EVALUATION OF KEY INDICATORS OF WASTE COLLECTION VIA GIS TECHNIQUES AS A PLANNING AND CONTROL TOOL FOR ROUTE OPTIMIZATION

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Abstract

Municipal Solid Waste (MSW) collection and disposal, especially in the context of developing countries, has become more complex in terms of logistics, fuel and labour costs. How to collect and dispose of the increasing amounts of MSW has become a hot topic, due to the fact that the existing MSW collection systems still use up to two thirds of the total budget for a municipality's waste disposal operations. It is therefore crucial to optimize the routing network used for waste collection.

This paper presents the results of a study funded by the German Society for International Cooperation (GIZ) GmbH for estimating the key indicators of domestic waste collection as a planning and control tool for route optimization, including tracking the overall operational cost for solid waste collection. In this study, a methodology for the optimization of the waste collection and transport system, based on a Geographical Information System (GIS), was developed. Using domestic collection round data from three waste collection cities in Jordan (Irbid, Mafraq and Karak), three scenarios for waste collection were suggested. Cost analysis has been performed for each suggested scenario and compared with the current empirical collection scheme. Results demonstrate that the proposed scenarios' savings compared to the current situation in terms of the total cost for waste collection are 15%, 13% and 23% for scenarios 1, 2 and 3, respectively, in the city of Irbid and 6%, 3% and 8% for scenarios 1, 2 and 3, respectively, in the city of Karak. Although using the alternative scenarios was shown to provide significant savings, the operating time of the vehicles was reduced by 30%.

Keywords

Municipal Solid Waste (MSW), Geographical Information System (GIS), Collection, Transportation, Route optimization, Cost analysis.

1. Introduction

The rapid and constant growth in the urban population has led to a dramatic increase in municipal solid waste (MSW) generation, with a crucial socio-economic and environmental impact. MSW management is a multidisciplinary activity that includes generation, source separation, storage, collection, transfer and transportation, processing and recovery, and, last but not least, disposal [1- 3]. In order to develop a sound material-cycle society, a cost-effective integrated MSW management system is required for the municipalities [4, 5].

Solid waste collection is a major part of the process of solid waste management (SWM) and it is estimated to consume up to two thirds of the entire SWM budget. Typically, depending on geographical location and fuel price, the figure can reach 80–90% and 50–80% of a MSW management budget in low income and middle income countries, respectively. Fuel consumption plays a dominant role in the costs of MSW management systems [6-8].

The functional element of collection addresses MSW from its generation at the source until its final disposal location, including all the operations in between [9]. This location may be a materials-processing facility, a transfer station, or a landfill disposal site. Collection of solid waste in an urban area is difficult and complex because the generation of waste takes place in every house, apartment, commercial and individual facility, as well as in the streets, parks, and even vacant areas [10]. Therefore, in any waste collection operation, it is important to look into: types of waste collection services/systems, type of equipment to be used and associated labour requirements and collection routes.

Once equipment and labour requirements have been determined, collection routes must be laid out so that both collectors and equipment are used effectively. There is no universal set of rules that can be applied to all situations [9]. Nowadays, most of the developing countries in the world, of which Jordan is one, are currently in the process of urbanization and industrialization, resulting in the augmentation of various types of wastes that leave a burden on both the municipality's infrastructure and the community. According to the Department of Statistics (DoS) of Jordan, the growth rate was 1.78% in 2011 and will decrease to 1.27% in 2022. We have considered a conservative assumption of 2% per year for MSW generation, in order to consider the population growth and a potential increase in waste production per capita. Assuming this 2% yearly increase in MSW generation, it should reach more than 3,000 tons/day by 2030, i.e. a 50% increase in the next 20 years [11, 12]. Therefore, MSW collection and disposal, especially in the context of developing countries, are indeed the urgent requirements for the sustainable development of waste management systems. Additionally, optimizing MSW collection in those countries has a considerable impact in terms of the environment, landscape developments and economic savings. Currently, optimizing collection services is still dependent on the knowledge of local conditions such as one-way streets and road construction by the collection teams. Therefore, many studies have been carried out globally to overcome the MSW collection problem on localized scales [13].

The review of literature shows the popularity of the Geographical Information System (GIS) for the route optimization studies. GIS is a suitable tool for these kinds of study as it is capable of storing, retrieving and analysing a large amount of data as well as outputs visualization in a reasonable duration [9, 14]. Fundamentally, the GIS tool has been found to play a potential role for solving various types of engineering and management problems in siting of waste disposal sites. GIS enables the development of a multi-objective model for collection vehicle routing and scheduling for SWM systems, such as generation of optimal routing (reduction of travel time), distribution of collection bins, load balancing of vehicles, and generation provides a data bank for future monitoring [9, 15].

Route optimization of solid waste as a management sphere has not yet been used in Jordanian municipalities and the existing waste collection systems are developed based on limited data. As such, an effective and integrated SWM system that will consolidate routes; reduce the distance travelled, time and cost; balance the distribution of waste collection in all the districts, and ensure equitable involvement of all assigned vehicles in waste hauling is needed, not only to reduce the costs of waste disposal but also to keep the city environment in good order. The main objective of this study was to estimate the key indicators via GIS techniques as a planning and control tool to optimize the routing network used for waste collection and transportation to the landfill or/and transfer station. This includes tracking and analysing the overall operational cost (vehicles and staff) for solid waste collection and transportation. A further objective was to determine the best scenarios for waste collection with regard to travel distance and time as well as cost. As a consequence, this will reduce the total costs of waste management and the negative environmental impact of waste in Jordan's cities.

