RGNZ/MGPB

Mitigation of waste transportation costs in Taif Province, Saudi Arabia

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
UDC: 628.4
DOI: 10.17794/rgn.2022.5.13

Original scientific paper

Abdullah M. Y. Alzahrani
Department of Civil Engineering, Engineering College, Taif University, Taif 21944, Saudi Arabia,
ORCID: (https://orcid.org/0000-0003-4812-4283)

Abstract
Municipal solid waste (MSW) management is a critical issue in the Kingdom of Saudi Arabia (KSA). Management of solid waste in crowded conditions, especially in main cities such as the Al-Taif Province. This paper deals with that case study and focuses on how to solve material handling problems by applying conventional methods and computer ability. One of the costliest operations in the civil sector is transportation for material handling. City mayors considered transportation and materials handling as a subclass of the linear programming technique, thus linear programming problems take into consideration that the main objective is to handle materials from the city centre site to the identified dumping area. There are many methods and tools used to solve the transportation problem (TP) to find out the maximum or minimum in order to reduce cost or maximize profit. The methods related to manual solutions and others used many different computer applications. Manual solutions include the northwest corner method, the minimum cost method, the row minimum cost method, the column minimum cost method, and Vogel's approximation method, and computer applications such as LINGO, Lingo, and solver function using Microsoft Excel. This case study focuses on applying the Microsoft Excel function to find the minimum cost of the transportation system in waste materials to reduce the transportation cost from the city centre to the final destination (dumping area) to be used. The results achieved with the model aided in obtaining optimal solutions and finally, the optimal solutions were checked.

Keywords:
waste material handling; transportation problem; linear programming (LP); Microsoft Excel solver; LINGO.

1. Introduction

In recent years, the rapid growth of the urban population and economic prosperity has increased governments' responsibilities to mitigate the negative effects of this growth. The increasing growth in environmental degradation and waste per capita in recent years is one of the most severe repercussions. As a result of these worrying circumstances, major innovation is required to enhance solid waste management (SWM) (Asnani and Zurbrugg, 2007). Municipal solid waste (MSW) is any solid waste produced within the boundaries of a district, despite its physical or chemical nature or origin (Sharma and Jain, 2020). Table 1 gives the allocation of various types of solid waste to their respective sources.

Due to population increase, rapid urbanization, and industrialization tendencies, cities and counties in the Kingdom of Saudi Arabia (KSA) are currently confronting issues in managing enormous volumes of solid garbage. With the present population of around 35 million inhabitants based on the most recent 2020 statistics, KSA generates over 15.3 million tonnes of solid waste per year (Zafar, 2015). Urban areas are home to even more than 75% of the nation's people, necessitating the development and implementation of evolution that is long-term techniques in city and county MSWM systems, especially in mid to large cities. Some significant municipalities in Saudi Arabia (e.g. Riyadh, Jeddah, Makkah, Dammam, Dhahran and Jubail) have already implemented effective management strategies, such as waste treatment, sorting, handling, reusing, and recuperation of energy (Al Mazrouei, 2015; Nizami, 2017).

In many countries, the management of municipal solid waste (MSWM) is getting more difficult as landfill-based systems give way to resource-recovery-based solutions (**Burnley et al., 2007**). According to a recent estimate of greenhouse gas emissions from solid waste, which accounts for 4.1 percent of total GHG emissions and, of course, poses a significant management and disposal challenge (**Agreement, 2015**).

In Saudi Arabia, solid waste collection, such as garbage, is collected in bin containers from various locations and disposed of in landfills or dumpsites. Saudi Arabia also lacks adequate waste disposal infrastructure, with most landfills predicted to reach capacity within ten years (**Tadesse et al., 2008**). Though many MSWM alternatives have indeed been applied to decrease health hazards, sanitary landfill remains the most commonly

Corresponding author: Abdullah M Y Alzahrani
e-mail address: amyalzahrani@tu.edu.sa

