical for the decisions based on that model (Atkinson et. al., 2001, p. 467). The most critical parameters affecting the feasibility and the performance of alternative waste management solutions in this study are the quantity of wastes and the ratio of decrease in wastes. The sensitivity analysis can not be performed in this study because the data given by the company covers a duration of only one year. However, Table 6.2 shows the difference in waste management costs when quantity of wastes are decreased according to the suggested alternatives. Waste management costs are calculated based on the net present values described in the evaluation of alternative waste management solutions. It can be seen in Table 6.2 that a cost improvement of 51% is achieved by implementing all the alternative waste management solutions suggested. The calculation of the waste management cost of the suggested alternative for the dross obtained in grid casting operation is based on the alternative waste management solution covering the addition of excess parts and rejected grids in batch mode. The calculation of the waste management cost of the suggested alternative for the wastewater is based on the alternative waste management solution covering the usage of caustic instead of lime.

Table 6.2 Comparison of Waste Management Costs

Waste	Current Waste Management Cost (YTL/year)	Waste Management Cost of Suggested Alternative (YTL/year)	Cost Improvement
ON-SITE RECYCLED WASTES			
Paste with improper density	2,603	2,603	-
Refurbished Battery	331,585	16,015	95.17%
OFF-SITE RECYCLED WASTES			
Dross of grid casting	325,684	174,273	46.49%
Rejected Plates of grid pasting	43,757	43,757	-
Drained Paste	23,772	401	98.31%
Lug wastes	51,927	51,927	-
Lead dust	4,765	4,765	-
Rejected Plates of cutting and brushing	20,078	20,078	-
Dross of COS machine	11,880	40,511	-
Rejected plates of enveloping machine	17,097	17,097	-
Rejected plates of COS machine	7,800	7,800	-
Battery Container and Cover	2,428	780	67.86%
DISCARDED WASTES			
Wasted Separators	34,949	34,949	-
WASTEWATER			
Wastewater	279,062	151,932	45.56%
TOTAL COSTS	**1,157,387**	**566,888**	**51.02%**

It is believed that several new approaches and techniques can be added to improve the proposed methodology. A decision support tool can be designed for calculating and comparing costs and benefits of possible alternatives. By using such a decision support tool, the unit costs and unit profits can be saved in the system and costs of possible alternatives can be easily calculated. It will be also possible to define criteria and give weights to them in order to compare the operational, technical, economical and environmental characteristics of alternatives. Implementation of this environmentally integrated manufacturing system analysis in a different sector or company will also provide important inputs for improving the system and understanding its capabilities.

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APPENDIX A

ENVIRONMENTAL LAWS, STANDARDS AND INTERNATIONAL ORGANIZATIONS

1. Environmental Regulations

Environmental regulation has traditionally been the main impulse for the adoption of environmental practices by enterprises. Taking into account the environmental regulations, manufacturers have to integrate environmental management practices as an important objective of their business policy (Spengler et al., 1997; Claver et al., 2007). Since the United States has the strictest and most comprehensive body of environmental regulations, US laws will be described firstly. After that, Turkish laws will be explained.

The Resource Conservation and Recovery Act (RCRA) of 1976 provides for the definition of solid and hazardous wastes. RCRA also regulates the management of hazardous wastes by generators and those who transport and dispose of these wastes. The RCRA regulations require companies (specifically hazardous waste producers) to have a waste minimization program in place in order to reduce or eliminate waste. Therefore, it requires that companies having a source reduction/pollution prevention program or a recycling program. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 authorized the Environmental Protection Agency (EPA) to finance the cleanup of abandoned hazardous waste sites and provided the legal means to recover the costs associated with these cleanups. CERCLA also established the means for determining the liability of companies for the cleanup of contaminated property. The Clean Water Act of 1977 and the Clean Air Act Amendments of 1990 regulate the quantity of chemicals that can be released into the air and water. The Occupational Health and Safety Act (OSHA) of 1970 have common characteristics with the environmental laws. OSHA regulations limit the type and quantity of regulated substances to which employees can be exposed (Gupta and Sharma, 1996).