2. Study area and existing waste management system

Part of Jordan including three cities, namely Irbid, Mafraq and Karak, were selected as a pilot study. In this context, Jordan is home to 7.3 million inhabitants in a surface area covering around 89,328 km^2, of which over 80 per cent is characterized by semi-desert conditions. Over two thirds of the growing population live in urban centres such as Amman, Zarqa and Irbid [16].

In Jordan, SWM is one of the most complex sectors due to the wide variety of solid waste types, which, in turn, involves many different competent entities depending on their relevant area of interest. Indeed, Jordan's environmental regulations are still basic. They only describe general responsibilities and principles and do not encourage the application of integrated SWM. Moreover, Jordan lacks a complete range of integrated practices in street cleaning, collection, transportation, transfer, treatment and disposal of MSW [16, 17]. However, the existing MSW collection system is considered to be adequate in urban centres, but services tend to be poor or non-existent in small towns and rural areas. This includes an absence of source separation and recycling. Some pilot projects have been launched, especially in Amman, for sorting the MSW at the source, as well as at final sorting plants, by non-governmental organizations (NGOs) and private companies. Yet, there are no particular standards or specifications for MSW management systems in Jordan. Currently, it is evident that the concern for safe and effective SWM has been steadily increasing, due to the political, demographic and economic conditions. This concern is more intense with regards to the management of MSW, mostly due to the directness of effects and impacts to the communities [18].

From a waste generation point of view, several studies have reported that the daily amount of MSW generated in Jordan was found to be about 6.680 million tons for the year 2011. Jordan generates per capita about 0.8–1.00 kg of MSW in the urban areas and 0.6–1.00 kg in rural areas. The major proportion of generated waste is composed of organic materials (50-60%) with 5-10% recyclable materials and 30-40% combustibles [16]. Up to 98% of generated waste is deposited directly, without any treatment, in landfills [16, 17]. Moreover, due to the crisis in Syria, the rapid increase in the population, estimated at 2.5 % per year, and the rise in community living standards have accelerated solid waste generation per capita in recent years [16]. Therefore, the large influx of refugees from neighbouring countries, the increase of per capita MSW generation rates, the impact of dumping MSW in non-engineered landfills, the gaps of current related legislation, as well as the absence of proper practices for MSW collection and management are the key challenges making this problem more complicated for the governmental bodies working on handling and managing the MSW.

The problem represents a measurable threat to the public health and environmental quality in the Kingdom and requires national attention of the highest priority and urgency. Consequently, a fresh look is required. There is a need for action. Logically, a new integrated MSW management system focusing on the overall MSW management cycle (street-cleaning, collection, transfer and transport, treatment and disposal) and supplemented by legal, organizational and institutional recommendations is required to ensure optimum results all over the Kingdom.

3. Methodology

The study was conducted during the second half of 2015, and took six months from June until December. Three cities, namely Irbid, Mafraq and Karak, were selected as a pilot scale study. In the three cities involved, as is the case in other Jordanian cities, there is no separation at source of MSW before collection and municipalities are responsible on a day-to-day basis for the collection and transportation of mixed household waste. Part of the collection of valuable materials such as cardboard and plastic is conducted by an informal sector and sold to local companies. Due to geographical area and population, the cities concerned in this study are divided into zones or districts for effective solid waste collection, which can be summarized as 25, 18 and 17 zones for Irbid, Mafraq and Karak, respectively. Collection of solid waste is carried out seven days per week by using suitable vehicles. It includes collection of residential area waste as well as bulky waste produced from industrial areas, shopping complexes and shops. Information related to the distribution of collection shifts has been stated by the human resource departments and the environmental directorates of the municipalities involved. These can be summarized as follows:

- Shift A (Early morning shift): 6:00 to 12:00, about 60-75% of the service,
- Shift B (Late morning shift): 12:00 to 18:00, about 10-15% of the service,
- Shift C (Evening shift): 18:00 to 00:00, about 10-20% of the service, focusing on commercial areas in all districts,
- Shift D (Night shift): 00:00 to 6:00, about 5-10% of the service, focusing on cardboard and sacks collection on commercial areas in all districts.

The MSW collection and cleaning services are carried out in four shifts in Irbid and Mafraq municipality, while the collection of solid waste is carried out in Karak municipality in three shifts. Three types of vehicles are used to manage solid waste, namely three-axle vehicles with a capacity of 12 m^3, two-axle vehicles with a capacity of 8 and 10 m^3 and small vehicles with capacity of 2–3 m^3.

The collection method is curbside collection for returnable bins of 1.1 m^3 spread throughout the entire city, so that the crews empty the containers into compaction vehicles prior travel to a disposal site. A typical solid waste collection crew consists of a driver and two loaders. The type of vehicle to be used depends on the type of collection bin and width of road. All of the municipalities' waste (residential and commercial/ industrial, and from both urban and rural areas) is disposed of in its own landfill, located some 34 km, 22 km and 30 km from the depots of Irbid, Mafraq and Karak municipalities, respectively.