Table 1: The origins and forms of solid waste

Origin	Common waste producers	Solid waste classifications
Household (private sector)	Single or multi dwellings	Sheet, cartons, kitchen waste, plastics, fabric cloths, nubuck, garden waste, bottle, cellulose nanocrystals (timber, vegetation, and trimming), metal alloys, dusts (heaters and pipe tobaccos), special waste of precious (e.g. thick and heavy consumables, white goods, electrical components, battery packs, car tires, oils), and various types of hazardous household waste are all acceptable.
The manufacturing industry	Fabrication, energy and industrial plants, and renovation are all examples of luminous and heavy industry company sites.	Household waste, various packaging, kitchen wastes, industrial materials, cremated remains, toxic materials, and special waste are all examples of waste.
Enterprise of commerce	Warehouses, businesses, culinary, hotels, and office buildings, among other things.	Parchment, cartons, plastic products, timber, food scraps, glass, metals, special waste, and toxic materials are all acceptable materials.
Educational sector	Colleges, academic institutions, elementary schools, clinics and other health-care facilities, prisons and jails, and federal facilities.	Similar to the commercial industry
Renovation, infrastructure and destruction	Sites for new builds, renovation of existing, highway restoration, and structure dismantling.	Lumber, metal, pavements, concretes, insulators, mud, debris, and other materials.
Service offered by municipalities	Road maintenance, green spaces, gardening, shorelines, orchards, play areas, athletic facilities, other outdoor spaces, and sewage treatment plants are all examples of public works projects.	Road scrapings, scenery, tree- and forest peelings, various waste accumulating in gardens, coastline, shores, and other sports fields, and sludge from splashing.
The processing industry	Heavy and light industrial production, petrochemical industries, (bio) refineries, power stations, natural resource mineral processing, furniture making, and laminate works.	Waste from industrial processes, forest residues, disposal, off-spec product lines, ash, and slags.
All of the aforementioned items should be classified as "municipal solid waste" (**Saleh and Koller, 2019**).		

used MSWM technology. Runoff from landfills, on either hand, contaminates the soil and has an impact on surface and groundwater (**Ivošević et al., 2022; Damijanić et al., 2022; Jakovljević et al., 2022**). Pollutants can be avoided by developing waste disposal frameworks in such a way that the garbage is secluded from the entire environment (**Voběrková et al., 2017; Jovanov et al., 2018; Hadidi et al., 2020**). The majority of waste is presently placed or dumped into landfills all over the world. Nearly 37% of waste ends up of in a landfill, with 8% heading to sanitary landfills equipped with landfill gas storage tanks. Roughly 31% of waste is deposited publicly, 19% is regained through recyclables, and 11% is burned for disposal (**Kaza et al., 2018**), as shown in **Figure 1**.

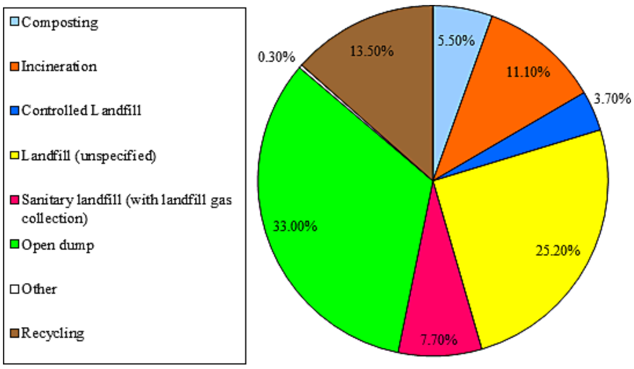

Figure 1: Global waste management

Many tools are used to reduce the total cost and select the best selection of landfill. Water, sanitary, garbage pickup, hurricane drains, public utilities, asphalted walkways, and streets for quick access are all lacking. Linear programming (LP) is an indispensable tool for solving optimization problems (**Graham-Taylor, 1992; Hasan et al., 2022; Khalaf et al., 2022**). **Anderson (1968)** was the pioneer to propose a computational formula for optimizing waste disposal. Numerous different scientists have since developed SWM models to serve as choice tools for waste treatment facility decision making, placement, and dimensioning. **Rathi (2007)** developed a mathematical optimization method in Mumbai to incorporate multiple alternatives and relevant parties in Municipal waste management. Various financial and ecological costs associated with MSW disposal were considered. As waste processing/disposal alternatives, society upcycling plants, mechanical anaerobic treatment plants, and landfills were all included in the model, with environmental costs (**Paul et al., 2020**). **Najm et al. (2002)** proposed maximization strategies for designing low-cost SWM systems that take into account a range of management activities. Their modelling approach takes into account solid waste production, characteristics, selection, diagnosis, removal, and the possible environmental consequences of various MSW management systems.

Daskalopoulos et al. (1998) suggested a linear programming (LP) model that considered both financial and ecological factors. In this model, the optimal MSW evolves to different kinds of alternative treatments are obtained by finding a linear cost function Environmental costs were calculated using carbon dioxide emissions and their possibilities for climate change. In Istanbul, Turkey's MSW management system, **Kirca and Erkip (1988)** created a linear programming model for locating transfer stations. **Baetz (1990)** used dynamic programming to determine the size and timing of massive garbage dumps and disposal plants. **Or and Curi (1993)** adopted a mix integer linear programming (MILP) model to improve the city of Izmir's system for collecting and transporting solid waste and reduce total solid waste collection and transportation costs. **Kulcar (1996)** employed a linear programming approach to optimise techniques for collection in a major urban area with low waste transportation costs. **Chang et al. (1997)** suggested a fuzzy interval mixed integer multi-objective linear programming model for evaluating solid waste management strategies in a cosmopolitan region, indicating how variations could be measured using particular membership function parameters and interval digits within a multi-objective analytical framework.