1. Environmental Regulations in Turkey

The Environment Ministry is responsible of the waste management in Turkey and the environmental law is described as The Control of Hazardous Waste Act. Due to these laws, municipalities have to plan the management of hazardous wastes and have to report it to the ministry. The Control of Hazardous Waste Act of Turkey covers rules about:

- transporting, reuse and dispose of wastes,

- storage and purification facilities,
- giving licenses to disposal facilities,
- construction and management of storage facilities,
- the transfrontier transportation of wastes.

The objectives taken from the production of hazardous wastes until their disposal in Turkey are:

- to standardize their management technically and administratively,
- to protect human health and environment by preventing their interfere with the nature ,
- to control their production and transportation,
- to minimize them in the production stage,
- to destruct them as near as possible to the place where they are generated when their production is unavoidable,
- to build a sufficient number of disposal facilities and to control them,
- to interdict their imports and to control their exports.

As it is seen above, Turkish laws do not allow the import of hazardous wastes, and permit their export only when it is controlled. On the other hand, it is known that RCRA do not cover such a limitation. The different economical standards of these countries may be the reason of this difference.

2. International Organizations

Cleaner production is a voluntary action that companies can adopt in order to minimize their environmental impacts and costs and to improve their efficiency. While CP is not a mandatory action, it is supported by some international organizations. These organizations are briefly described below:

United Nations Environment Program (UNEP)

UNEP launched its CP Program in 1990. The Program includes fostering information exchange among countries, capacity building in developing countries, undertaking demonstration projects in developing countries. UNEP outlined a number of policy instruments including legislation, financial instruments and information, education and demonstrations programs that may be applied to encourage CP (ANZECC, 1998).

United Nations Industrial Development Organization (UNIDO)

UNIDO promotes CP and works with governments to devise industrial policies and strategies with a preventive focus. UNIDO is designing and supporting programs of institutional strengthening which combine technical advice, training, study tours and the provision of equipment. UNIDO and UNEP are organizations that jointly support establishment of cleaner production centers in developing countries to provide advice, assess information and develop guidelines and manuals for key industries (ANZECC, 1998).

Organization for Economic Cooperation and Development (OECD)

The OECD incorporates cleaner production in its Sustainable Consumption and Production Program. Major goals for current and future OECD cleaner production efforts are to: develop methods for review and evaluation of policies aimed at cleaner production; identify barriers impeding cleaner technology adoption; improve the means for determining precisely and consistently the pollution burden; and promote capacity building in the area of life-cycle analysis, especially sustainable product policies (ANZECC, 1998).

World Business Council for Sustainable Development (WBCSD)

The World Business Council for Sustainable Development (WBCSD), formed in 1995, is a coalition of 120 international companies that have a shared commitment to environmental protection. WBCSD actively promotes cleaner production and its extension, eco-efficiency, to its members, and is encouraging governments to develop policies to support these concepts. WBCSD recognizes the potential of cleaner production to improve business efficiency in the short term, and maintain economic viability in the long-term. WBCSD promotes the benefits of resource conservation, life cycle analysis, open reporting and effective managerial systems and infrastructure (ANZECC, 1998).

3. ISO 14000

The International Organization of Standards (ISO) is establishing international standards for environmental management with its ISO 14000 series of standards. ISO 14001 adopted in 1996 (specification for an environmental management system) is the first standard in the series. Ultimately, ISO 14001 replaces the numerous and often conflicting sets of criteria found in various countries as it is flexible enough to be applied to most of the countries (ANZECC, 1998; Melnyk et al., 2003).

The introduction of ISO 14001 international standard for environmental management systems (EMS) has created a focus on environment performance and management in the business community. Applied appropriately, with a policy of improving performance, ISO 14001 is a valuable tool for providing the discipline and methodology for environmental improvements.

