# Principles of Building an Effective Waste Sorting System at Industrial Enterprises

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## ABSTRACT

*The article discusses the problem of building an effective waste sorting system at industrial enterprises through the lens of relevant principles. Against the backdrop of natural resource depletion and stricter environmental legislation, the transformation of waste material from an expense item into a valuable secondary resource is becoming not just an opportunity but a strategic link. The relevance of the study is justified by the need to move from fragmented solutions to the creation of holistic management systems. The goal is to characterize and substantiate a multi-component model for building an effective sorting system in industrial enterprises, which integrates technological, logistical, managerial, and cultural aspects. During the literature review, a contradiction was identified: most studies focus either on technological automation, presenting it as a self-sufficient solution, or on general managerial concepts (missing out on specific implementation barriers and, most importantly, the role of the human factor). The author concludes that maximum efficiency and economic return are achieved not solely through advanced equipment, but through the synergy of four key elements: a thorough audit of waste streams, well-chosen technologies, optimized internal logistics, and a purposefully developed corporate culture of responsibility. The author's contribution lies in shifting the focus from a purely technical to a comprehensive, organizational, and technological approach, and in developing specific, practically applicable recommendations for involving personnel, an aspect that remains undeservedly on the periphery of scientific research. The presented materials will be useful for industrial managers, process engineers, environmental specialists, and lean management professionals.*

Keywords: *waste audit, key performance indicators (KPIs), corporate culture, industrial waste, waste management, circular economy.*



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## Introduction

The problem of waste management, long situated on the periphery of managerial tasks, has in recent years transformed into one of the central challenges for the global economy. Although high-income countries are home to only 16% of the world's population, they account for over 34% of global waste [2]. Industrial enterprises, which generate colossal volumes of waste, bear a particular responsibility. It is anticipated that these materials will be maximally reintegrated into the economic turnover as secondary material resources.

The transition to a circular economy is not an ordinary environmental initiative but a strategic imperative, dictated both by tightening legislation and by economic expediency. The central link in the transition to this new model is the creation of an effective system for the separate collection and sorting of waste at enterprises. It is at this initial stage that the "foundation" is laid for its further processing and return to the production cycle.

Meanwhile, building such a system is a complex, multifactorial task. Its success depends both on the availability of appropriate infrastructure and on the competent organization of processes, economic motivation, and the involvement of the entire team. Despite the extensive research on individual components of waste management, a significant research gap remains in integrating technological automation, logistical optimization, and human resource management into a single cohesive model. Within this study, the aim is to systematize and examine the fundamental principles, the adherence to which allows for the creation of a truly effective and sustainable sorting system at an industrial facility. To address the identified gap, this paper proposes a comprehensive conceptual framework that synergizes these elements, offering a novel, multi-dimensional approach compared to existing studies that primarily focus on isolated technological or managerial solutions.

**Materials and Methods**

The literature review process involved a systematic search of academic databases, including Scopus, Web of Science, and Google Scholar. The search strategy utilized combinations of keywords such as "industrial waste management," "circular economy," "waste sorting automation," and "corporate environmental responsibility." The initial search yielded over 50 potential sources published primarily within the last 10 years. After screening for relevance and scientific rigor, a core set of key sources was selected for detailed analysis. A review of the scientific literature dedicated to industrial waste management helped to identify several key research vectors.

Some works, in particular the publications by Beyond an age of waste and Graham E. [1, 2], are review-oriented and focus on collecting and summarizing global statistical data, which allows for an assessment of the problem's scale and the identification of general trends.

Another significant layer of research is focused on developing conceptual frameworks and managerial models. For instance, Mishra D. [4] and Naqvi S.R. et al. [5] examine the problem through the prism of sustainable development and circular economy, while Sindhu R.K. [8] and Thongkong S. et al. [9] propose more applied systemic approaches and guidelines for creating effective waste management systems in production.

Finally, the most dynamically developing direction is the study and implementation of advanced technological solutions. The works of Kiyokawa T. et al. [3], Ponni R. et al. [6], Prasher S. and Nelson L. [7], and Yang T. et al. [10] describe in detail the possibilities of using robotics, machine learning methods (in particular, the EfficientNetB3 and Extreme Learning Machine models), and intelligent systems to automate the sorting process, aimed at increasing its accuracy and productivity.

