Recyclable Materials (Waste) Management in Enterprise’s Production Process

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Abstract. Currently, in view of the increasing garbage crisis, the notion of a “new lease of life” for waste becomes even more relevant. Waste recycling makes it possible not only to solve obvious environmental problems, but also to offer new resource opportunities for industries. Among the obvious economic, social and environmental advantages, however, waste recycling meets various problems. These problems and solutions for them, as well as the problems of economic efficiency improvement and recycling activities’ appeal for industrial companies in Leningrad region, are discussed in the present study.

1. Introduction

The current situation with waste disposal and recycling in Leningrad region is quite disappointing. The Committee on State Environmental Control is receiving complaints on toxic smoke from the residents of the nearest settlements. At the same time, one of the largest landfill - "Krasny Bor" – is considered to be a high consequence facility of federal significance, has been operating for more than 45 years, instead of the expected 3-5 years according to its design, and now it has almost completely depleted its resources.

The cells, containing waste, are almost 100% filled up. Every year the landfill collects a large amount of precipitation, which automatically turns into waste. It is strongly prohibited to empty moisture proof cells into the environment. Consequently, there is no place for new waste disposal.

Experts believe that the landfill waste accumulated for more than 45 years must be recycled using environmentally sound technologies which do not make harm to the health of people living nearby.

In Russia it is annually generated about 3.5 billion tons of waste. According to official data, only about a quarter of that amount, and in practice - even less, goes to recycling. The remaining waste can be incinerated or removed to special landfills, or simply thrown away, so the number of so-called black landfills is constantly growing.

In 2014 on the territory of St. Petersburg, the Committee on Environmental Management revealed 86 unauthorized waste dumps with the total area of about 159,676 square meters, and the volume of 107,593 cbm. Most of landfills are located in Krasnogvardeysky and Kirovsky regions.

The total volume of accumulated wastes in Russia is equal to about 90 billion tons, and the total area of landfills in the country is steadily growing, having exceeded 2.5 thousand square kilometers. Raw materials appear to be treated wastefully.

The Russian Government believes that waste disposal and recycling is a complicated but very promising business activity. Creating good conditions for investors, companies representing small and
medium businesses, so that they could enter this field – is regarded as a near-term issue.
The current situation shows that there are no distinct economic incentives for complex waste
treatment. Sometimes it is more profitable to bury or incinerate waste rather than to dispose or re-use it
at production site.

2. Literature Review and Hypotheses
The problems of recyclable materials economics have been thoroughly investigated in foreign literature;
here one can highlight the works of the following scholars: A. Amundsen [1], B. Bilitevski [2], J.
Krutilla and A. Fisher [3], and others [7]. Certain aspects on the rational use of recyclable materials are
discussed in the studies of the Russian scholars: A.E. Karlik [4], L.L. Kamenik [5], D.S. Demidenko [6],
and others.
With all due appreciation for the investigations results, it should be noted that there are some
aspects of industrial waste recycling which are still insufficiently studied, such as efficiency issues of
manufacturing. Currently, there is no either consistent approach to the methods of evaluating
economic efficiency based on recyclable materials, or any recycling-based manufacturing optimization
model. The above-mentioned problems in the field of recycling economics make us emphasize that the
chosen research topic is of a very high relevance.

3. Methodology
Waste, which is inevitably generated in the process of manufacturing at an enterprise, can be a source
of secondary resources: fuel, energy and material. Nevertheless, according to the statistical reports
analysis for St. Petersburg and the Leningrad region, the products of recycled resources are almost
never used as energy source, and not more than 10% of the total waste amount is used as recyclable
materials, which proves that there is a certain necessity in developing a huge waste processing
industry.

3.1. Research Goal
Today there is no consistent approach to the methods of waste management in production process of
an industrial enterprise. Let us consider the mechanism of waste "management" at all stages of the
enterprise’s production process, in the form of the following graphic-analytical model. The model
comprises all the stages of product life cycle, interprets these stages, instrumentation, material
elements and management tools for each stage, thus creating approaches to management which are
applicable at each stage.

3.2 Analyses and Results
The management mechanism should include criteria and methods of developing and assessment of
management decisions efficiency in the process of recyclable materials management at an enterprise.
The model (Fig.1) shows that the problem of management decisions optimization, with its own control
mechanism represented, can be only a multi-objective one, comprising many other limitations (resource
limitations, limitations to an allowed variables ratio, to meeting other requirements of products
consumption and manufacturing - production capacity, enterprise’s assets and existing limits of
investments, minimum requirement for various types of products, quality of provided products, and
others). Although the approaches to multi-objective problems are known and described in economics
literature, formulation of multi-objective problems for effective recyclable materials management in the
process of manufacturing, as well as practically acceptable methods of solving them, can find its
development in the research topic.
The first phase of the mechanism covers waste management at the product design stage. Even at this
stage, the environment-oriented engineering raises the question of a crucial alternative to move
manufacturing waste into the category of recyclable material, that is an environmentally sound method,
as well as the questions of economic viability of waste processing.
As it is known, the first phase of designing includes formulation of technical requirements containing a production task and project limitations. In fact, technical requirement represents organizing of initial data, project limitations and objectives. There are certain critical values of parameters, variability intervals and limits determined for each limitation / requirement. Having defined initial terms, there is an array of permissible solutions formed, with the optimal solution to be selected.