ISO 14001 has the benefits of:

- enabling a firm to manage, measure and improve the environmental impacts of their operations effectively by providing internal and external reporting information,
- facilitating better management of waste-related costs,
- providing information used to aid decision making and the allocation of scarce resources for managers,
- giving the culture of pollution prevention leading to reduced costs of production and higher profits,
- giving the base to enhance overall corporate performance,
- helping companies to create a culture change by environmental management practices incorporated into overall business operations; improving an organizations public image and

increasing competitive advantage (Russo and Fouts, 1997; ANZECC, 1998; Melnyk et al., 2003; Sroufe, 2003).

It is important to notice that the ISO 14001 EMS standards are process, not performance standards. In other words, these standards do not mandate a particular organization's optimum environmental performance level but describe a system to help an organization achieve its own environmental objectives. The focus of the standard is on the processes involved in the creation, management, and elimination of pollution. Underlying this approach is the assumption that by helping a firm focus on each stage of its manufacturing process, the firm will develop better environmental management practices and, ultimately improve its environmental performance. This process of evaluation often identifies not only the environmental, but also financial benefits of improved environmental performance. Basically, ISO 14001 is set forward as an effective tool to guide managers in their efforts to capitalize on the cost reduction potential of waste reduction (Dechant and Altman, 1994; ANZECC, 1998; Melnyk et al., 2003).

APPENDIX B

GIVEN DATA

Table B1. Types of Batteries and Demands of 2006

	DEMANDS OF PRODUCTS IN 2006																	
MONTH	**44 AH**	**45 AH**	**55 AH**	**60 AH**	**72 AH**	**75 AH**	**88 AH**	**90 AH**	**100 AH**	**105 AH**	**110 AH**	**120 AH**	**135 AH**	**150 AH**	**165 AH**	**180 AH**	**200 AH**	**TOTAL**
JANUARY	1.414	1.062	2.997	18.885	4.141	3.351	716	5.141	577	5.505	985	2.011	2.012	3.250	871	1.994	900	**55.804**
FEBRUARY	1.414	1.062	2.997	18.885	4.141	3.351	716	5.141	577	5.505	985	2.011	2.012	3.250	871	1.994	900	**55.804**
MARCH	1.162	952	2.439	17.444	3.773	3.351	582	5.062	0	5.447	913	1.919	1.890	2.809	808	1.773	860	**51.625**
APRIL	1.162	952	2.439	17.444	3.773	3.351	582	5.062	0	5.447	913	1.919	1.890	2.809	808	1.773	860	**51.625**
MAY	1.082	0	2.300	13.901	3.063	2.394	550	3.695	0	3.949	724	1.463	1.472	2.448	640	1.487	655	**41.054**
JUNE	1.023	0	2.187	13.618	2.987	2.394	531	3.684	0	3.940	691	1.438	1.432	2.348	613	1.419	642	**40.124**
JULY	956	0	2.021	13.181	2.879	2.394	0	3.655	0	3.920	688	1.417	1.411	2.227	609	1.377	635	**38.965**
AUGUST	830	0	1.742	12.460	2.695	2.394	0	3.616	0	3.891	653	1.371	1.350	2.007	577	1.267	614	**36.875**
SEPTEMBER	1.647	1.231	3.511	21.814	4.788	3.830	847	5.893	673	6.303	1.118	2.307	2.303	3.772	991	2.289	1.030	**64.338**
OCTOBER	1.705	1.254	3.624	22.098	4.864	3.830	866	5.904	705	6.312	1.151	2.331	2.343	3.872	1.018	2.357	1.043	**65.268**
NOVEMBER	1.831	1.309	3.903	22.818	5.048	3.830	932	5.943	769	6.341	1.187	2.378	2.404	4.092	1.049	2.468	1.064	**67.357**
DECEMBER	1.705	1.254	3.624	22.098	4.864	3.830	866	5.904	705	6.312	1.151	2.331	2.343	3.872	1.018	2.357	1.043	**65.268**
TOTAL	**15.925**	**12.042**	**33.779**	**214.641**	**47.009**	**38.292**	**8.082**	**58.694**	**6.466**	**62.867**	**11.153**	**22.889**	**22.859**	**36.750**	**9.866**	**22.552**	**10.241**	**634.100**