No direct factual contradictions are observed in the presented literature. However, an implicit contradiction in emphasis can be identified. For example, authors focused on technological solutions tend to present automation as the primary, if not the only, key to effectiveness, potentially underestimating organizational and human factors. At the same time, researchers concentrated on managerial models; although they form a holistic vision, they do not always pay sufficient attention to the specific economic and technical barriers to implementing the systems they propose.

In preparing this article, the following methods were applied to disclose the topic: analysis and synthesis of scientific literature, systematization and classification, comparison, and a structural-functional approach (viewing the waste management system as a collection of interconnected elements, each performing a specific function to achieve a common goal).

**Results and Discussion**

Against the backdrop of global intensification of industrial production and stricter environmental norms, the problem of waste management has transformed from a purely operational task into an element of strategic planning [11]. Rational handling of waste not only minimizes environmental damage but also opens up significant economic opportunities. The graph below illustrates the global volume of waste by region, broken down by composition (Fig. 1) [1].

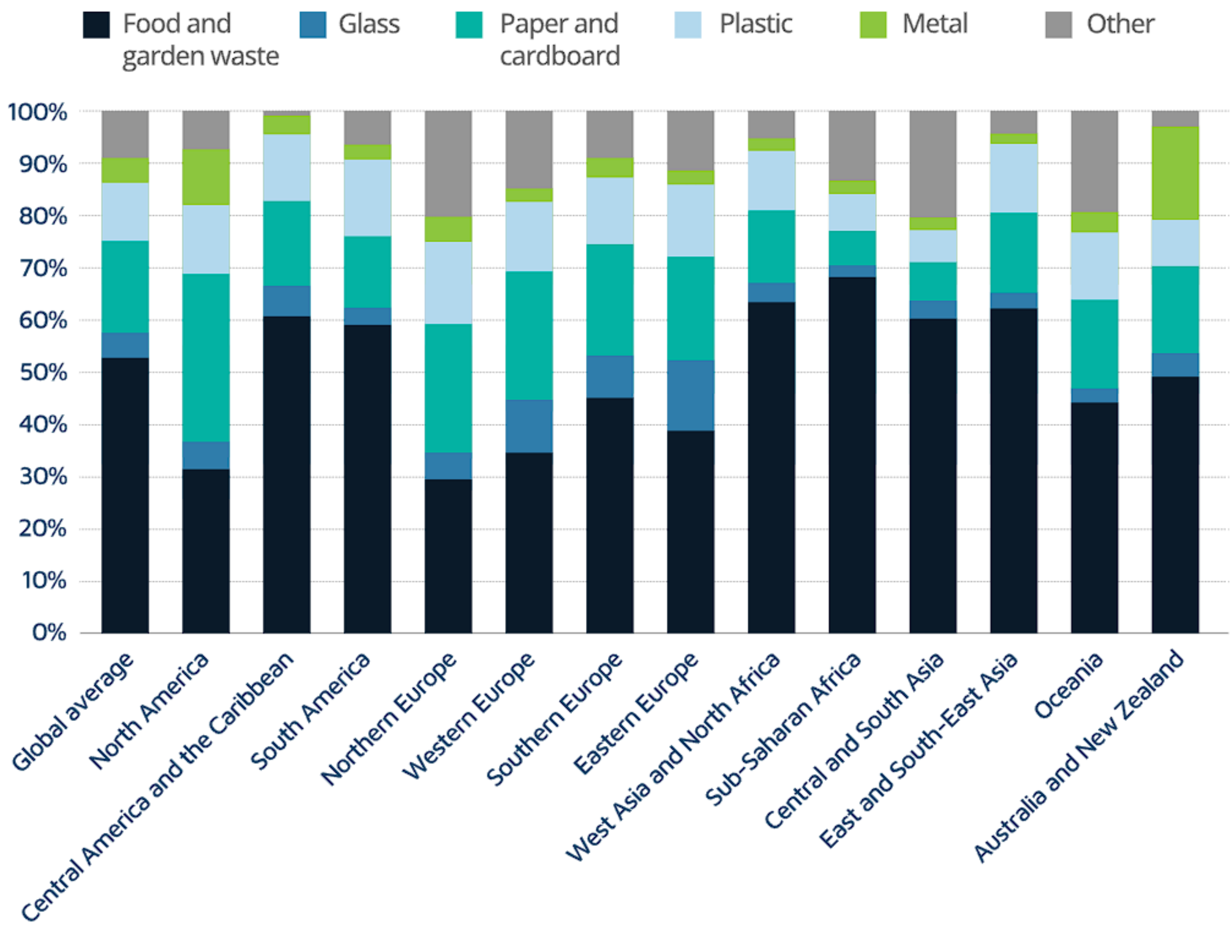


**Figure 1.** Global volume of waste by region, broken down by its composition (Adapted from [1])

The fundamental principle in engineering any waste management infrastructure is a scrupulous audit of the generated streams. Without a deep understanding of the composition and volumes, it is unrealistic to design an effective system. This process includes:

- Quantitative assessment (involving the measurement of the total volume and mass of waste generated over a specific period (shift, day, week));
- Qualitative (morphological) analysis—detailed classification by fraction: plastic (with separation by type, e.g., PET, HDPE), paper and cardboard, glass, ferrous and non-ferrous metals, wood, organic residues, hazardous waste, and non-recyclable materials [4, 7, 8].

The results of such a study help to precisely determine the necessary equipment and areas for sorting and to identify the potential for reducing waste generation at its source. For example, the analysis might reveal excessive use of packaging materials, which would serve as a basis for revising logistical processes or negotiating with suppliers.

The choice of technological equipment is, perhaps, one of the most critical aspects (in the context of discussing principles). The modern market offers a wide range of solutions—from basic to fully automated complexes. The effectiveness of the system directly depends on the correct combination of technologies, adapted to the specific morphological composition of the enterprise's waste. It is advisable to distinguish three basic levels of technological equipment (Table 1):

**Table 1 –** Levels of technological equipment (based on [3-5, 9, 10])

| Comparison criterion | Sorting | | |