The roads are wide enough to be used by the waste collection vehicles without any problems. However, in the city centre difficulties can arise in certain areas because of old and narrow streets. In these areas, waste is collected by the use of small vehicles with a capacity of 2–3 m^3 which is allocated for sacks and cardboard waste materials collection. All solid waste collected is transported directly to the abovementioned landfills, except in Irbid municipality, where around 80% of the solid waste collected is transported directly to the landfill and the remaining 20% is carried by small vehicles to the transfer station, which is located some 3 km from the Irbid municipality depot. Table 1 provides an overview of the waste collection routes analysed.

Table 1: An overview of the waste collection routes analysed.

Study area	Sampling distribution					
	Collection vehicle/ crew	**Shift A**	**Shift B**	**Shift C**	**Shift D**	**Total**
Irbid*	**3-axle**					
	Two persons	7	3	0	0	**10**
	2-axle					
	Two persons	12	6	1	1	**20**
	One person	3	4	1	1	**9**
	Small vehicle					
	Two persons	2	1	0	2	**5**
	One person	1	0	0	0	**1**
	Total	**25**	**14**	**2**	**4**	**45**
Mafraq	**3-axle**					
	Three persons	0	0	3	0	**3**
	Two persons	1	2	1	2	**6**
	2-axle					
	Two persons	10	5	2	0	**17**
	Total	**11**	**7**	**6**	**2**	**26**
Karak	**3-axle**					
	Two persons	2	0	1	0	**3**
	2-axle					
	Two persons	4	1	0	0	**5**
	Small vehicle					
	Two persons	6	0	0	0	**6**
	Total	**12**	**1**	**1**	**0**	**14**
Total routes analysed for the three cities						**87**
***** There were additional staff in collection areas (street workers)						

In order to efficiently manage the solid waste collection and transportation system as well as to trace the minimum distance for efficient collection paths for transporting the solid waste to the landfill or/and transfer station, GIS techniques were used to work out the collection routes. By using a GIS tool, the road network, landfill site and garage, container locations, container density per route, etc. were generated. Figure 1 illustrates an example of a collection route tracking with GIS data.

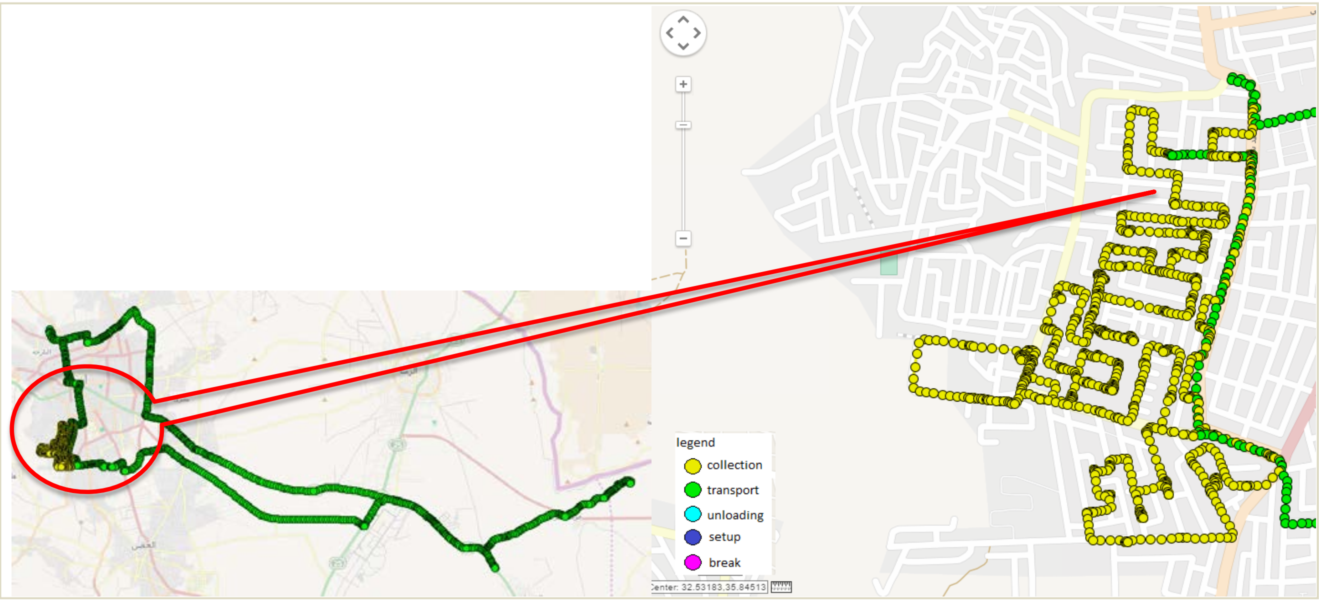


Fig. 1: A sample of one collection route tracking with GIS data.

Moreover, for more detailed investigations, the time spent at the containers for clearance of the waste, travel distances/ time between containers, collection/ transportation duration, transport distances/ time to disposal area, breaks/setup time, time spent at the landfill, etc. were also obtained, analysed and evaluated. Figure 2 shows an example of trip recorder analysis for evaluating the route tracking data.

