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# Management and economic planning of waste collection and transportation using WAGS Software: A case study of the Ports and Maritime Department of Guilan Province, Northwest Iran

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## ABSTRACT

Effective waste management is a crucial component of sustainable development due to its significant role in environmental preservation. Given that a substantial portion of waste management expenditures is allocated to collection and transportation, strategic planning and efficient management can significantly enhance system performance and reduce unnecessary costs and time delays. This study evaluates the application of the WAGS software—a managerial-economic tool comprising 40 primary variables and 16 default parameters—for the optimization of waste collection and transportation systems over a 15-year period. The case study focuses on the Ports and Maritime Department of Guilan Province, Northwest Iran which covers an area of 142 hectares and serves a population of 6,700. Waste sampling was conducted three times per month throughout 2017 at various collection points across the port. Each sample was weighed, separated into categories (organic, plastic, metal, paper, etc.), and analyzed for moisture content and density. The software facilitated the assessment of key resource requirements including supplies, equipment maintenance, personnel, and fuel. Findings indicate that in 2017, the total cost of waste collection and transportation was approximately 5,850 million Rials. Projected costs for the next 15 years amount to 11.162 billion Rials, with machinery procurement accounting for the highest share. Capital distribution was as follows: machinery (49%), manpower (28%), fuel (14%), and maintenance (9%). The study proposes an optimized model for organizing and managing waste systems in port environments.

**Keywords:** Waste management, WAGS software, Collection and transportation, Port authority, Economic planning.
**Article type:** Research Article.

## INTRODUCTION

In recent decades, the volume of industrial waste has increased substantially in tandem with technological advancement (Mokhtarani *et al.* 2006). Efficient waste management has emerged as a priority in developing countries to address rapid economic growth and rising population levels. It plays a critical role in ensuring environmental sustainability and public health (Jin *et al.* 2006; Bakhshi *et al.* 2025). The quantity and composition of waste are influenced by diverse factors including climatic conditions, seasons, geographic location, and socio-economic and cultural parameters (Nahman & Godfrey 2010). Among the most pressing challenges for sustainable development is the management of solid waste systems, which serve as a cornerstone for resolving waste-related constraints (De Vega *et al.* 2008). Modern waste management involves the implementation of suitable technologies and planning methods to meet specific objectives. The current waste management paradigm emphasizes the full lifecycle of waste, from generation to final disposal. This includes: (i) generation and storage, (ii) waste reduction and pollution prevention, (iii) material recovery and recycling, (iv) collection and transportation, (v) treatment, and (vi) disposal (Tchobanoglous *et al.* 1993). Industries are major generators of waste and are considered critical indicators of national development. As each production process results in residual and non-recyclable waste, the variety and volume of such waste pose significant environmental risks (Sadeghi *et* *al.* 2009). Therefore, industrial waste management is a pivotal issue in the broader context of global environmental protection (Xiumin 2010). The absence of a robust waste management infrastructure—due to political, social, cultural, and economic complexities—can have detrimental effects on public health and natural resources (Abdoli & Hasanian 2013). In coastal regions, waste management is fundamental to the protection and restoration of marine ecosystems. It involves systematic, sanitary, and engineering-based procedures for handling waste (Abduli *et al.* 2011). Despite notable advancements over the past three decades, these improvements have been limited to a small number of countries and fail to address broader environmental concerns. Coastal and marine degradation continues unabated and, in many cases, is worsening (UNEP 2005). Iran possesses an extensive coastline—922 km along the Caspian Sea in the north and 2,530 km along the Persian Gulf and the Oman Sea in the south. In many developing nations, coastal pollution remains one of the most critical threats to fragile marine ecosystems (Abduli *et al.* 2008). The International Convention for the Prevention of Pollution from Ships (MARPOL) provides a comprehensive legal framework for managing ship-generated waste. Its six annexes address various types of pollution, including oil, noxious liquids, harmful packaged substances, sewage, and air emissions. According to this convention, ports, oil/gas terminals, and shipyards are required to provide adequate waste reception and treatment facilities without hindering maritime operations (Butt 2007). Establishing efficient waste collection and disposal systems is essential for regulating material production and consumption. Rising per capita waste generation, limited land for landfilling, and increasing costs for equipment and personnel necessitate innovative scientific and economic approaches to waste management.