Table B2. Prices of Batteries in 2006

PRODUCTS	PRICES
44 AH	54,20
45 AH	53,10
55 AH	57,40
60 AH	60,60
72 AH	79,70
75 AH	81,80
88 AH	92,40
90 AH	89,20
100 AH	104,10
105 AH	103,00
110 AH	108,30
120 AH	121,10
135 AH	132,70
150 AH	147,50
165 AH	164,50
180 AH	182,60
200 AH	192,10

Table B3. Capacities of Assembly Lines According to Product Types

ASSEMBLY LINES	CAPACITIES OF THE ASSEMBLY LINES ACCORDING TO PRODUCT TYPES																
	44 AH	45 AH	55 AH	60 AH	72 AH	75 AH	88 AH	90 AH	100 AH	105 AH	110 AH	120 AH	135 AH	150 AH	165 AH	180 AH	200 AH
FIRST LINE	800	800	800	800	500	500	0	300	0	300	300	0	0	0	0	0	0
SECOND LINE	800	800	0	0	0	0	500	500	500	500	500	400	400	350	350	350	300

APPENDIX C

BILL OF MATERIAL OF A BATTERY

The product, semi-finished products, and raw materials are shown in the bill of material. It can be observed that the quantities of raw materials and semi-finished products are shown in units or grams due to their types. The weighted percentages of raw materials and semi-finished products in the battery are also given.

Akü Ürün Ağacı

Doküman No : FR/PR/73-01/03
Yayım Tarihi : 16.08.2006
Revizyon No : 01
Revizyon Tarihi : 25.08.2006

