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Technical and Economical Selection of Optimum Transfer-Transport Method in Solid Waste Management in Metropolitan Cities

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ABSTRACT: Transfer-transport of the waste is one of key functional elements in solid waste management from technical and financial viewpoint. Unfortunately very few reach activities has been conducted in this field regarding local characteristic of phenomenon which urges undertaking local surveys and research projects. Tehran Organization of Waste Recycling and Composting has decided to investigate different transfer-transport options for new Tehran landfill in Houshang Site which is located in far distance from Current landfill in Kahrizak. The study surveyed 3 main options comprising of 8 alternatives. This alternatives covered so many aspects of transfer-transport like road or rail transport, compaction of waste, size of containers and system of loading/unloading, The surveyed showed that the two alternative of heavy compaction in 65m3 semi-trailers will be the most economical system that enjoys so many environmental-ecological advantages over current practice.

Key words: Solid waste, Transport, Transfer, Management, Optimization, Tehran

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INTRODUCTION

Transport and transfer of solid waste is a critical part of any solid waste management program. The management of solid waste transfer and transport is most difficult and complex in an urban environment. It is partly due to generation of residential & commercial-industrial solid waste and recyclables takes place in every home, every apartment building and every commercial and industrial facility; as well as in the streets and parks as the patterns of waste generation become more diffuse and the total quantity of waste increase, the logistics of collection and transfer become more complex. Managers must recognize and deal with the concerns of a population paying bills for services that reflect the high cost of fuel and labour. This is also very important from financial point of view. Because a large fraction of the total cost is associated with the transport operation. Thus a small percentage improvement in the transfer-transport operation can affect a significant savings in the overall system cost. (Handbook of Solid Waste Management, 2002). Recently, Tehran Organization of Waste Recycling and Composting has decided to investigate the options of transporting waste to a new landfill site (Houshang site) which is 50 km from south-western boundary of city (BC Berlin, 2003). So a study concerning optimization of waste transport and transfer in the Iran's capital, Tehran, which is a metropolitan area has been done.

MATERIALS & METHODS

All transfer stations in Tehran were analyzed with respect to their potential for optimization. There are 12 active transfer stations in the Tehran metropolitan area that handle the most part of the household waste generated in the city. A negligible amount of waste is carried directly to the landfill which is currently located in Kahrizak. In table 1 the coding of transfer stations and their distance to the current Tehran landfill is mentioned (OWRC, 2001). As it can be deduced from Table 1 the transfer stations are scattered all over the city and so the distances between transfer stations and the landfill vary a lot (OWRC, 2003).

Table 1. Distance of Each Transfer Station to the New Landfill (OWRC, 2003)

Station No.	Name	Distance (km)
TS.1	Dar Abad	85.5
TS.2	BaniHashem	76.0
TS.3	Chitgar	80.0
TS.4	Beihaghi	76.5
TS.5	Golbarg	75.0
TS.6	Hakimiyeh	78.0
TS.7	Zanjan	69.5
TS.8	Harandi	61.7
TS.9	Aazadegan	61.0
TS.10	Miveh-va-Tarebar	59.0
TS.11	Jade Saveh	62.5
TS.12	Shahr-e-Rei	53.4

All transfer stations in Tehran except one are classified as large transfer stations according to the amount of waste transferred from each one (EPA, 2000). Current waste turnover of each active transfer station is shown in Table 2. All transfer station in Tehran has a considerable amount of spare capacity. The main point that limits the capacity of current transfer station is the number of semi-trailers available and the absence of waste storage system which increase the waiting time of collection vehicles. The method used in transfer stations is the direct haul method which is based on usage of more semi-trailer than tractors as the storage capacity. No classical compaction is implemented in transfer stations but some manual compaction or using shovels and pushing blade to compact the waste has been observed during site visits. At the landfill the pushing blade method is used by semi-trailers to unload the waste.Management of waste transport is done by private sector contractors and is supervised by the Motor Pool Department. The semi-trailers are owned by the Motor Pool Department and are lent to the contractor under conditions of contract. The circle time varies from each transfer station to another and is highly dependent on the timing of the transportation, technology of tractors and containers and the technology used in transfer stations.