|---|---|---|---|
| | Manual | Mechanized | Automated |
| Capital costs | Low | Medium | High |
| Operational costs | High | Medium | Low (energy consumption, maintenance) |
| Productivity | Low | Medium | High |
| Sorting accuracy | 60–75% | 75–85% | 95–99% |
| Flexibility | High (easy adaptation) | Medium | Low (requires reconfiguration) |
| Dependence on human factor | Critical | Moderate | Minimal |

Consequently, the choice of optimal technology is a compromise between initial investment, operational costs, and the required quality of the final product—the sorted secondary raw material.

The effectiveness of a sorting complex is determined both by the equipment and by well-thought-out internal logistics. The key principle in this context is the minimization of movements and the prevention of mixing already separated streams. This is achieved through:

- Site zoning (clear separation of zones for accumulating initial waste, sorting it, temporarily storing fractions, and shipping);
- Container system (implementation of standardized color or text labeling for different types of waste directly at their points of origin (workshops, offices). This promotes primary sorting by personnel and significantly reduces the load on the main sorting complex.
- Route optimization (developing optimal paths for waste movement from collection points to the sorting shop to avoid crossing paths with raw materials, finished products, and personnel).

A modern management system in the characterized area is unthinkable without data collection and analysis. The implementation of key performance indicators (KPIs) helps to monitor the effectiveness of processes in real-time and make informed managerial decisions (Table 2).

**Table 2 –** Main KPIs for evaluating the performance of waste sorting systems at industrial enterprises (based on [4, 7, 8, 10])

| KPI (Key Performance Indicator) | Description | Calculation Formula | Goal |
|---|---|---|---|
| Waste diversion rate | The share of waste diverted to recycling or reuse out of the total volume. | (Volume of recycled waste / Total volume) * 100% | Maximization of the indicator; striving for "zero waste to landfill." |
| Fraction contamination rate | The percentage of impurities (non-target materials) in a sorted batch of secondary raw material. | (Mass of impurities / Total mass of batch) * 100% | Minimization of the indicator, as high contamination levels reduce the value of the raw material. |
| Cost of managing one ton of waste | Total costs for collection, sorting, and disposal per ton. | Total costs / Total volume of waste (in tons) | Cost reduction by increasing efficiency and increasing revenue from the sale of secondary raw materials. |
| Revenue from the sale of secondary raw materials | Financial proceeds from the sale of sorted materials to recycling companies. | Σ (Volume of fraction * Sale price) | Maximization of revenue, which confirms the economic viability of the system. |

Regular monitoring of the metrics listed in the table helps to identify "bottlenecks," in particular, insufficient staff awareness or inefficient equipment operation.