1. Kademe	Kodu	2. Kademe	Kodu	3. Kademe	Kodu	4. Kademe	Kodu	5. Kademe	Kodu	6. Kademe	Kodu	7. Kademe	Kodu	Türü	Birim Miktar	Toplam Miktar	Aküdeki Ağırlık	Ağırlıkların Yüzdesel Oranları			
Exp. Kuru Akü	0620005													Ürün	1 Ad.	1 Ad.	11,403 kg	%100,00			
		Kutu	0800027											Ham Madde	1 Ad.	1 Ad.	0,580 kg	%5,09			
		Kapak	0800019											Ham Madde	1 Ad.	1 Ad.	0,320 kg	%2,81			
		İndikatör	0											Ham Madde	0 Ad.	0 Ad.	0,000 kg	%0,00			
		Buşon	0130002											Ham Madde	8 Ad.	6 Ad.	0,016 kg	%0,14			
		Sap	0140001											Ham Madde	1 Ad.	1 Ad.	0,000 kg	%0,00			
		Sıkıştırma	0											Ham Madde	0 Ad.	0 Ad.	0,000 kg	%0,00			
		Sıkıştırma	0											Ham Madde	0 Ad.	0 Ad.	0,000 kg	%0,00			
		Hotmelt	0											Ham Madde	0 gr	0 gr	0,000 kg	%0,00			
		Eleman	1900055											Yarı Mamul	6 Ad.	6 Ad.	10,467 kg	%91,07	%100,00		
				Separatör	0090002									Ham Madde	0,040 m2	1,440 m2	0,251 kg		%2,38		
				Grif	1100007									Yarı Mamul	2 Ad.	12 Ad.	0,946 kg		%9,01	%100,00	
						ÇOS Kurşunu	0010005							Ham Madde	161 gr	0.964 gr	0,964 kg			%102,00	
				Pozitif Plaka	1560022									Yarı Mamul	6 Ad.	36 Ad.	4,807 kg		%45,94	%100,00	
						Pozitif Izgara	1350018							Yarı Mamul	48 gr	1.728 gr	1,728 kg			%36,84	%100,00
								Şerit	1250002					Yarı Mamul	58 gr	2.033 gr	2,033 kg				%117,67
										Alaşımlı Kurşun	0010007			Ham Madde	57 gr	2.038 gr	2,068 kg				
						Pozitif Hamur	1050002							Yarı Mamul	97 gr	3.502 gr	3,502 kg			%72,85	
								Kurşunmonoksit	1400001					Yarı Mamul	81 gr	2.908 gr	2,908 kg			%80,45	%100,00
										Saf Kurşun	0010003			Ham Madde	77 gr	2.768 gr	2,759 kg				%94,82
								1,40 Asit	0050005					Yarı Mamul	9 gr	0.308 gr	0,308 kg			%8,41	%100,00
										Saf Asit	0050001			Ham Madde	4 gr	0.164 gr	0,164 kg				%50,00
										Saf Su	0040001			Yarı Mamul	4 gr	0.164 gr	0,164 kg				%50,00
												Şebeke Suyu	0040002	Ham Madde	4 gr	0.164 gr	0,164 kg				
								Saf Su	0040001					Yarı Mamul	11 gr	0.383 gr	0,383 kg			%7,97	%100,00
										Şebeke Suyu	0040002			Ham Madde	11 gr	0.383 gr	0,383 kg				%100,10
								Elyaf	0060001					Ham Madde	0 gr	0.004 gr	0,004 kg			%0,08	
				Negatif Plaka	1510020									Yarı Mamul	8 Ad.	38 Ad.	4,484 kg		%42,78	%100,00	
						Negatif Izgara	1300015							Yarı Mamul	39 gr	1.404 gr	1,404 kg			%31,31	%100,00
								Şerit	1200002					Yarı Mamul	48 gr	1.852 gr	1,852 kg				%117,67
										Alaşımlı Kurşun	0010006			Ham Madde	48 gr	1.858 gr	1,858 kg				
						Negatif Hamur	1000003							Yarı Mamul	09 gr	3.485 gr	3,485 kg			%77,29	
								Kurşunmonoksit	1400001					Yarı Mamul	80 gr	2.870 gr	2,870 kg			%64,00	%100,00
										Saf Kurşun	0010003			Ham Madde	76 gr	2.724 gr	2,724 kg				%94,82
								1,40 Asit	0050005					Yarı Mamul	8 gr	0.287 gr	0,287 kg			%8,40	%100,00
										Saf Asit	0050001			Ham Madde	4 gr	0.143 gr	0,143 kg				%50,00
										Saf Su	0040001			Yarı Mamul	4 gr	0.143 gr	0,143 kg				%50,00
												Şebeke Suyu	0040002	Ham Madde	4 gr	0.144 gr	0,144 kg				
								Saf Su	0040001					Yarı Mamul	10 gr	0.373 gr	0,373 kg			%8,32	%100,00
										Şebeke Suyu	0040002			Ham Madde	10 gr	0.373 gr	0,373 kg				%100,10
								Elyaf	0060001					Ham Madde	0 gr	0.004 gr	0,004 kg			%0,09	
								Expander	0070001					Ham Madde	0 gr	0.014 gr	0,014 kg			%0,32	
								Prestrene	0080001					Ham Madde	0 gr	0.000 gr	0,000 kg			%0,00	

APPENDIX D

MATERIAL SAFETY DATA SHEET
OF A BATTERY

MATERIAL SAFETY DATA SHEET

1) PRODUCT AND COMPANY IDENTIFICATION

Product : LEAD ACID BATTERY
Company :
Company Address:

Contact Telephone:

2) HAZARDOUS INGREDIENTS

MATERIAL	% WEIGHT
Lead (Pb)	50-62
Electrolyte (Sulfuric Acid(H_2SO_4) and water)	28-35
Polypropylene (PP) (Lid & Box)	6-10
Polyethylene(PE) (Separator)	1-2