RESULTS & DISCUSSIONS

The scenario underlying the transportation study is based on the main assumed scenario for landfill design. In recent years the density of waste in semi-trailers fell to 325 kg/m^3, thus proving that the waste density is decreasing in Tehran. This makes the compaction more favorable. In addition the amount of waste is increasing due to increasing in population and public welfare. Because of lack of yearly and continuous data on waste density, it is assumed that with the increasing percentage of non-degradable materials in waste the density of waste in the horizon of study would be 250 Kg/m^3 that would mean a middle range, reported for a middle income country (Rudolf, 2000). Transfer station alternatives include an extensive range of facilities from a simple soil platform to a multi-story building with sophisticated instruments. Consequently, the potential technologies used for these transfer stations vary considerably.

Table 2. Turnover of Each Transfer Station (OWRC 2003)

Station	Station No.	Turnover (2004) ton/year	Turnover (2019) ton/year
Darabad	TS.1	145,978.75	225,975.11
Bani Hashem	TS.2	47,510.41	73,546.12
Chitgar	TS.3	231,166.52	357,845.78
Beihaghi	TS.4	214,080.38	331,396.43
Golbarg	TS.5	128,100.00	198,298.80
Hakimieh	TS.6	194,920.82	301,737.44
Zanjan	TS.7	191,786.87	296,886.07
Harandi	TS.8	146,686.19	227,070.22
Azadegan	TS.9	230,914.85	357,456.18
Mive-Tarebar	TS.10	146,317.36	226,499.27
Jade Saveh	TS.11	164,675.42	254,917.56
Shahr-e-Rei	TS.12	92,964.78	143,909.48
Total		1,935,102.36	2,995,538.45

In Table 3 the advantages/ disadvantages and the common usage of transfer containers are discussed (EPA, 2002). One of the main points that should be considered in waste storage is the leachate generation. In tipping floor and surge pits systems because of significant amount of waste moisture, there would be considerable amount of leachate to collect and treat. This will create substantial cost of leachate treatment in order to release it to the surface water runoff drainage system (Ehrig, 1989).

The process of loading transport vehicles is the main issue of waste transfer which has a great effect on the whole transportation system. In Table 4 the advantages, disadvantages and the common usage of various alternatives are discussed (EPA, 2002).

Table 3. Transfer container and vehicle loading alternatives

Technology	Advantages	Disadvantages	Application
Tipping floor waste storage	Simple arrangement; little potential for equipment breakdown. Generally less expensive and provides more operational flexibility than pits. Storage provides "disconnect' between waste receipts and waste loading. (Shortage of empty trailers does not shut down facility.) Allows for easy screening and removal of unacceptable wastes. Allows for the breaking up of bulky items and the compacting of waste to increase density for more economical shipping.	Garbage on tipping floor can be messy and slippery (fall hazard). Potential for accident between customers and transfer station mobile equipment (e.g., wheel loader) that moves/stacks waste (safety issue). Requires roll-out space for trucks to pull forward when discharging their loads. Equipment is needed to reload the waste into the transfer trailer. Requires additional fire control equipment (e.g., fire hoes, water cannon) to control fires in waste piles on tipping floor. Expensive to construct.	Suitable for small and large transfer station; can manage nearly all waste types.
Surge pit	Storage provides 'disconnect" between waste receipts and waste loading. (Shortage of empty trailers does not shut down facility). Allows for the breaking up of bulky items and the compacting of waste to increase density for more economical shipping. No roll-out space required for unloading vehicles; waste falls from back of truck into pit. Eliminates potential for collision between transfer station equipment and customers.	Fall hazard for people and vehicles. Hazards to equipment operator working in pit when waste is being unloaded by customers. Can be difficult to remove unacceptable waste founding the pit. Extra building level (three stories instead of two might increase building above grade, increasing building profile. Equipment is needed to reload the waste into transfer trailer. Requires additional fire control equipment (e.g., fire hoses, water cannon) to control fires in waste piles in surge pit.	Most suitable for large transfer stations with high peak flows.