LP is one of the most widely applied techniques in many operations and is applicable to surface landfill waste, considering all operations and all constraints. The algorithm used by LINDOTM has been applied efficiently to generate a suitable design for long-term landfill waste. This has added considerable theoretical knowledge of network LP (**Shamshiry et al., 2011**). One of the oldest and most productive implementations of linear optimization algorithms is the transportation problem. After adjusting the formulation and solution of the transportation problem as described, all equations were used in conjunction with a linear programming technique. Many solutions necessitated a significant amount of effort, relying on complex calculations, and requiring a considerable amount of time to reach the answers by manual process. Computer skills are increasing dramatically, and they are used to solve many problems in different sectors of the engineering industry. One target is finding out the optimal solution to overcome the transportation problems (**Keivani et al., 2015**). The main challenges are evaluating the quantities and stand up to transport these materials from cities to final destination landfill areas. Linear programming is a good tool to find the optimal solutions (**Dharma and Ahmad, 2005**), that is analysis for actual works. There are many researchers who studied and introduced the implementation of the transportation problem algorithm (**Hasan, 2012; Nikolić, 2007**). There is some lack of information to completely understand and find the solution for that problem. Thus, manual methods were used to achieve the optimal solution, also computer application safe time and cost to carry out the optimal solution while taking into consideration the largest matrix. The primary goal of this research is to find the best solution for any identified problem by using a fully automated balance process. Analysis is one of the real tools to find and formulate a good model to find the optimal solution also recommended to focus on material handling problems to get the highest profit from solving these problems.

The remainder of this manuscript is organized as follows. In Section 2, the problem's description and methodology are defined. In Section 3, data collections and problem assumption are discussed. Availabilities and production of waste in the Taif Province are revealed in section 4, and besides that, the results are presented, and the solutions are discussed in relation to the previous methodology. Section 5 concludes with the findings.

2. Method and problem description

The cost of transporting municipal waste to disposal sites has been calculated using linear programming (LP). Such a tool makes it possible to simulate the movement of waste from sources (cities) to disposal sites. The following factors have been implemented into LP:

- Calculate the amount of waste generated by cities.
- Determine the distance between dumping sites, the volumes of the disposal sites, and their locations.
- Use linear programming equations to link these variables (source quantity, dumping site locations and volume, distance).
- LP equations provide the solution in terms of the minimum cost.

Therefore, consider the m-dumping locations (origins) as O_1, O_2,… O_m and the n-region (destination sites) as D_1, D_2,..., D_n respectively. Let $a_i > 0$, i= 1,2, ….m, b the amount available at the i^{th} cites O_i. Let the amount required at the j^{th} region (landfill) D_j, $b_j > 0$, j= 1,2,….n. Linear programming problems that describe a valid practical programming problem usually non-negative solution with a corresponding finite value of the objective function. The general linear programming is used to find a vector (X_1, X_2…X_j,….X_n) which minimizes the linear form (i.e. the objective function). The most common forms of linear programming problems are manual and computer solutions.

2.1. Traditional Methods

Material handling is regarded as a subset of linear programming. The main purpose is handling any materials from various «origins" (districts at the Taif Province) to different «destinations» (dumping site) with a minimum of total cost (**Saul, 1990**). Many methods are used in solving that problem as example a case of linear programming. Both the traditional and advanced methods are used in three objectives as mentioned below:

The first step is determining the linear objective function, (Maximization or Minimization) as given in **Equation 1** as follows:

$$F(X) = \sum C_{ij} X_{ij}, \text{ I} = 1, 2, \ldots \text{m}; \text{ j} = 1, 2, \ldots, \text{n} \quad (1)$$

Where:

X_{ij} – set of structural variables,

C_{ij} – set as so-called "price coefficients".

$$F(X) = C_{11}X_{11} + C_{21}X_{22} + \ldots + C_{mn}X_{mn}$$

The second step is formulated linear structural constraints, all linear programing problems contain a set of linear constraints as given in **Equation 2** as follows:

$$\Sigma\Sigma X_{ij} \geq b_i,\ \Sigma\Sigma X_{ij} \geq a_i \quad (2)$$

Where:

i = 1, 2,……, m,

j= 1, 2, ……., n.

Formulation is the main target for solving the linear programming problem. This formulation is a technical specification of the problem to build the structure. Also, all constraints should be formulated and mentioned below.

2.2. Computer solution

In this study, Excel Solver is used to solve the transportation problem for different models in the surrounding Taif governorate. A worksheet requires the establishment of column and row headings for the specific model, as well as the input of constraint and objective function formulas in their entirety, rather than just the design variables. This is also an additional benefit of Excel sheets, as it allows the problem to be arranged in an appealing layout for tracking and appearance purposes.