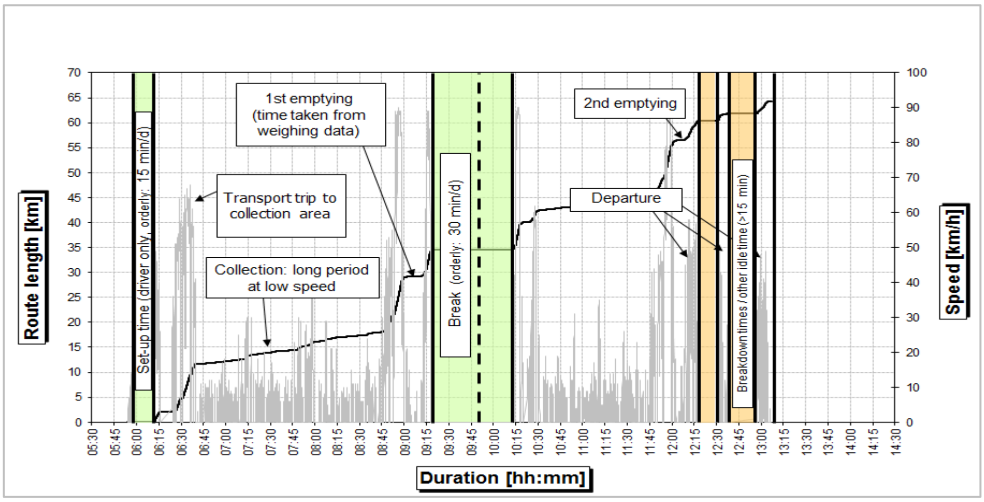


Fig. 2: Evaluation of route tracking data.

With a view to tracking the overall operating cost for the solid waste collection process, costs analysis was needed in this study. To this end, in order to obtain detailed operational information, a simple methodology was carried out which can be summarized as: collect cost data, collect operational data, analyse data and finally, report and follow-up. Table 2 summarizes the basis of calculation that has been touched upon and obtained during the project period in the study areas concerned.

Table 2: The basis of calculation that has been addressed during the study.

Basis of calculation	Data that has been analysed
Analysis of staff	➢ **number of employees** ▪ head of department ▪ observer ▪ driver ▪ loader ▪ street worker ➢ **personnel costs** ▪ monthly staff salaries ▪ overheads ▪ reserve
Analysis of vehicles	➢ **number of vehicles** ▪ vehicles for container collection ▪ vehicles for bulky waste ▪ vehicles for transfer station ▪ other vehicles ➢ **vehicle costs** ▪ capital cost ▪ fuel costs ▪ oil costs ▪ maintenance costs
Analysis of routes	➢ **number (container collection, bulky waste, transfer station)** ➢ **routes per day** ➢ **numbers of driver, loader and worker per vehicle and route**
Analysis of containers	➢ **number of containers** ➢ **container costs** ▪ capital cost ▪ maintenance cost

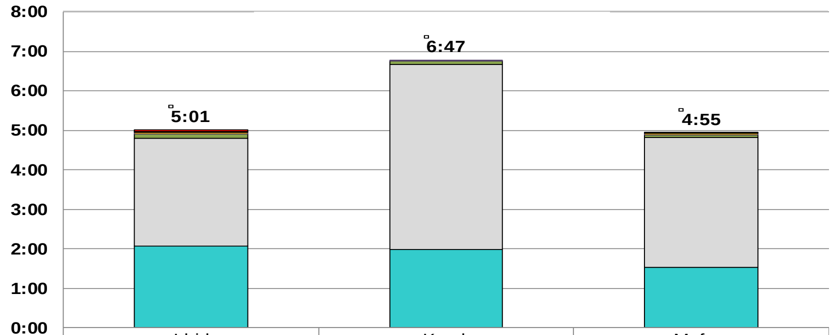
4. Results and discussion

Three cities were defined to carry out this study, namely Irbid, Mafraq and Karak. Returnable collection bins with capacities of 1.1 m^3, cardboard and sacks are considered in the calculations. Some of the collection points comprise more than one bin. All three allocated types of vehicles (three and two-axle compaction trucks, small vehicles) start a trip at the garage, collect the waste from the returnable bins at predefined locations and move towards the final destination (landfills for three and two-axle compaction trucks and transfer station for small vehicles), making a closed loop circuit. Only one landfill and one garage at each city were set out for the present study.

4.1 Evaluation of key indicators of waste collection

The experimental results obtained were based upon supportive field data on waste collection statistics of the three cities such as, daily work time utilization; containers emptied per route and per vehicle; container filling level; time spent to empty the containers (S/Cu); payload per route; vehicle payload utilization (%) and distance travelled per route.

One of the most important objectives of this study is to reduce the operating time of the vehicles compared to the amount of transported waste. To this end, the required time for waste collection and transportation was estimated. On the basis that the average daily working time in Irbid and Mafraq cities was five hours per day and seven hours per day in Karak city, as shown in figure 3, results revealed that the time spent to transport waste was very high in the three cities; 41%, 29% and 24% of the daily working time in Irbid, Mafraq and Karak, respectively. Moreover, the time spent in waste collection, depending on the amount of waste collected and distance travelled, was also very high; 49%, 70%, 68% of the daily working time in Irbid, Mafraq and Karak, respectively. Therefore, there is usually one disposal trip per shift. Also, the long time for waste haulage in turn results in an unbalanced utilization of the collecting routes (working time, container units per route, tonnage per route). With reference to the abovementioned, the usage/ renewal of the transfer station would be the most optimal solution.