## MATERIALS AND METHODS

### Study area

The Ports and Maritime Department of Guilan Province—referred to as Anzali Port—occupies 142 hectares and is situated approximately 44 km southwest of the provincial capital, on the southern coast of the Caspian Sea. The port is equipped with comprehensive infrastructure and superstructure, including 10 operational berths capable of handling diverse cargo types such as timber, bulk goods, grains, and steel products. Consequently, it generates both domestic and industrial waste. Fig. 1 shows the geographical location of Anzali Port within Guilan Province and the Caspian Sea.

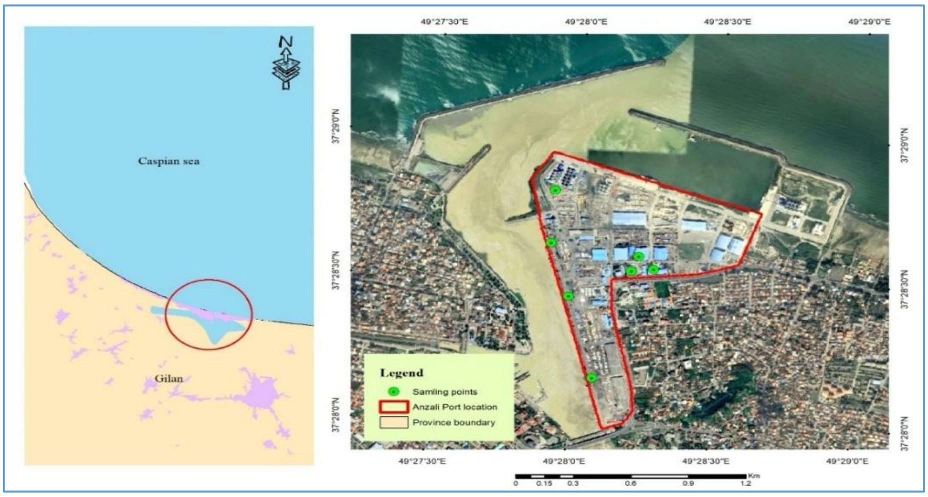



**Fig 1.** Location of Anzali Port and sampling locations.

### Methodology

This cross-sectional study was conducted in 2017 at major operational sites within Anzali Port. The research employed WAGS software, a specialized tool designed for optimal management of waste collection systems. The WAGS software comprises 40 input variables and 16 default parameters, grouped into five modules: demographic, waste generation, site characteristics, equipment, and cost analysis. The software integrates operational, economic, and environmental indicators to optimize waste collection and transportation efficiency. Input data include population, per capita generation, vehicle capacity, and workforce availability. The software outputs predicted waste quantities, collection schedules, and resource requirements. Demographic data were sourced from the Anzali Ports Authority. Additional information on infrastructure, operational characteristics, and cost parameters were obtained through collaboration with Anzali Municipality, the Recycling Organization, the Department of

Labor and Social Affairs, and via field surveys and direct observation. Data on waste quantity and composition were primarily drawn from reports by the Recycling Organization. To ensure accuracy, one year of waste sampling was conducted and compared against organizational records. Monthly samples were collected three times per month. All waste produced in the area was weighed and analyzed for per capita generation prior to its transfer to Sangachin landfill in Anzali City. A designated truck of known volume was used to determine waste density. The truck's empty weight was subtracted from its loaded weight, and the resulting waste mass was divided by truck volume to calculate density. The prediction of municipal solid waste generation in Anzali Port up to 2031 was performed using the *WAGS software forecasting module*. This module applies a compound annual growth model based on population and per capita waste generation trends. Per capita waste generation was assumed to follow a linear trend derived from 2017 field sampling data. Key predictors include population growth, historical waste generation, and infrastructure expansion factors. Sensitivity analysis was conducted by adjusting population growth and per capita generation ± 5% to validate model stability. The WAGS model was calibrated by adjusting parameters such as collection efficiency, vehicle loading rate, and manpower productivity to match observed 2017 operational data.

## RESULTS

The WAGS software produces seven primary outputs based on input data, each described as follows:

### General information output

The analysis showed that the total time required for collecting waste from the port and transporting it to the Sangachin Disposal Site by mini truck (round trip) is approximately 240 minutes. The compacted volume of waste in the collection machine is 3.5 $m^3$, with a maximum load capacity of 2 tons. The truck’s operational efficiency in collecting and transferring waste is estimated at 90%, and its expected lifespan in Anzali Port is 7 years.