3) HEALTH HAZARD INFORMATION

Routes of entery	Under normal conditions of use, sulfuric acid vapors and mist are not generated. Sulfuric acid vapors and mist may be generated when product is overheated, oxidized, or otherwise processed or damaged. Under normal conditions of use, lead dust, vapors, and fumes are not generated. Hazardous exposure to lead may occur when product is overheated, oxidized, or otherwise processed or damaged to create lead dust, vapor, or fumes.
Inhalation	High levels of sulfuric acid vapors or mist may cause severe respiratory irritation.
Skin Contact	Sulfuric acid may cause severe irritation, burns, and ulceration.
Skin Absorption	Sulfuric acid is not readily absorbed through the skin. Lead compounds are not readily absorbed through the skin.
Eye contact	Sulfuric acid vapors can cause severe irritation, burns, cornea damage, and blindness. Lead compounds may cause irritation

4) FIRST AID MEASURES

Inhalation	Sulfuric acid: Remove to fresh air immediately. If breathing is difficult give oxygen. Lead compounds: Remove from exposure, gargle, wash nose and eyes, and consult physician.
Skin contact	Sulfuric acid: Flush with large amounts of water for at least 15 minutes, remove any contaminated clothing and do not wear again until cleaned. If acid is splashed on shoes, remove and clean. Lead compounds are not readily absorbed through the skin.
Eye contact	Sulfuric acid: Flush immediately with cool water for at least 15 minutes, then Consult physician.

Ingestion	Sulfuric acid: Give large quantities of water – DO NOT induce vomiting – then consult physician. Lead compounds: Consult a physician.

5) FIRE AND EXPLOSION DATA

Extinguishing media: Carbon dioxide (CO2) , foam, dry chemical

If batteries on charge, turn off power. Use positive pressure, self- contained breathing apparatus. Water applied to electrolyte generates heat and causes it to splatter. Wear acid resistant clothing.

Hydrogen and oxygen gases are produced in the cells during normal battery operation or when on charge(hydrogen is highly flammable and oxygen supports combustion). These gases enter the air the vent caps. To avoid risk of fire or explosion, keep sparks and other sources of ignition away from the battery, and ensure that adequate ventilation is provided. Do not allow metallic material to simultaneously contact both the positive and negative terminals of batteries. Follow manufacturers' instructions for installation and operation.

6) SPILL OF LEAK PROCEDURES

Remove combustible materials and all sources of ignition. Stop flow of material and contain spill by diking with soda ash (sodium carbonate) or quick lime (calcium oxide). Carefully neutralize spill with soda ash, etc. Make certain mixture is neutral then collect residue and place in a durum or other suitable container with label specifying "contains hazardous waste" or if uncertain call distributor regarding proper labeling procedures. Dispose of as hazardous waste. If battery is leaking, place battery in a heavy-duty plastic bag. Wear acid resistant boots, face shield, chemical splash goggles and acid resistant gloves. DO NOT RELEASE UNNEUTRALIZET ACID.

7) HANDLING AND STORAGE

Store and handle lead acid batteries in well- ventilated areas.
Make certain vent caps are on tightly. Follow all manufacturers' recommendations when stacking or palletizing. Do not allow metallic materials to simultaneously contact both the positive and negative terminals of the batteries. Use a battery carrier to lift battery or place hands on opposite corners to avoid spilling acid through the vents. Avoid contact with internal components of the batteries.

8) PERSONEL PROTECTIVE EQUIPMENT

Eyes and face: Chemical splash goggles or face shiled.
Hands, arms, body: Rubber or plastic acid resistant gloves with elbow length gauntlet.
Other special clothing and equipment: Acid resistant apron. Under severe exposure or emergency conditions, wear acid resistant clothing and boots.
Hygiene practices: Wash hands thoroughly before eating, drinking or smoking after handling batteries.
Protective measures to be taken during
non- routine tasks including equipment maintenance: Charged batteries can present an electrical hazard. Take all appropriate precautions.