	Irbid	Kerak	Mafraq
Actual working time	5:01	6:47	4:55
Standstill	0:03	0:00	0:00
Break	0:00	0:00	0:00
Set up time	0:02	0:02	0:02
Unloading	0:06	0:05	0:04
Collection	2:43	4:40	3:18
Transport	2:04	1:58	1:31

Fig. 3: Daily work time utilization in the study areas [h/d].

From the vehicles' payload point of view, three types of vehicles were used to manage solid waste, namely three-axle vehicles with a capacity of 12 m^3, two-axle vehicles with capacities of 8 and 10 m^3 and small vehicles with a capacity of 2–3 m^3. In the city of Irbid, as set out in figure 4, the results have shown good payload utilization for all vehicles that were used. By contrast, in Mafraq city, the utilization of the vehicles' payload was bad and there is an urgent need for improvement. Regarding Karak city, due to its good payload utilization, it can be concluded from the results that the use of two-axle vehicles (8 and 10 m^3) would be the most viable.

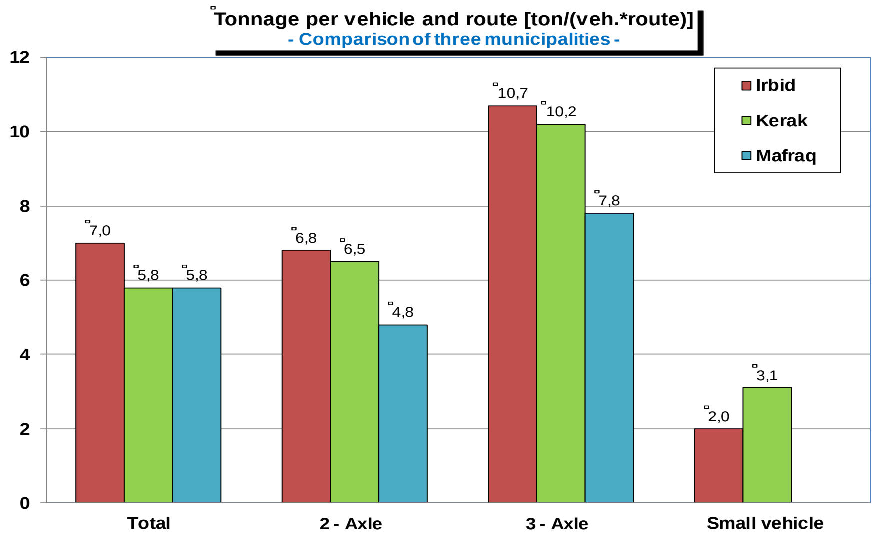


Fig. 4: Tonnage per vehicle and route [ton/ (veh. route)].

The amount of returnable collection containers, cardboard and sacks collected per vehicle type and route was also estimated. In order to determine the collection unit amount per vehicle and route the following weighting factors have been developed:

2-wheel containers: factor 1

4-wheel containers: factor 4

Sacks and cardboard: factor 0.25

In the city of Karak, a good performance in terms of the number of waste containers collected per unit (305 units) was observed. The container units collected per vehicle and route are illustrated in Figure 5.

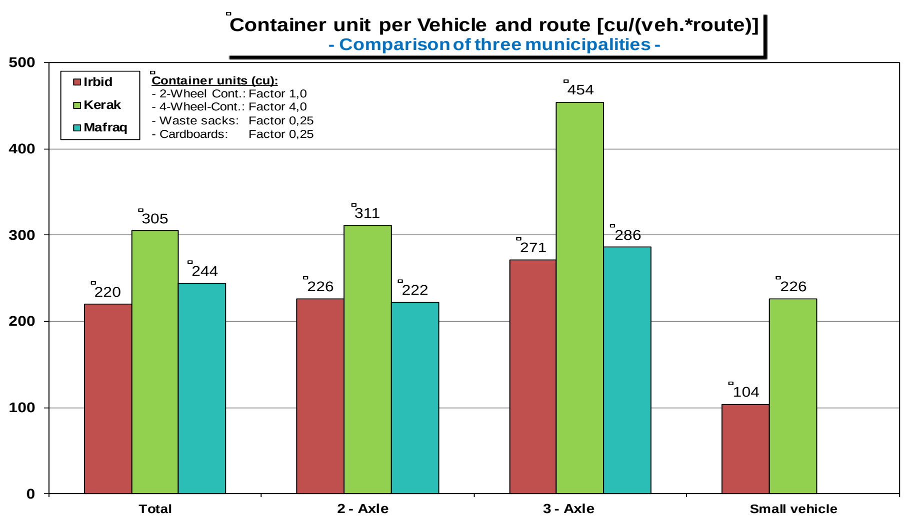


Fig. 5: Container unit per vehicle and route [cu/ (veh. route)].

In the same framework, the container filling ratios for Irbid, Mafraq and Karak were 97%, 92% and 85%, respectively. Therefore, despite the fact that Karak has the highest number of containers that have been collected and also the highest daily working time (7 h/d), the city of Irbid still occupies the forefront in terms of the amount of waste collected followed by the city of Mafraq.