### Prediction of waste production

In 2017, the total number of permanent staff, passengers, and ship crew using the port was 6,700 individuals. The per capita waste generation was recorded at 1,250 g $day^{-1}$. Accordingly, the estimated daily waste generation was 8.5 tons, leading to a total of approximately 3,057 tons annually. Table 1 displays the yearly increase of waste quantity, density, and volume from 2017 to 2031. Figs. 2 to 5 illustrate trends in population growth, daily per capita waste generation, total annual waste production, and changes in waste density, respectively.

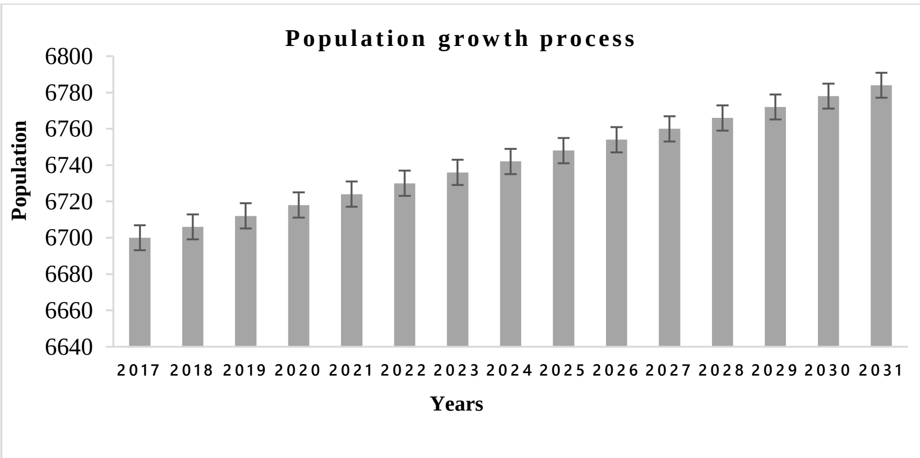



**Fig. 2.** Population growth.

### Estimation of required machinery

Mini trucks are used at Anzali Port to transfer waste to Sangachin Disposal Facility. Based on vehicle capacity and projected waste volumes, Table 2 outlines the estimated number of trucks required from 2017 to 2031.

### Forecasting of required assets to acquire machinery

In 2017, a total of 2.7 billion Rials was invested in purchasing six waste-collection vehicles. Future capital investment requirements for fleet expansion are shown in Table 3 and Fig. 6.

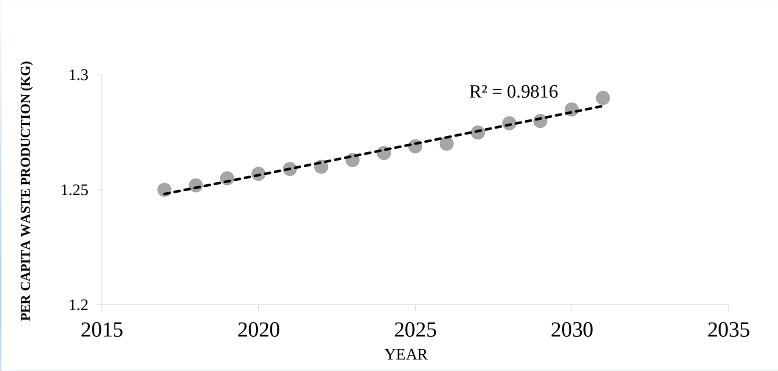



**Fig. 3.** Per Capita Waste Generation (kg day[-1]).

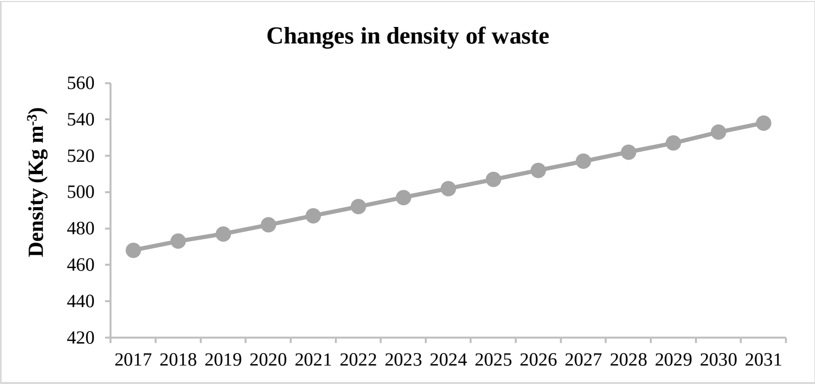
**Table 1.** Predicted Waste Volume and Characteristics (2017–2031).