(1)

(2)

Figs. 1 & 2: Preload waste compaction into conical containers with container shift system

Table 4. Transfer container and vehicle loading alternatives

Technology	Advantages	Disadvantages	Application
Top-loading trailers and containers	Simple, gravity-loading method. Might be supplemented with compaction Suitable for a wide range of waste types.	Generally involves imperfect, permeable closure on top of trailer. Odors and litter can escape. Trailers can be damaged when dense or sharp materials fall into an empty trailer. Sound of waste falling into trailers can be noisy.	Suitable for small and large transfer stations.
Compaction into trailer and container	A trailer or container can be completely closed to prevent rainwater entry and odor and liquid from escaping.	A heavy trailer or container decreases effective payload. Capital cost of trailer fleet is greater. Tail end of trailer or container (near compactor) tends to become overloaded. Front end of trailer tends to be light. Hydraulic power equipment for compactor can be noisy.	Not commonly used for new transfer stations.
Preload compaction into rear-loading trailer or container	Allows use of lightweight trailer or container to increase effective payload. Trailer or container can be completely closed to prevent rainwater entry and liquid from escaping. Payload can be measured as it is compacted.	High capital costs. Relatively complex equipment. Less suitable for certain types of waste (oversize materials, concrete, wire, cable). Hydraulic power equipment for compactor can be noisy. A heavy electrical power consumption system.	Most suitable for high-volume transfer stations. Container alternative ideally suited for intermodal transfer to rail system.
Baling	Allows for efficient transportation due to density of waste and ability to use light-weight trailers. Trailer can be completely closed to prevent rainwater entry, and odor and liquid from escaping. Compatible with bale fills, which allow filling a large amount of waste in a small space. Baler can also be used to prepare recyclables for transport and sale.	High capital cost. Relatively complex equipment; when it breaks down. Hydraulic power equipment for baler can be noisy. Special equipment needed at landfill.	Suitable for large transfer stations, particularly those that need to haul waste over long distances.

Top loading into semi-trailers is the method which is currently in practice and the introduction of any alternative will need significant amounts of capital investment. With a longer distance to the new landfill than to the Kahrizak landfill, the option of minimization of volume of waste has to be evaluated. Baling will not be considered further, because of unstable bales due to large amounts of high density and moist organic waste, high capital and operational costs for balers in transfer stations and the need of a totally new technical and operational system to unload bales.

Each bale of approximately 1 ton of weight should be unloaded and stapled in the landfill. This would result in 8000 bales a day to be stapled in the landfill which is not feasible. Compaction directly into containers is a rarely applied practice for transfer stations and is not recommended for Tehran. Press water will remain in the containers and the container is especially enforced to absorb the direct pressing power. The only alternative to the currently successfully applied system is the pre-load compaction into containers. This study will, in addition to the current system, describe different container types and sizes for both rail and road transport. The unloading procedure is highly dependent on the technology in use and the type of container to be used. There are four options to unload vehicles.

In Table 5 the advantages, disadvantages and the common usage of varoius alternatives are discussed. Among all alternatives the trailer tippers is used in current situation and will have less needed capital cost to modify present system.
It is also compatible for container-type railway transfer. If there would be operation problems due to short tipping front to cause some delays for transport trailers open top railcar tippers would be considered.

From the Table 5, two possible options derivs: either the trailer tipper, for smaller containers (e.g. 30 m³) by a hook-lift system, or the push-out blade for larger containers (up to 65 m³). Both options will be compared and described in the text. In order to select the best Transfer-Transport method for the city, technical and economical characteristics of the systems must be taken into consideration.

Option 1: Open semi trailer and sample of methodology used

In the case of current way of transportation to the landfill with some minor changes (Top closing, cleaner transfer…), the available transfer stations will be used further on, without building a new one. The same trailers and tractors as currently used will transport the waste and therefore no compaction is possible, at least not to an efficient level.

The only system which could be considered for open trailers in this respect is the power roller. The investment costs for this system is around US$ 20,000 and the compaction rate is only significant for light densities such as packaging and paper. So with no recycling it is not recommended to use this approach. Because of the longer distance to the new landfill the cycle times will increase and additional vehicles will be necessary. Accordingly more drivers will be needed. The vehicles will also have a higher rate of wear and will not last as long as the currently used vehicles.