In order to determine the best performance among the three cities concerned, a comparison between the experimental results obtained from those cities was conducted in terms of the total amount of collected waste, containers collected per vehicle and route, utilization of vehicles; payload, travelling distances and the operational time. Despite insufficient daily working time in Irbid (5 h/d), the experimental results have shown that the city of Irbid has the best performance regarding managing the solid waste collection services. Figure 6 shows the performance of the three study areas.

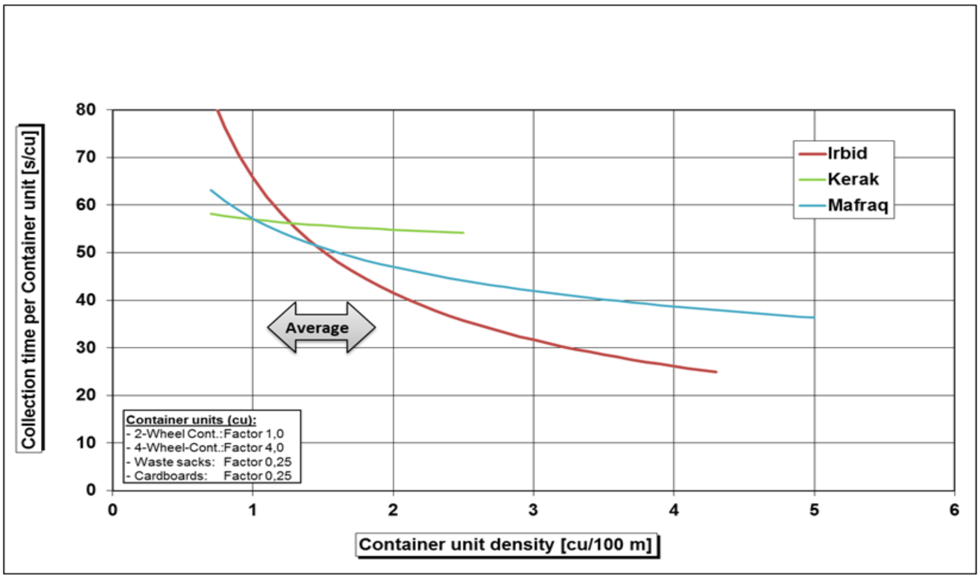


Fig. 6: The waste collection services performance of the three cities concerned.

4.2 Evaluation of key indicators of operational cost

Tracking the overall operational cost for solid waste collection and transportation was one of the main goals of this study. Thus, costs analysis in terms of solid waste collection and transportation staff (staff type, amount and salaries) and vehicles (number of vehicles, capital costs, fuel cost, oil cost and maintenance) were estimated. Detailed data were obtained from the three cities concerned. The data included existing staff, number of staff needed per route and their salaries per month, year and route. Table 3 provides an overview of the staff who carry out the waste collection services and the associated costs in Jordanian dinars (1 € is about 0.70 JD).

Table 3: The existing staff involved in waste collection services and the associated costs.

Study area	Job Title	Number of staff	Number of staff needed/ route	Monthly Salary in JD ***	Personnel cost for one route in JD	Personnel cost in %
Irbid*	**Head of Department**	25	0.3	508.50	5.15	3
	An observer	173	1.8	395.50	27.70	19
	Drivers (incl. reserve)	107	1.1	395.50	17.06	12
	Loader	190	2.0	339.00	26.08	18
	Workers	512	5.4	339.00	70.27	48
	Total	**1,007**	**10.6**	**1977.5**	**146.26**	**100%**
Mafraq*	**Head of Department**	1	0.0	508.50	0.81	1
	An observer	6	0.3	395.50	3.80	5
	Drivers (incl. reserve)	22	0.9	395.50	13.94	19
	Loader	48	2.0	339.00	26.08	35
	Workers	55	2.3	339.00	29.88	40
	Total	**132**	**5.5**	**1977.5**	**74.51**	**100%**

Karak**	**Head of Department**	15	0.9	508.50	17.26	14
	An observer	17	1.0	395.50	15.21	13
	Drivers (incl. reserve)	17	1.0	395.50	15.21	13
	Loader	45	2.6	339.00	34.51	28
	Workers	51	3.0	339.00	39.12	32
	Total	**145**	**8.5**	**1977.5**	**121.31**	**100%**
***** Daily working time 6 h/d ****** Daily working time 7 h/d ******* Salary includes 13% insurance						

The table shows a shortage of staff for administration and management in the city of Mafraq, here an increase is urgently needed. The balance of staff in the city of Irbid depending on the task is realistic and can be used as an indicative figure for other cities in Jordan.

The previously obtained data, contained in table 3, were used as the main inputs to perform the cost analysis process in order to estimate the personnel and vehicle running costs of waste collection per hour as shown in table 4.

Table 4: Estimation of the personnel and vehicle running costs of waste collection per hour.

	Key figures	Irbid*	Mafraq*	Karak**
Personnel rates per hour [JD/ h)]	**Drivers**	**3.60**	**2.68**	**2.97**
	Loader and workers	**2.75**	**2.30**	**2.54**
Vehicle rates per hour[JD/ h)]	**2-axle**	**9.82**	**4.87**	**11.91**
	3-axle	**11.92**	**5.62**	**9.49**
	Small vehicle	**4.38**	**0.00**	**4.58**
***** Daily working time 6 h/d ****** Daily working time 7 h/d				

The specific costs for waste collection per ton in terms of personnel, vehicle and container costs were also estimated as shown in table 5.