Currently, that type of designing, which takes into account not only economic benefits of the project, but also its environmental performance, the environmental impact of waste and its disposal, is considered to be relevant. Such designing can be called environment-oriented. The main feature of such waste management alternative is that it is based on environmental and economic aspects of
saving resources, and is aimed at reducing negative impact of production and products consumption processes on the environment.

This analysis’ multicriteriality allows assessing not only the environmental impact of manufacturing, but also the effects of processing / incineration / disposal of related waste. However, one should keep in mind resources saving. Thus, project analysis should take into account all the factors: either technical and economic, or environmental ones.

The design stage implies limitation of the future product’s quality characteristics, its saving ability and power generation, during production process, as well as new products manufacturing or scavenging. All these limitations and objectives will emerge in the form of additional resource utilization options during the disposal process.

Furthermore, the very stage has the greatest potential in terms of waste minimization. It is exactly the very stage when the main resource-saving steps are taken, energy and material intensity levels are justified, environmental and technological resource processing parameters, as well as quality requirements for the final product manufactured from recycled resources, are determined (it must be competitive with similar products manufactured from primary resources).

The main objective of an enterprise at the second stage is reducing waste, or adjusting it for its personal use. It is also possible to make use of the generated waste for the needs of other companies in the area, which implies an ongoing market surveillance. The waste which does not make economic sense for the enterprise, can really find other consumers. Theoretically, it is also possible to implement waste pre-treatment for the needs of other businesses while maintaining economic viability (the price does not exceed the price of the similar primary resource, and the quality will not be worse) and environmentally safe processing.

The third stage includes consumption residue management. At this stage it is necessary to use some marketing tricks to create demand for products which can be recycled, contain recyclable resource, or can take part in the process of resource-recovery (if it is economically and environmentally viable).

The fourth stage involves waste management in the process of product utilization. As part of this process, it is necessary to build a sufficient infrastructure and provide services for retrieving resource-valuable components from waste.

All four stages meet a huge impact of government influence on the waste management efficiency. Its major role is to build a market infrastructure by means of a motivational mechanism formation in regard to different economic system agents, whose activities are connected with waste management.

Studies suggest that there are certain limits for economic growth of the enterprise using recyclable materials. On these terms, the enterprise it trying to optimize its economic growth programs in a resource-constrained environment. Resources scarcity forms economic growth limits at the enterprise, and it is necessary to enhance the economic growth.

In case of an appropriate growth programs management, resources consumption for each program is expressed by a scheduled variable which can take a certain value of scarce resources consumption. Resource limits for each growth program for each product are shown in Table.

The measure for the enterprise efficiency in achieving the desired economic growth rate is supposed to be an index, which being extremely variable can characterize the composite index of the enterprise economic growth for a certain period.

The general formulation of the problem of optimal resources allocation between the economic growth programs can be represented, as follows:

\[
\prod_{i=1}^{n} \frac{N_i}{\Phi_i(r_i)} \rightarrow \min 
\]

(1)

with the following limitations:

\[
\Phi_i(r_i) = \Phi_{oi} + \Delta_i(r_i) = \begin{cases} 
N_i & \rightarrow r_i = L_i \\
\Phi_{oi} & \rightarrow r_i = 0 
\end{cases}
\]
\[
\sum_{i=1}^{n} r_i = R
\]

Where:
- \( i \) – direction of growth (product type), the same index corresponds to growth program, in case that each product has only one growth program - such situation is investigated by us,
- \( r_i \) – scarce resources consumption required for the «i» program implementation for each product.
- \( n \) – number of product types or number of growth programs at the enterprise,
- \( \Phi_i(r_i) \) – actually attained growth for the «i\textsuperscript{th}» product, which requires the use of \( r_i \) – scarce resources.
- \( R \) - general limit of scarce resources for implementing growth programs at the enterprise,
- \( \Phi_i(r) \) - scarce resources limit for implementing the «i\textsuperscript{th}» growth program,
- \( \Delta_i(r_i) \) - attainable growth for the «i\textsuperscript{th}» product when implementing the relevant program.