| Year | Population | Compressed | | Normal | | Weight (Ton) | Per capita waste production (Kg) |
|---|---|---|---|---|---|---|---|
| | | Volume ($m^3$) | Density (Kg $m^{-3}$) | Volume ($m^3$) | Density (Kg $m^{-3}$) | | |
| 2017 | 6700 | 7859 | 389 | 6532 | 468 | 3057 | 1.25 |
| 2018 | 6706 | 7811 | 392 | 6474 | 473 | 3062 | 1.252 |
| 2019 | 6712 | 7765 | 395 | 6430 | 477 | 3067 | 1.255 |
| 2020 | 6718 | 7699 | 399 | 6373 | 482 | 3072 | 1.257 |
| 2021 | 6724 | 7638 | 403 | 6320 | 487 | 3078 | 1.259 |
| 2022 | 6730 | 7575 | 407 | 6266 | 492 | 3083 | 1.26 |
| 2023 | 6736 | 7532 | 410 | 6213 | 497 | 3088 | 1.263 |
| 2024 | 6742 | 7471 | 414 | 6161 | 502 | 3093 | 1.266 |
| 2025 | 6748 | 7414 | 418 | 6112 | 507 | 3099 | 1.269 |
| 2026 | 6754 | 7355 | 422 | 6067 | 512 | 3104 | 1.27 |
| 2027 | 6760 | 7315 | 425 | 6014 | 517 | 3109 | 1.275 |
| 2028 | 6766 | 7259 | 429 | 5966 | 522 | 3114 | 1.279 |
| 2029 | 6772 | 7206 | 433 | 5920 | 527 | 3120 | 1.28 |
| 2030 | 6778 | 7151 | 437 | 5863 | 533 | 3125 | 1.285 |
| 2031 | 6784 | 7098 | 441 | 5818 | 538 | 3130 | 1.29 |


**Fig. 4.** Annual waste production.

**Estimation of required asset for human resources**

Table 4 outlines the staffing and associated costs for drivers, labours, and administrative personnel. From 2017 to 2031, manpower expenses increase from 1.74 billion Rials to 2.88 billion Rials, as shown in Fig. 7.

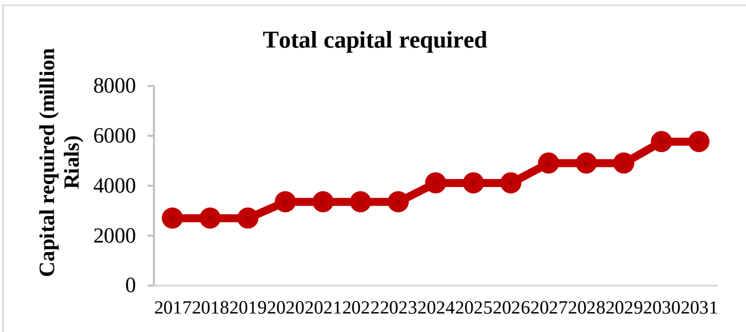



**Years**

**Fig. 5.** Waste density trends.

**Table 2.** Estimated annual truck requirements.

| Year | Number of purchases required per year | Total number of vehicles required |
|---|---|---|
| 2017 | 6 | 6 |
| 2018 | 0 | 6 |
| 2019 | 0 | 6 |
| 2020 | 1 | 7 |
| 2021 | 0 | 7 |
| 2022 | 0 | 7 |
| 2023 | 0 | 7 |
| 2024 | 1 | 8 |
| 2025 | 0 | 8 |
| 2026 | 0 | 8 |
| 2027 | 1 | 9 |
| 2028 | 0 | 9 |
| 2029 | 0 | 9 |
| 2030 | 1 | 10 |
| 2031 | 0 | 10 |