Table 5: Estimation of the specific costs [JD/ Mg] for container collection.

Costs [JD/Mg]					
Study area	**Waste amounts in 2015**	**Personnel costs**	**Vehicle costs**	**Container costs**	**Total**
Irbid	**158,400**	**27.48**	**10.41**	**1.13**	**39.02**
Mafraq	**25,920**	**22.43**	**08.87**	**3.95**	**35.26**
Karak	**23,040**	**27.99**	**12.96**	**1.54**	**42.49**

From the table, regarding the city of Mafraq, the vehicle costs are low because the vehicles used are new and no maintenance costs were incurred in 2015. Staff costs are also low because no street workers are employed on the roads for transporting the waste to the collection points. Therefore, the vehicle crews carry out these tasks, which in turn increases the time required for waste collection and thus leads to an increase in costs.

The total cost for collection and transport were 39.02, 35.26 and 42.49 JD per Mg in in the city of Irbid, Mafraq and Karak, respectively. Only about 10-20% will be covered by waste charges, which are levied from the electricity bills. The remaining 80-90% is paid by the municipal revenues from the Ministry of Municipal Affairs. From a fuel cost point of view, the results have shown that fuel cost accounts for 10% of the total cost per ton for Irbid and Karak city and 8% for Mafraq city, which in turn highlights the urgent need to optimize the routing network in order to reduce the distance travelled and, thus, reduce fuel consumption. Moreover, the waste collection costs per ton according to the vehicle types were estimated as given in table 6.

Table 6: Waste collection costs per ton according to the vehicle types.

Costs [JD/Mg]				
Study area	**3-axle**	**2-axle**	**Small vehicle**	**Total**
Irbid*	**22.11**	**32.33**	**108.01**	**39.02**
Mafraq	**41.85**	**29.86**	**00.00**	**35.26**
Karak	**28.81**	**42.54**	**58.63**	**42.49**
***** Including transfer station vehicle costs				

During this study, many strengths and weaknesses were determined in the areas covered by this research. Table 7 summarizes the strengths and weaknesses of the cities studied.

Table 7: The main strengths and weaknesses of the areas studied.

<table>
<tr><th>Study area</th><th>Strengths</th><th>Weaknesses</th></tr>
<tr><td>Irbid</td><td>• frequent usage of 3-axle vehicles
• good utilization of vehicle payload
• good utilization of container volume</td><td>• 5 h/d average daily working time
• very high transport time percentage
• usually just one disposal trip per shift
• unbalanced utilization of the collecting routes (working time, container units per route, tonnage per route)
• no structured route planning (traditional structures)</td></tr>
<tr><td>Mafraq</td><td>• frequent usage of 3-axle vehicles
• good utilization of container volume</td><td>• 5 h/d average daily working time
• high transport time percentage
• usually just one disposal trip per shift
• bad utilization of vehicle payload
• unbalanced utilization of the collecting routes (working time, container units per route, tonnage per route)
• no structured route planning (traditional structures)</td></tr>
<tr><td>Karak</td><td>• 3-shift working hour model
• 7 h/d average daily working time
• frequent usage of 3-axle vehicles
• good utilization of vehicle payload
• good utilization of container volume</td><td>• high transport time percentage (esp. small vehicles)
• high amount of sacks
• usually just one disposal trip per shift
• unbalanced utilization of the collecting routes (working time, container units per route, tonnage per route)
• no structured route planning (traditional structures)</td></tr>
</table>

4.3 Proposed scenarios for waste collection

Based on the results of the evaluation of the current situation and the strengths and weaknesses of the waste collection process, a GIS technique was used to calculate round times and travel distances associated with the existing collection rounds and to generate new, ‘optimal’ collection rounds for the various new operating scenarios. Three proposed scenarios have been developed and are given in table 8.

Table 8: The proposed scenarios for solid waste collection.

Scenario	Description	Target	
		Irbid	**Karak**
0	**Initial situation (working time as current situation)**	• daily working time: 5:00 h/d • set-up time / paid breaks: < 0:15 h/d • utilization of payload: 90 to 95 % for all vehicles	• daily working time: 6:45 h/d • set-up time / paid breaks: < 0:15 h/d • utilization of payload: 90 to 95 % for all vehicles
1	**Optimization of working time**	• daily working time: 6:00 h/d • set-up time / paid breaks: 0:30 h/d • utilization of payload: 85 % for all vehicles	• daily working time: 8:00 h/d • set-up time / paid breaks: 0:30 h/d • utilization of payload: 85 % for all vehicles
2	**Use of a transfer station (working time as current situation, no investment costs for building considered)**	• transfer station at “Truck City” outside of Irbid for 2- and 3-axle vehicles • current transfer station for small vehicles at same place • reduction of distances for unloading (2-, 3-axle vehicles) • more 6-axle vehicles for transfer stations	• transfer station outside of Karak for 2-, 3-axle and small vehicles • reduction of distances for unloading for 2-, 3-axle and small vehicles • new 6-axle vehicles for transfer stations
3	**Combination of scenario 1 and 2**	• daily working time: 6:00 h/d • set-up time / paid breaks: 0:30 h/d • utilization of payload: 85 % for all vehicles • transfer station at Truck City outside of Irbid for 2- and 3-axle vehicles • current transfer station for small vehicles at same place • reduction of distances for unloading (2-, 3-axle vehicles) • more 6-axle vehicles for transfer stations	• daily working time: 8:00 h/d • set-up time / paid breaks: 0:30 h/d • utilization of payload: 85 % for all vehicles • transfer station outside of Karak for 2-, 3-axle and small vehicles • reduction of distances for unloading for 2-, 3-axle and small vehicles • new 6-axle vehicles for transfer stations