9) PHYSICAL & CHEMICAL PROPERTIES

Electrolyte : Sulfuric acid and water
Boiling point: (760 mm-Hg): 197-216 ^{0}C
Specific gravity: 1,23 - 1,35 g/cm3
Vapor density (air =1): >1
Appearance and odor: Electrolyte is a clear liquid with a sharp, penetrating, pungent odor.
Vapor pressure (20 ^{0}C): 10 mm-Hg
Solubility in water (% by Wt.): %100
Evaporation rate (Butyl acetate =1): <1
Explosion Limit (Hydrogen gas): At least: %4,65 Top: %93,9

10) STABILITY AND REACTIVITY

Stability	Stable
Conditions to avoid	Sparks and other sources of ignition. Prolonged overcharge and overheating.
Incompatibility (material to avoid)	Combination of sulfuric acid with combustibles, and organic materials may cause fire and explosion. Also avoid strong reducing agents, most metals, carbides chlorates, nitrates, picrate. Lead compound: potassium. Carbides, sulfides, peroxides, phosphorus, and sulfur.
Hazardous decomposition products	Sulfuric acid: hydrogen, sulfur trioxide, hydrogen sulfide, and sulfuric acid mist.
Hazardous polymerization	Will not occur.

11) TOXICOLOGICAL INFORMATION

Acute effects	Sulfuric acid may cause severe skin irritation, upper respiratory irritation, burns, damage to cornea, and possible blindness. Lead compounds may cause abdominal pain, nausea, headages, vomiting, diarrhea, severe cramping, and difficulty in sleeping. Oral LD50 (oral, rat) : 2140 mg/kg (%25 concentration electrolyte) Oral LC50 (inh. rat) : 510 mg/m3 /2H (at dilute element) Oral LC50 (Mouse) : 320 mg/m3 /2H
Chronic effects	Sulfuric acid may lead to scarring of the cornea, inflammation of nose, throat and bronchial tubes, and possible erosion of tooth enamel. Lead compounds may cause anemia, and damage to the kidneys and nervous system. May cause reproductive harm in both and males and females.
Cause Cancer	Human studies are inconclusive regarding lead exposure and an increased cancer risk. The EPA and the international Agency for Research on Cancer (IARC) have categorized lead and inorganic lead compounds as B2 classification (probable/ possible human carcinogen) based on sufficient animal evidence and inadequate human evidence. Its acid has Group 1 carcinogen according to IARC.

12) ECOLOGICAL INFORMATION

The lead acid battery is harmful to aquatic life. It may be dangerous if it enters water intakes. The aquatic toxicity for bluegill in fresh water was 24.5 ppm/24hr, which was lethal. Fish Toxicity: 2.8 µg/L 96 hrs LC50 Rainbow trout.

13) DISPOSAL CONSIDERATION

Sulfuric acid: Neutralize as described above for a spill, collect residue and place in a container labeled as container labeled as containing hazardous waste. Dispose of as a hazardous waste. If uncertain about labeling procedures call your local battery distributor. DO NOT FLUSH LEAD CONTAMINATED ACID TO SEWER.

Batteries: Send to lead recycling facility following applicable federal, state, and local regulations.

14) TRANSPORT INFORMATION

Accordance with international regulations.
Land & Railroad: ADR
Sea route: IMCO8

15) REGULATORY INFORMATION

Batteries has safety precautions labeling according to European Standard EN 60095-1 Lead-Acid Starter Batteries Part 1: General requirements and methods of test .

Risk Phrases:

R5, R8, R10, R26/27/28, R36/37/38, R4, R4, R5, R58

Safety Phrases:

S7/9, S24/25, S29/56 , S36/37/39

16) OTHER INFORMATION

Battery posts, terminals, and related accessories contain lead and lead compounds, chemical known to cause cancer and reproductive harm. Wash hands after handling.

The Who International Agency for research on cancer have conclude that occupational exposure to strong inorganic acid mists containing sulfuric acid is carcinogenic to man, causing cancer of the larynx (the voice box) and, to a lesser extent, the lung. Although no direct link has been established between exposure to sulfuric acid, itself, and cancer in man, exposure to any mist or aerosol during the use of this product should be avoided and, any case, keep exposures below the occupational limit of sulfuric acid.