3. Data collection and problem assumption

The engineering structures are composed materials. These materials are known as the waste form of human activities, as shown in **Figure 2**. One of the most important materials is construction and building materials which are used in infrastructure, such as roads, building, etc., those materials considered as the biggest responsible for varied environmental impacts. During the development and building phases, there should be a focus on the environmental impacts to reduce them as much as possible. Waste has become a concern for all nations, and from them it was necessary to bury these wastes in a correct scientific manner and at the lowest possible cost by making a mathematical model to transport these wastes from the possibility of collecting them to the burial places at the lowest possible cost.

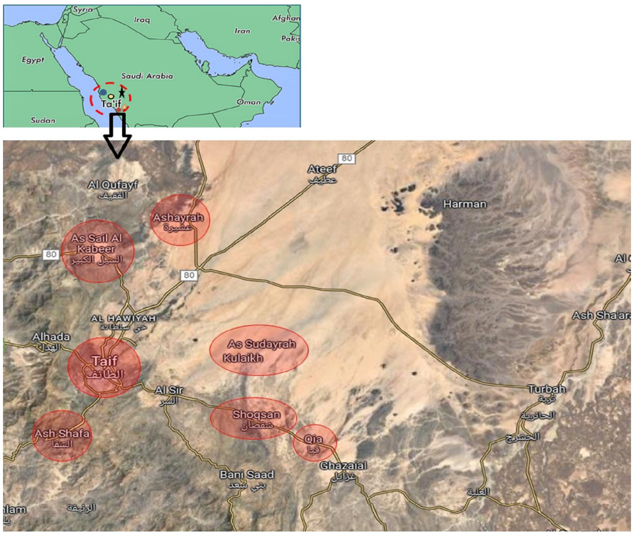

Figure 2: Location map for Taif city

Table 2: The productions waste from different locations

#	Dumping site	Available of the capacity m³
	Northeast dumping site	30000
	South centre dump site	40000
	Southwest dump site	30000
	Northwest dumping site	25000

4. Availabilities and production of waste in Taif province

To solve the transportation problems of waste materials, the following assumptions are considered in the determination of the availabilities and production of waste cities. Assume that:

- The waste production is distributed according to the percentage of inhabitants of each metropolitan area to the total Governorate inhabitants in each region during the five-year plan.
- The total cost per unit distance to transport the unit volume of one cubic meter is considered constant. We shall use the distance from the origin (cities) to the construction site (dumping sites) as coefficients "C" from i^{th} origin to j^{th} destination to be C_{ij}, i= 1,2, …m, j=1,2,….n., all data collected from the management of council of cites are illustrated in **Tables 3 to 5**.

Table 3: Matrix of waste problem

Dumping Site	City / Site	Taif A_1	Ashayrah A_2	As Sail Al Kabeer A_3	Ash Shafa A_4	Shoqsan A_5	Qia A_6	As Sudayrah A_7	Vol., m^3
Northeast dumping site	DC_1	7	10	6	15	8	11	5	30000
South centre dumping site	DC_2	5	7	3	4	10	13	7	40000
Southwest dumping site	DC_3	9	14	15	3	2	5	8	30000
Northeast dumping site	DC_4	11	15	12	2	6	10	13	25000
Total		22000	18000	15000	11000	18000	20000	21000	

$DC_{1,2,3}$ etc. – Dumping districts 1,2,3, etc.

Table 4: The optimum solution of the waste site problem

City / Site	A_1	A_2	A_3	A_4	A_5	A_6	A_7
DC_1	9000	0	0	0	0	0	21000
DC_2	7000	18000	15000	0	0	0	0
DC_3	0	0	0	0	10000	20000	0
DC_4	6000	0	0	11000	8000	0	0

Table 5: Constraints and objective function for the sand problem

DC_1	0						
DC_2	0						
DC_3	0						
DC_4	0						
	A_1	A_2	A_3	A_4	A_5	A_6	A_7
	0	0	0	0	0	0	0
Total cost	630000						

4.1. *Software programming*

We may notice the difficulties if we try to solve the problems of the dumping waste around the Taif Province either manually or by desk calculator when solving a small problem by hand applying the northwest corner rule. Vogel's approximation method is a time-consuming method. When we solve any matrix equal (rows, columns) or non-equal (rows, columns) by using that Software called Premium Solver Platform (PSP) the solution takes only few minutes. This software is easier; it uses a subclass of the Microsoft Excel function (**Ali et al., 2018; Ali and Sik, 2012; El Beblawi et al., 2007**).