**Years**

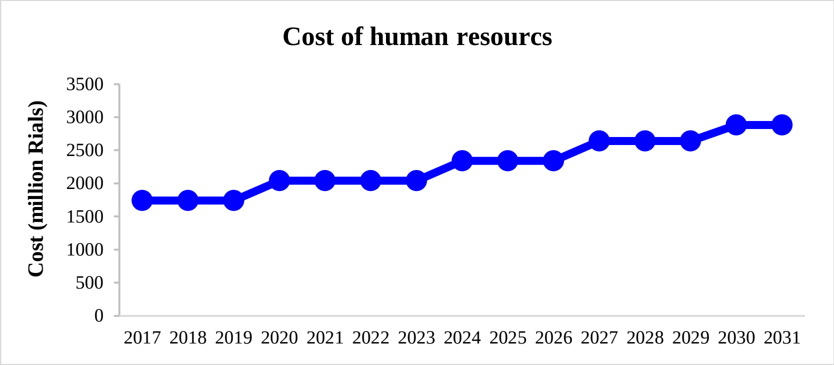
**Fig. 6.** Capital investment trend (2017–2031).

**Table 3.** Annual capital requirement for vehicle procurement.

| Year | Total capital required (million Rials) | Annual capital requirement (million Rials) |
|---|---|---|
| 2017 | 2700 | 2700 |
| 2018 | 2700 | 0 |
| 2019 | 2700 | 0 |
| 2020 | 3350 | 650 |
| 2021 | 3350 | 0 |
| 2022 | 3350 | 0 |
| 2023 | 3350 | 0 |
| 2024 | 4100 | 750 |
| 2025 | 4100 | 0 |
| 2026 | 4100 | 0 |
| 2027 | 4900 | 800 |
| 2028 | 4900 | 0 |
| 2029 | 4900 | 0 |
| 2030 | 5760 | 860 |
| 2031 | 5760 | 0 |

**Table 4.** Human resource costs and staffing levels.

| Year | Number of drivers and workers | Total cost (million Rials) |
|---|---|---|
| 2017 | 12 | 1740 |
| 2018 | 12 | 1740 |
| 2019 | 12 | 1740 |
| 2020 | 14 | 2040 |
| 2021 | 14 | 2040 |
| 2022 | 14 | 2040 |
| 2023 | 14 | 2040 |
| 2024 | 16 | 2340 |
| 2025 | 16 | 2340 |
| 2026 | 16 | 2340 |
| 2027 | 18 | 2640 |
| 2028 | 18 | 2640 |
| 2029 | 18 | 2640 |
| 2030 | 20 | 2880 |
| 2031 | 20 | 2880 |




**Years**

**Fig. 7.** Managerial and other human resources related expenses.

**Forecasting of fuel and maintenance costs**

Fuel and maintenance costs from 2017 to 2031 are presented in Table 5 and illustrated in Fig. 8. These elevations reflect gradual cost increases in both fuel and maintenance due to fleet aging and operational expansion.

**Table 5.** Fuel and maintenance cost forecast.

| Year | Total maintenance cost (million Rials) | Total fuel cost (million Rials) | Total (million Rials) |
|---|---|---|---|
| 2017 | 540 | 870 | 1410 |
| 2018 | 570 | 875 | 1445 |
| 2019 | 570 | 880 | 1450 |
| 2020 | 630 | 1020 | 1650 |
| 2021 | 640 | 1022 | 1662 |
| 2022 | 650 | 1025 | 1675 |
| 2023 | 660 | 1025 | 1685 |
| 2024 | 720 | 1165 | 1885 |
| 2025 | 750 | 1168 | 1918 |
| 2026 | 760 | 1170 | 1930 |
| 2027 | 810 | 1314 | 2124 |
| 2028 | 830 | 1316 | 2146 |
| 2029 | 850 | 1318 | 2168 |
| 2030 | 900 | 1450 | 2350 |
| 2031 | 920 | 1460 | 2380 |

**Estimation of total costs**

Table 6 summarizes the total cost projections across four major categories: capital investments, human resources, fuel, and maintenance. Fig. 9 visualizes the relative share of each category. Capital investment and manpower represent the largest portions of the budget, while maintenance has the smallest share.