### Table 1. Resource limits for each program of growth for each product.

| Product (i) | Plan (\( \Pi_i \)) (convert.unit) | Actual (\( \Phi_0 \)) (convert.unit) | Index \( I_{0i} \) | Resource limit \( (r_i) \) (monet.unit) |
|-------------|----------------------------------|-----------------------------------|----------------|---------------------------------|
| 1           | 10                               | 8                                 | 10/8=1.25      | 1                               |
| 2           | 11                               | 10                                | 11/10=1.1      | 2                               |
| 3           | 11                               | 9                                 | 11/9=1.222     | 1                               |
| Total       |                                  |                                    | 1.25*1.1*1.222=1.68 | 2                               |

### Table 2. Computation Table.

| Product 1 | 0   | 1   | 2 |
|-----------|-----|-----|---|
| Product 2 | 1.375 | 1.25*1.1=1.375 | 1.25*1=1.25 | 1.375 |
| 1         | 1*1.1=1.1 | 1*1.1=1.1 | 1,1 |
| 2         | 1*1.1=1.1 | 1,1 |

### Table 3. Computation Table.

| Product 3 | 0   | 1   | 2 |
|-----------|-----|-----|---|
| Product 1+2 | 1.68 | 1.375*1.222=1.68 | 1.375*1=1.375 |
| 1         | 1.1*1.222=1.344 | 1.1*1=1.1 |
| 2         | 1.1*1.222=1.344 |

Actually attained growth across the board of the enterprise depends on the number of available resources which can be directed to each growth program fulfillment. Each growth task corresponds to respective growth programs, and in order to fulfill them it is necessary to spend a certain planned amount of financial or other scarce resources.

If the total resources limit was equal to, or exceeded the total resources limit for all the growth programs of all the products at the enterprise, presented in Table 1, there would be no problem of optimal growth program management for resources allocation, as there would be the possibility to fulfill all the programs. However, if the total resources limit is less than the programs resources sum, then the existing limit should be divided between the programs in the best possible way, in order to achieve the best result with the selected criterion of efficiency - company’s activity on measuring up the required growth rate - the comprehensive index of an enterprise economic growth.
For the purpose of optimal scarce resources allocation, which ensures reaching the desired growth level, we have chosen the dynamic programming method; the example using the method is given in Computation Tables 2 and 3. Each diagonal of the computation table corresponds to specific resource limits. For example, let us consider Table 2. So, if 2 different resources are allocated between product 1 and product 2, there are three ways of their distribution:

2 resource units for product 1, and 0 resource unit for product 2, or
1 resource unit for product 1, and 1 unit for product 2, or
0 resource units for product 1, and 1 resource unit for product 2.

To determine the planning figures for the actual economic growth performance (as a result of the relevant growth programs implementation) you can be guided by the following alternative rules:

In a range of values \( \Phi_i \leq \Pi_i \), \( \Delta \Phi_i = \Pi_i - \Phi_i \),

In a range of values \( \Phi_i > \Pi_i \), \( \Delta \Phi_i = 0 \),

where \( \Delta \Phi_i \) represents the economic growth planning figures for the \( i^{th} \) Product.

Another approach with a range of values \( \Phi_i > \Pi_i \), \( \Delta \Phi_i = \Pi_i - \Pi_{i-1} \), is also possible.

The optimization problem of economic growth is limited to an optimal allocation of limited resources between different products (growth programs) out of the products manufactured by the enterprise. The problem solving steps are both certain types of products and corresponding growth programs. The first step implies pointing out resource limits for the first product. The second step includes resource costs for the second product, on the \( n^{th} \) step - the costs for \( n^{th} \) products, etc.

Each program will be successfully implemented, if the resources consumption is realized entirely in the planned volume, otherwise the program cannot be completed.

In order to achieve the planned figures for the production volume growth or sales of the \( i^{th} \) product manufactured by the enterprise, the adequate growth program should be implemented. If it is not implemented, the plan will not be able to be completed, and actual economic growth performance for the \( i^{th} \) product will remain as it was before the growth program implementation, i.e., unchanged.

In the first and the second allocation patterns the minimum index of economic growth is achieved. Likewise, all the values at other diagonals of Table 2 can be determined.

The next step of the solution, which is shown in Table 3, involves product 3 to be distributed. Table 3 is quite similar to Table 2. 2. The optimal solution is determined in the reverse order:

At the last (second) step of solution (Table 2) the optimal (minimum) growth index value equal to 1.1 (in bold) on the table diagonal which corresponds to the total limit of the enterprise’s limited resources, equal to 2 mon.units, 1 resource unit is directed to product 3, and 1 resource unit is directed to a set of products 1 and 2.

At the first step of the solution (see the second diagonal of Table 2), 1 resource unit (out of the remaining limit) is directed to product 1 and 0 units - to product 2. This represents the optimal distribution of the total resources limit, which is equal to 2, as it provides a minimum value of general growth index at the enterprise, equal to 1.1. Any other resources allocation leads to a higher value of the growth index (1.344 or 1.375 - see Table 3).

4. Conclusion
The described mechanism provides a combination of restrictive and expansionary tools which can ensure the maximum possible and most secure energy saving. They can be used relating to all subjects of the economic system. The given statement and the example of the problem of scarce resources limit optimal allocation with the help of the economic performance improvement programs can be of great practical importance for enterprises.

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