There are four steps which must be determined as follows:

- After opening a worksheet in Microsoft Excel, according to the matrix, row column (m×n) should be determined to select the number of cells in the work sheet.
- In the first cells, insert the distance as cost with the availability of dumping site in the last column, and the requirements for regions in the last row.
- The second cell contains the changing variables such as (X_{ij}) before solving. These cells are taken as zero and it takes the amount which is considered as the optimal solution later.
- The third cell contains constraints.
- The fourth cell contains the objective function.

4.2. *Optimum solution for transportation problem*

As discussed earlier, the transportation problem has many ways to find a solution and each one has its difficulties and advantages in accuracy and saving time. The linear programing methods for dumping sites are in the studied area will be used to define the optimum solution for this problem. The linear programing will be checked by two methods:

1. Solver function in an Excel worksheet.
2. Lingo solution model.

4.3. *Linear programming for sand model*

4.3.1. Solver function in Excel sheet for sand:

The following **Tables 3 to 7** represent the matrices of linear programming for waste around the Taif Province also, indicate the objective functions and constraints and finally, the optimal solution for that proposed model.

4.3.2. Lingo solution for the proposed model

Firstly, the constraints and their formulations should be considered when solving the transportation problems, set them up as "regular" linear programming problems using LP Software's (Lingo) in three steps:

- The first step is determining the objective function, the constraints and the optimum solutions for the waste model as shown in the following tables.
- The second step is choosing the linear programming from the software options available.
- The third step is applying solve from the icon in Lingo Software. The optimal solution obtained is related to all the objective functions and all the constraints equations.

Table 6: The objective function and constraints

Min

$$7X_{11}+10X_{12}+6X_{13}+15X_{14}+8X_{15}+11X_{16}+5X_{17}+$$
$$5X_{21}+7X_{22}+3X_{23}+4X_{24}+10X_{25}+13X_{26}+7X_{27}+$$
$$9X_{31}+14X_{32}+15X_{33}+3X_{34}+2X_{35}+5X_{36}+8X_{37}+$$
$$11X_{41}+15X_{42}+12X_{43}+2X_{44}+6X_{45}+10X_{46}+13X_{47}$$

ST

$$X_{11}+X_{12}+X_{13}+X_{14}+X_{15}+X_{16}+X_{17}\geq 30000$$
$$X_{21}+X_{22}+X_{23}+X_{24}+X_{25}+X_{26}+X_{27}\geq 40000$$
$$X_{31}+X_{32}+X_{33}+X_{34}+X_{35}+X_{36}+X_{37}\geq 30000$$
$$X_{41}+X_{42}+X_{43}+X_{44}+X_{45}+X_{46}+X_{47}\geq 25000$$
$$X_{11}+X_{21}+X_{31}+X41\leq 22000$$
$$X_{12}+X_{22}+X_{32}+X_{42}\leq 18000$$
$$X_{13}+X_{23}+X_{33}+X_{43}\leq 15000$$
$$X_{14}+X_{24}+X_{34}+X_{44}\leq 11000$$
$$X_{15}+X_{25}+X_{35}+X_{45}\leq 18000$$
$$X_{16}+X_{26}+X_{36}+X_{46}\leq 20000$$
$$X_{17}+X_{27}+X_{37}+X_{47}\leq 21000$$

End

5. Results and Discussions

The functions built into the Excel worksheet were used, and the outcomes were compared to those from Lingo. To operate the latter, expertise is required. Excel, on the other hand, is more user-friendly, but both methods yield results that are equally accurate. These findings are presented and discussed in the section that follows.

Table 3 displays the wastes produced in various cities and the locations where they are disposed of. The letter A represents the city, while the symbol DC stands for the disposal facilities. The values in **Table 3** represent the distance (in kilometres, for instance) between the waste production location and the disposal site. The cost of waste transportation per tonne is thought to be constant. These values thus represent the expenditure of transporting waste from the city to a disposal site. The last column of **Table 3** shows the total area of dumping space that is accessible at each disposal site. The bottom horizontal row of **Table 3** indicates the total amount of waste produced by each city.

The best disposal location for each city is shown in **Table 4**. The solution demonstrates that some cities (such as A_2, A_3, A_4, A_6 & A_7) have a single unique dumping location, however, some cities may have more than one dumping site (e.g. A_1, A_5). A universal matrix connecting all dumping sites and cities led to the solution. The cost of waste transportation ultimately determines this approach.