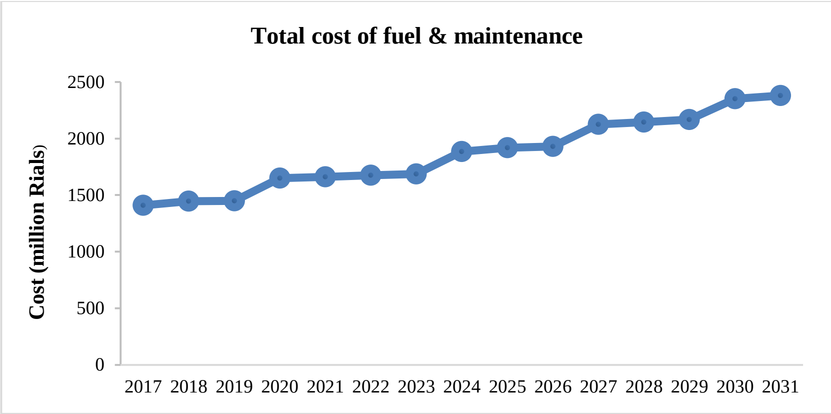



**Fig. 8.** Asset requirements for fuel and maintenance.

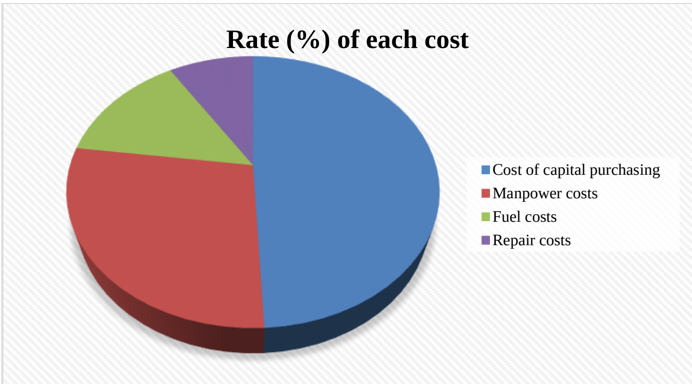



**Fig. 9.** Budget distribution by cost category.

**Table 6.** Total cost forecast (2017–2031).

| Year | Capital purchasing (Million Rials) | Manpower costs (Million Rials) | Fuel costs (Million Rials) | Repair costs (Million Rials) | Total cost (Million Rials) |
|---|---|---|---|---|---|
| 2017 | 2700 | 1740 | 870 | 540 | 5850 |
| 2018 | 2700 | 1740 | 875 | 570 | 5885 |
| 2019 | 2700 | 1740 | 880 | 570 | 5890 |
| 2020 | 3350 | 2040 | 1020 | 630 | 7040 |
| 2021 | 3350 | 2040 | 1022 | 640 | 7055 |
| 2022 | 3350 | 2040 | 1025 | 650 | 7065 |
| 2023 | 3350 | 2040 | 1025 | 660 | 7075 |
| 2024 | 4100 | 2340 | 1165 | 720 | 8325 |
| 2025 | 4100 | 2340 | 1168 | 750 | 8358 |
| 2026 | 4100 | 2340 | 1170 | 760 | 8370 |
| 2027 | 4900 | 2640 | 1314 | 810 | 9664 |
| 2028 | 4900 | 2640 | 1316 | 830 | 9686 |
| 2029 | 4900 | 2640 | 1318 | 850 | 9708 |

| | | | | | |
|---|---|---|---|---|---|
| 2030 | 5760 | 2880 | 1450 | 900 | 10990 |
| 2031 | 5760 | 2880 | 1460 | 920 | 11020 |
| Total | 60020 | 34080 | 17078 | 10800 | 121978 |