Cost analysis has been performed for the different scenarios and assumptions were made for the different parameters involved in the cost calculation that fit the cities’ situations. An estimation of the total costs per year and specific cost per ton compared to the current situation, made from the calculation prepared for the three scenario options, are given in table 9 and table 10, respectively.

Table 9: Estimation of the total costs per year for the proposed scenarios.

Total costs [JD/ a]					
Study area	**Key figures**	**Initial situation**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Irbid	**Personnel**	**4,352,325**	**3,661,030**	**3,486,005**	**3,013,548**
	Vehicles	**1,648,783**	**1,402,670**	**1,720,842**	**1,594,405**
	Containers	**179,531**	**179,531**	**179,531**	**179,531**
	Total	**6,180,640**	**5,243,232**	**5,386,379**	**4,787,484**
	savings in the total cost compared to the initial situation (JD/ a) in %		**15%**	**13%**	**23%**
Karak	**Personnel**	**644,977**	**577,658**	**591,161**	**537,010**
	Vehicles	**298,551**	**303,077**	**325,258**	**333,416**
	Containers	**35,403**	**35,403**	**35,403**	**35,403**
	Total	**978,931**	**916,138**	**951,822**	**905,829**
	savings in the total cost compared to the initial situation (JD/ a)		**6%**	**3%**	**8%**

Table 10: Estimation of the specific costs per ton for the proposed scenarios.

Specific costs [JD/ Mg]					
Study area	**Key figures**	**Initial situation**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Irbid	**Personnel**	**27,48**	**23,11**	**22,01**	**19,02**
	Vehicles	**10,41**	**8,86**	**10,86**	**10,07**
	Containers	**1,13**	**1,13**	**1,13**	**1,13**
	Total	**39,02**	**33,10**	**34,00**	**30,22**
	savings in the specific cost compared to the initial situation (JD/ Mg)		**15%**	**13%**	**23%**
Karak	**Personnel**	**27,99**	**25,07**	**25,66**	**23,31**
	Vehicles	**12,96**	**13,15**	**14,12**	**14,47**
	Containers	**1,54**	**1,54**	**1,54**	**1,54**
	Total	**42,49**	**39,76**	**41,31**	**39,32**
	savings in the specific cost compared to the initial situation (JD/ Mg)		**6%**	**3%**	**8%**

The results revealed that the proposed scenarios' savings compared to the current situation in terms of total operation cost for waste collection were 15%, 13% and 23% for scenarios 1, 2 and 3, respectively, in the city of Irbid and 6%, 3% and 8% for scenarios 1, 2 and 3, respectively, in the city of Karak. Moreover, using the alternative scenarios was shown to provide remarkable savings, as the operating time of the vehicles was reduced by 30%.

5. Conclusion

Collection of non-separated solid waste in an urban area is complex as waste generation becomes more diffuse. The GIS-ArcView application for route optimization in Jordan's cities has shown an urgent need for improving the key indicators for the waste collection and transportation. No structured key data-oriented route planning, inefficient and expensive waste collection and a lack of reporting and documentation was noticeable in the areas studied.

In this paper, an attempt has been made to estimate the key indicators for route optimization in order to reduce travel distances and fuel consumption by vehicles, costs on manpower, time and operational costs for three of Jordan's cities, namely Irbid, Mafraq and Karak. This study investigated a number of options for waste collection and compared the associated operation costs. Three scenarios were developed and a cost analysis has been performed for each suggested scenario and compared with the current empirical collection scheme. Introducing longer shifts, relocating or/and introducing new transfer stations, reducing the distance for unloading and increasing the fleet of vehicles were the main points highlighted in the proposed scenarios. The results demonstrate that the proposed scenarios' savings compared to the current situation in terms of total operation cost for waste collection were 15%, 13% and 23% for scenarios 1, 2 and 3, respectively, in the city of Irbid and 6%, 3% and 8% for scenarios 1, 2 and 3, respectively, in the city of Karak. Although using the alternative scenarios was shown to provide significant savings, the operating time of the vehicles was reduced by 30%. This fact is important as a small percentage improvement in the collection operation can effect a significant saving in the overall cost. Therefore, pay attention concerning the analysis of solid waste collection and transportation systems in order to optimize the operation of existing systems and to develop data and advanced techniques to design and evaluate new systems for urban areas urgently needed.

This paper can be used as a decision support tool by municipal authorities for efficient management of the daily operations for moving solid waste, load balancing within vehicles, managing fuel consumption and generating work schedules for the workers and vehicles. Furthermore, the results obtained from this pilot study encourage expanding the scope of the study to cover other entire cities, to control disposal logistics with the help of key figures for performance and cost as essential planning parameters. All of the key figures indicated can then be used to further refine operational factors in terms of efficiency and productivity.

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