The basic restrictions for each city are listed in **Table 5**. Such constraints must meet the requirements that all wastes generated by a city must be disposed of in one or more disposal sites, and the dumping area must be large enough to accommodate the generated wastes. All limitations have been met, as shown by the number zero in

Table 7: The optimum solution according to Lingo software

Variable	Value, m^3	Variable	Value, m^3	Variable		Value, m^3	
X_{11}	9000.000	X_{31}	0.000000	X_{24} X_{25} X_{26} X_{27}	0.000000 0.000000 0.000000 0.000000	X_{24} X_{25} X_{26} X_{27}	0.000000 0.000000 0.000000 0.000000
X_{12}	0.000000	X_{32}	0.000000	X_{24} X_{25} X_{26} X_{27}	0.000000 0.000000 0.000000 0.000000	X_{24} X_{25} X_{26} X_{27}	0.000000 0.000000 0.000000 0.000000
X_{13}	0.000000	X_{33}	0.000000	X_{24}	0.000000	X_{24}	0.000000
X_{14}	0.000000	X_{34}	0.000000	X_{24} X_{25}	0.000000 0.000000	X_{24} X_{25}	0.000000 0.000000
X_{15}	0.000000	X_{35}	10000.00	X_{43}	0.000000	X_{43}	0.000000
X_{16}	0.000000	X_{36}	20000.00	X_{43}	0.000000	X_{43}	0.000000
X_{17}	21000.00	X_{37}	0.000000	X_{43}	0.000000	X_{43}	0.000000
X_{21}	7000.000	X_{41}	6000.000	X_{43}	0.000000	X_{43}	0.000000
X_{22}	18000.00	X_{42}	0.000000	X_{43}	0.000000	X_{43}	0.000000
X_{23}	15000.00						

Table 5, and no waste will be returned. The total cost of transported waste material from source to final destination of dumping site is as mentioned in Table 5.

There is yet another LINGO-based solution in **Table 6**. The distance of the disposal location from the city and the amount of waste generated by each city was set up using a matrix to generate linear equations that showed the lowest costs. For instance, the symbols $7X_{11}$ symbolize the 7 km between City 1 and Dumping Site 1, the X_{11} indicates the amount of waste created in City 1 that needs to be transported to Dumping Site 1, and so on.

Table 7 displays the total amount of waste that has been disposed of from each city at a particular dumping site. For example, X_{11}=9000 m^3 specifies the entire volume of waste generated by City 1 and dumped at Site 1 is 9000 m^3. If X_{12} = 0, then there isn't any waste being transported from City 1 to Disposal Site 2, and so on.

Acknowledgement

The author would like to extend his profound gratitude to his colleagues at Civil Engineering Department, College of Engineering, Taif University, for their tremendous help with the linear programming formal analysis, reviewing & editing.

6. Conclusions

From this study and results, many conclusions can be written as follows:

1. All results achieved the minimum cost by using this application and the optimum solution is the best outcome of this study.
2. The transportation problem is solved and carried out the optimum solution as mentioned in the results, also, the Premium Solver Platform programme produced results for sand, gravel, and dolomite based on the mathematical models of the problem in the Taif Province.
3. This application can be applied in any location under any conditions,
4. According to the optimum solution, all materials are covered in all district requirements for the studied waste materials. This matrix indicates that these substances are entirely absorbed within the governorate's boundaries.

7. References

Agreement, P. (2015): United Nations Framework Convention on Climate Change (UNFCCC). Climate Change Secretariat: Bonn, Germany.

Al Mazrouei, F. (2015): Average annual production of household solid waste per person in the Kingdom. Al-Jazirah Daily, Al-Riyadh city.

Ali, A., Wasly, H., Abdellah, W. and Jang, H. (2018): Optimization of blending operation for Aswan phosphate mines using linear programming. Mining of mineral deposits, 12, 4, 1-8. https://doi.org/10.15407/mining12.04.001

Ali, M. A. and Sik, Y. H. (2012): Transportation problem: A special case for linear programing problems in mining engineering. International Journal of Mining Science and Technology, 22, 3, 371-377. https://doi.org/10.1016/j.ijmst.2012.04.015

Anderson, L. (1968): A mathematical model for the optimization of a waste management system. SERL Report. Sanitary Engineering Research Laboratory. University of California at Berkeley.

Asnani, P. and Zurbrugg, C. (2007): Improving municipal solid waste management in India: A sourcebook for policymakers and practitioners, World Bank Publications. http://hdl.handle.net/10986/6916

Baetz, B. W. (1990): Capacity planning for waste management systems. Civil Engineering Systems, 7, 229-235. https://doi.org/10.1080/02630259008970594

Burnley, S., Ellis, J., Flowerdew, R., Poll, A. and Prosser, H. (2007): Assessing the composition of municipal solid waste in Wales. Resources, Conservation and Recycling, 49, 3, 264-283. https://doi.org/10.1016/j.resconrec.2006.03.015

Chang, N.-B., Chen, Y. and Wang, S. (1997): A fuzzy interval multiobjective mixed integer programming approach for the optimal planning of solid waste management systems. Fuzzy sets and systems, 89, 1, 35-60. https://doi.org/10.1016/S0165-0114(96)00086-3

Damijanić, D., Crnić, A. P., Medunić, G., Bilandžić, N. and Sedak, M. (2022): Enhanced levels of hazardous trace elements (Cd, Cu, Pb, Se, Zn) in bird tissues in the context of environmental pollution by Raša coal. Rudarsko-geološko-naftni zbornik, 37, 1, 19-30. https://doi.org/10.17794/rgn.2022.1.3.