**DISCUSSION**

This study utilized WAGS software to systematically evaluate current and future solid waste management needs at Anzali Port from 2017 through 2031. The results revealed critical insights into waste generation patterns, infrastructure demands, and financial planning necessary to sustain efficient waste collection and transport operations in a port environment. The daily per capita waste generation in the study area was calculated at 1,250 g $day^{-1}$, which is relatively high compared to typical urban averages in Iran, commonly ranging between 800–1,100 g $day^{-1}$. This elevated rate can be attributed to the unique functional nature of port areas, characterized by high human activity density, transient populations, and specialized industrial operations. Although the projected increase in total waste generation from 3,057 tons in 2017 to 3,130 tons in 2031 appears moderate, the operational and logistical requirements to manage this rise are substantial. For instance, the number of required waste collection trucks increases from six to ten over the study period, necessitates capital investments and adjustments in workforce and operational planning. Vehicle procurement alone is expected to require over 5.7 billion Rials in capital by 2031. Additionally, maintenance and fuel costs nearly double, reflecting the impact of fleet aging and operational expansion. Previous research on urban waste collection and transportation (e.g., Hekmatnia *et al.* 2016; Andik *et al.* 2017) confirms that human resources and machinery procurement represent the largest components of municipal waste budgets—findings consistent with this study. However, the results contrast with studies conducted in Greece (Chalkias & Lasaridi 2009), where fuel expenses exceeded equipment costs. This difference may be attributed to lower machinery costs and higher fuel prices in those countries compared to Iran. Labor costs also exhibit a significant upward trend, increasing from 1.74 billion Rials in 2017 to 2.88 billion Rials in 2031. This rise not only correlates with population and waste volume growth but also emphasizes the importance of human resources in the sustainability of waste management systems. These findings suggest the need for improved labor productivity, ongoing training, and retention strategies to maintain operational efficiency. Importantly, the system's current operational efficiency—estimated at 90%—is commendable. However, the sustainability of this level depends heavily on regular fleet renewal, adequate maintenance, and investment in human capital. The increasing costs for vehicle repairs and maintenance observed over time further underscore the need for strategic asset management. When compared to prior research by Majlesi *et al.* (2013), which introduced the WAGS model, the present study advances the application of this tool by integrating longitudinal projections, empirical data validation, and inter-agency data synthesis. The combination of monthly sampling and verification against official records enhances the reliability of the findings and contributes to a robust forecasting framework. According to the abovementioned issues, it can be concluded that the first and most important step to reduce the production of waste by producers is to reduce costs. Process of waste production reduction consists of three main steps: (i) Refusing purchase (using high quality, non-disposable products with appropriate packaging); (ii) Reducing purchase (purchasing as much it is needed); (iii) Reusing the products. Also, manpower costs by mechanizing the collection system and fuel cost by improving the condition of machinery and their maintenance can be reduced and also the latter can improve the life expectancy of vehicles.

**Limitations**: Despite its strengths, the study is not without limitations. The forecasts assume relatively stable population growth and constant per capita waste generation, which may not hold true given potential demographic shifts, policy changes, or technological advances in waste reduction and recycling. Moreover, macroeconomic fluctuations, inflation, and unforeseen infrastructure developments could significantly affect the accuracy of cost predictions. Seasonal variations and the impact of tourism, which may be significant in a port city like Anzali, were not fully captured in the sampling design.

**Conservation implications**

Increasing the system efficiency in order to carry out comprehensive studies on recognizing the capabilities of waste collection systems and equipment appropriate to the physical, social, and economical structure of the region. To study, design, and optimize the equipment and machinery are required for mechanized and semi-mechanized collecting systems.

Establishment of a continuous monitoring and control system for materials and waste management.
Enhancement of the staff's awareness to reduce waste production by training courses.
Encouragement of regional staff to participate in waste recycling.
Compensation of portion of costs by selling recyclable wastes.

**CONCLUSION**

Overall, this study provides a valuable planning framework for port-based municipal waste management. The findings can inform strategic decision-making in terms of fleet investment, human resource planning, and cost allocation. Future studies are encouraged to incorporate adaptive models that account for dynamic variables such as climate change, economic trends, and behavioral shifts in waste generation. Additionally, greater emphasis should be placed on waste minimization, recycling initiatives, and public awareness to enhance long-term sustainability.

According to the obtained information, the following outcomes are observed:

Ports and Maritime Department of Guilan Province needs to purchase machinery with a worth of 60.02 billion Rials for the next 15 years to collect and transport solid waste. This is equal to 49% (the highest portion) of the total budget required during these years. A sum of 2.7 billion Rials was paid in 2017, therefore, for the next 14 years, 5.732 billion Rials of investment still will be required. So, in average, a new waste collection vehicle needs to be purchased every 3 years which means essential arrangements and proper planning to be carried out for fund absorption.

Required fund for manpower (including the salaries of employees, drivers, and their management) during the 15-year period is 3.408 billion Rials. An amount of 1.74 billion Rials is provided for 2017. Therefore, in the next 14 years, Anzali Municipality should provide a budget accounting for 3.234 billion Rials. Manpower costs consume 28% of the total fund of solid waste collection and transportation.

The cost of fuel over the next 15 years is 1.708 billion Rials, of which 0.87 billion Rials are paid in 2017 and 1.621 billion Rials is still required for the next 14 years. In total, it is estimated that over the next 15 years, fuel costs (if remains constant) will be 14% of the total budget.

The cost of maintenance and repairing of machinery by the end of 2031 is estimated to be 1.08 billion Rials, which is 9% of the total estimated budget over the next 15 years.

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