It is reasonable to assume that even the most advanced automated system will not function at its highest efficiency without the active participation and support of the enterprise's employees. The formation of a culture of responsible waste handling is an equally significant principle. Table 3 formulates author-developed recommendations for its implementation.

**Table 3 –** Suggestions for implementing the principle of staff involvement (compiled by the author)

| Direction | Recommendation | Implementation Tools | Expected Result |
|---|---|---|---|
| Information and education campaign | Development and implementation of a comprehensive training program aimed at forming a systemic understanding of the waste management process among employees. | Introductory briefings for all new employees. Periodic (quarterly/semi-annual) mandatory training. Displaying visual aids (infographic posters showing the waste life cycle and the economic effect of recycling). Clear and unified labeling of all waste | Increased staff awareness of sorting rules. Formation of an understanding of each employee's personal contribution to overall environmental and economic efficiency. |

| Direction | Recommendation | Implementation Tools | Expected Result |
|---|---|---|---|
| | | collection containers with examples. | |
| Motivation and incentive system | Creation of a transparent system of material and non-material stimulation that directly links the quality of sorting to rewards. | Implementation of team bonuses for shifts or departments for achieving target KPIs. Public recognition and rewarding of the best teams/employees (e.g., "Eco-hero of the month," acknowledgments from management). Gamification elements—organizing competitions between departments with a public rating. | Creation of sustained personal and collective interest in the high-quality performance of sorting procedures. Transformation of a routine duty into an engaging and competitive process. |
| Leadership and organizational integration | Demonstration of commitment to sustainable development principles by senior management and integration of responsibility into the organizational structure. | Personal participation of top management in launching and promoting the program. Appointment of responsible persons ("environmental ambassadors") from among authoritative employees in each department. Inclusion of waste management performance indicators in the evaluation system for mid-level managers. | Raising the status and significance of the initiative in the eyes of rank-and-file employees. Creation of a vertical of responsibility, where control and support are carried out at all levels of management. |
| Feedback and continuous improvement mechanisms | Building effective two-way communication to collect suggestions from personnel and promptly resolve emerging problems. | Creation of a simple and accessible channel for feedback (special e-mail, chatbot, physical suggestion boxes). Conducting regular short meetings of "environmental ambassadors" to discuss problems and exchange best practices. Publishing reports on improvements implemented based on employee suggestions. | Involving personnel in the optimization process increases their loyalty to the program. Ensuring the rapid adaptation of the system to real production conditions and eliminating "bottlenecks." |

The system of recommendations presented in the table is based on a comprehensive approach that addresses four key aspects of human behavior in an organization: knowledge, motivation, leadership, and involvement.

**Conclusion**

Thus, building an effective industrial waste sorting system is a complex task that extends beyond the simple acquisition of equipment. The characterized process requires a strategic approach based on deep analysis, technological integration, logistical optimization, and active personnel involvement. The shift from perceiving waste as an unavoidable cost to viewing it as a valuable resource serves as a "core" of the modern industrial paradigm. Enterprises that successfully implement the principles discussed in the article reduce their environmental impact and gain a tangible competitive advantage by reducing costs and creating new sources of revenue, thereby taking a confident step toward a circular economy model.

Forming a culture of responsible waste management is not a set of disparate activities, but the purposeful construction of a holistic ecosystem within the company. The author-developed recommendations are presented through the prism of this vision. Technology and equipment create the potential for effective sorting, but only involved, trained, and motivated personnel can realize this potential with the greatest return. Investments in the "human factor" through education, motivation, leadership, and feedback are no less significant than investments in automated lines. Ultimately, it is the synergy of advanced technological developments and a high organizational culture that allows for the achievement of the strategic goal—transforming waste from a problem into a valuable resource and building a truly sustainable production.

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