Daskalopoulos, E., Badr, O. and Probert, S. (1998): An integrated approach to municipal solid waste management. Resources, conservation and recycling, 24, 1, 33-50. https://doi.org/10.1016/S0921-3449(98)00031-7

Dharma, S. and Ahmad, A. (2005): Optimization of transportation problem with computer-aided linear programming: Proceedings of the Postgraduate Annual Research Seminar, Universiti Teknologi Malaysia, Malaysia, 140.

El-Beblwi, M., El Sageer, H., and Ali, M. (2007): Comparison between Some Methods Used in Solving Transportation Problem. 10th International Conference on Mining, Petroleum and Metallurgical Engineering, Assiut, Egypt, 6-8 March 2007. p 289-300.

Graham-Taylor, T. (1992): Production scheduling using linear and integer programming: Australasian Institute of Mining and Metallurgy Annual Conference (AusIMM), 159-162.

Hadidi, L. A., Ghaithan, A., Mohammed, A. and Al-Ofi, K. (2020): Deploying municipal solid waste management 3R-WTE framework in Saudi Arabia: Challenges and future. Sustainability, 12, 4, 5711. https://doi.org/10.3390/su12145711

Hasan, M. K. (2012): Direct methods for finding optimal solution of a transportation problem are not always reliable.

International Refereed Journal of Engineering and Science (IRJES), 1, 2, 46-52.

Hasan, M. M., Bader, S. A., Ali, M. A. M., Abdellah, W. R. and Abdelhaffez, G. S. (2022): Linear programming as a tool to design the mix of cement plant raw materials. Rudarsko-geološko-naftni zbornik, 37, 4, 109-117. https://doi.org/10.17794/rgn.2022.4.9

Ivošević, T., Momčilović, M., Bilandžić, N., Sedak, M. and Petrović, J. (2022): Levels of hazardous trace elements in estuarine sediments, fish, mussels and wild boar collected from the Raša Bay area (Croatia). Rudarsko-geološko-naftni zbornik, 37, 4, 119-135. https://doi.org/10.17794/rgn.2022.4.10

Jakovljević, I., Mešić, I. and Pehnec, G. (2022): Soil pollution of the Labin city area with polycyclic aromatic hydrocarbons derived from Raša coal mining and associated industries. Rudarsko-geološko-naftni zbornik, 37, 1, 139-150. https://doi.org/10.17794/rgn.2022.1.12.

Jovanov, D., Vujić, B. and Vujić, G. (2018): Optimization of the monitoring of landfill gas and leachate in closed methanogenic landfills. Journal of environmental management, 216, 32-40. https://doi.org/10.1016/j.jenvman.2017.08.039

Kaza, S., Yao, L., Bhada-Tata, P. & Van Woerden, F. (2018): What a waste 2.0: a global snapshot of solid waste management to 2050, World Bank Publications.

Keivani, N., Maatuk, A. M., Aljawarneh, S. and Ali, M. A. (2015): Towards the maturity of object-relational database technology: promises and reality. International Journal of Technology Diffusion (IJTD), 6, 1-19. DOI: 10.4018/IJTD.2015100101

Khalaf, H. A., Mohammed, N. A. and Federer, G. (2022): Evaluation of using waste pinecones as an eco-friendly additive to water-based mud. Rudarsko-geološko-naftni zbornik, 37, 2, 1-11. https://doi.org/10.17794/rgn.2022.2.1

Kirca, Ö. and Erkip, N. (1988): Selecting transfer station locations for large solid waste systems. European Journal of Operational Research, 35, 3, 339-349. https://doi.org/10.1016/0377-2217(88)90224-X

Kulcar, T. (1996): Optimizing solid waste collection in Brussels. European Journal of Operational Research, 90, 1, 71-77. https://doi.org/10.1016/0377-2217(94)00311-4

Najm, M. A., El-Fadel, M., Ayoub, G., El-Taha, M. and Al-Awar, F. (2002): An optimisation model for regional integrated solid waste management I. Model formulation. Waste management & research, 20, 1, 37-45. https://doi.org/10.1177/0734242X0202000105

Nikolić, I. (2007): Total time minimizing transportation problem. Yugoslav Journal of Operations Research, 17, 1, 125-133. https://doi.org/10.2298/YJOR0701125N

Nizami, A. (2017): Waste recycling in Saudi Arabia. Ecomena, Doha (Qatar). https://www.ecomena.org/recycling-in-saudi-arabia/

Or, I. and Curi, K. (1993): Improving the efficiency of the solid waste collection system in Izmir, Turkey, through mathematical programming. Waste management & research, 11, 4, 297-311. https://doi.org/10.1006/wmre.1993.1032

Paul, K., Chattopadhyay, S., Dutta, A., Krishna, A. and Ray, S. (2020): Developing and optimising an urban integrated solid waste management model: effect of transfer stations. Journal of urban & environmental engineering, 14, 1, 119-131, DOI:10.4090/juee.2020.v14n1.119131

Rathi, S. (2007): Optimization model for integrated municipal solid waste management in Mumbai, India. Environment and development economics, 12, 1, 105-121. https://doi.org/10.1017/S1355770X0600341X

Saleh, H. M. and Koller, M. (2019): Introductory chapter: Municipal solid waste. Municipal Solid Waste Management. IntechOpen. https://doi.org/10.5772/intechopen.79020

Saul, B. (1990): Optimisation of waste haulage with linear programming. Proceedings Mine Planning and Equipment Selection, Balkema, Rotterdam, Netherlands, 455-461.

Shamshiry, E., Nadi, B., Mokhtar, M. B., Komoo, I., Hashim, H. S. and Yahya, N. (2011): Forecasting generation waste using artificial neural networks. Proceedings of the International Conference on Artificial Intelligence (ICAI), Athens.

Sharma, K. D. and Jain, S. (2020): Municipal solid waste generation, composition, and management: the global scenario. Social Responsibility Journal. Emerald Publishing Limited, DOI:10.1108/SRJ-06-2019-0210

Tadesse, T., Ruijs, A. and Hagos, F. (2008): Household waste disposal in Mekelle city, Northern Ethiopia. Waste Management, 28, 10, 2003-2012. https://doi.org/10.1016/j.wasman.2007.08.015

Voběrková, S., Vaverková, M. D., Burešová, A., Adamcová, D., Vršanská, M., Kynický, J., Brtnický, M. and Adam, V. (2017): Effect of inoculation with white-rot fungi and fungal consortium on the composting efficiency of municipal solid waste. Waste Management, 61, 157-164. https://doi.org/10.1016/j.wasman.2016.12.039

Zafar, S. (2015): Solid waste management in Saudi Arabia. EcoMENA, Doha, Qatar. http://www. ecomena. org/solid-waste-management-in-saudi arabia

SAŽETAK

Smanjenje troškova transporta otpada u provinciji Taif, Saudijska Arabija

Gospodarenje čvrstim komunalnim otpadom kritično je pitanje u Kraljevini Saudijskoj Arabiji (KSA), posebice u uvjetima guste naseljenosti u glavnim gradovima i pokrajinama kao što je Taif. Ovaj rad prikazuje studiju slučaja i usredotočen je na to kako riješiti probleme gospodarenja i manipulacije materijalima primjenom konvencionalnih metoda i informatičkom tehnologijom. Jedan od najskupljih poslova u komunalnome sektoru jest transport materijala. Gradske uprave transport i rukovanje materijalima smatraju potklasom tehnologije linearnoga programiranja, stoga problemi linearnoga programiranja uzimaju u obzir da je glavni cilj rukovanje materijalima od središta grada do identificiranoga odlagališta. Postoje mnoge metode i alati koji se koriste za rješavanje problema transporta (TP) kako bi se saznao maksimum ili minimum u smislu smanjenja troškova ili maksimiziranja profita. Te metode primarno su se odnosile na manualna rješenja, a druge su se koristile mnogim različitim računalnim aplikacijama. Manualna rješenja uključuju metodu sjeverozapadnoga kuta (*northwest corner method*), metodu minimalnoga troška, metodu minimalnoga troška retka, metodu minimalnoga troška stupca i Vogelovu metodu aproksimacije te računalne aplikacije kao što su LINGO, Lingo i funkciju Solver koja je uključena u Microsoft Excel. Ova studija slučaja usredotočuje se na primjenu Microsoft Excel funkcije za pronalaženje minimalne cijene sustava transporta otpadnoga materijala kako bi se smanjio trošak transporta od centra grada do konačnoga odredišta (odlagalište). Rezultati dobiveni modeliranjem dali su optimalna rješenja koja su na kraju rada i provjerena.

Ključne riječi:
manipulacija otpadnim materijalom, problem prijevoza, linearno programiranje (LP), Microsoft Excel Solver; LINGO

Author’s contribution

Abdullah M. Y. Alzahrani (Ph. D., Assistant professor of Architectural Engineering) provided the conceptualization, validation of data, investigation, conducted the formal analysis of linear programming, interpretations and presentation of the results and writing – original draft.