Table 5. Transfer Container and Vehicle Unloading Alternatives

Technology	Advantages	Disadvantages	Application
Push-out blade transfer trailer	Allows for unloading anywhere (not just at a landfill with a trailer tipper).	Some trailer capacity used for the push-out blade, which reduce effective waste payload. Material can became stuck behind push-out blade. Blade can bind during extension or retraction.	Most suitable for short-distance, low-volume hauling.
Walking floor transfer trailer	Allows for unloading anywhere (not just at a landfill with a trailer tipper).	More prone to leak liquids from the bottom of the trailer. More prone to damage from dense or sharp objects.	Suitable for a range of volumes and distances.
Trailer tipper for transfers trailers and trailer mounted containers	Allows use of light-weight trailer to maximize payloads. Ideal for rail-based container intermodal system	High reliability or redundancy required. No way to unload trailer at the landfill if the tipper fails. Tippers can be unstable if placed over waste at landfill.	Most suitable for long-distance, high-volume hauls. Most suitable for hauls to large landfill (small to medium-sized landfills most likely to have a tipper).
Open-top railcar tippers	Extremely rapid, large-volume unloading.	Fixed unloading point requires reloading and some other form of transport from unloading point to final destination.	Most suitable for a fixed disposal method such as at a solid waste incinerator.

In Table 6 a sample methodology used to calculate investment costs and required fleet for transport of waste is mentioned. In other alternatives the same methodology is used.

Option 2: Container with compaction on road

In this option, the waste is compacted before loading into containers. The objective is to reduce the size of the transportation fleet, which in turn means reduction of the number of trips and overall investment. The option works with using sticks to the present way of waste delivery to the landfill using the road. The preload compaction system can compress the waste in range of 400-500 kg per cubic meter. If compared to the 300 kg/m^3 average current waste density increase the capacity of containers to about 30-40%.

Option 2a: 50 m^3 containers on semi-trailers

The containers of 50 m^3 volume are put on semi-trailers, the loading is via the compaction unit (Chapter 5), the unloading via push-out blade. Compaction of waste is performed by installation of compactors at the existing transfer stations.

Option 2b: Two 30 m^3 flexible containers

This option is increasing the transported amount of waste by using two 30 m^3 containers: one each on the chassis and the trailer. Loading and un-loading will be done with the help of a hook-lift. The hook lift will also be used to lift the container from the trailer and to empty it too.

Option 2c: 65m^3 containers on semi-trailers

This option is the continuation of option 1 after addition of compaction facilities at the existing transfer stations. Also, it utilizes 65 m^3 fully closed containers fixed on semi-trailers which are filled with compacted waste at the transfer stations and pulled to the landfill by tractors. The process of unloading waste at the landfill is made through installation of push-out blades at each container.

At the new transfer station (with railway connection) compactors will be installed. The delivered waste is tipped into the compaction hopper and pressed into enclosed 30-ft container. The delivery from nearer districts is directly done by collection vehicles, from far-away districts the existing transport vehicles transport from the existing transfer station to the new one. In this mode a part of the existing transfer stations can be closed to save space and personnel. The full container is removed from the compactor and an empty one is linked by an automatic container change system.

Table 6. Circle time and investment

Assumed average speed of vehicles:	30 km/h
Circle time:	
Loading:	30 min
Driving to landfill:	140 min
Unloading:	30 min
Driving back to transfer station:	140 min
Total circle time:	5.7 h
Resulting circles per vehicle and day:	4 circles
Container volume:	65 m^3
Payload:	16.4 tons
Waste transported by one vehicle per day:	66 tons
Number of vehicles needed for daily transport of waste:	130 vehicles
Safety percentage of vehicles needed (including spare vehicles):	35 %
Number of extra vehicles needed:	46 vehicles
Vehicles in total:	176 vehicles
Investment in US$:	
Semi-trailer and Container:	7,661,176
Pushing-Blade:	8,800,000
Tractor vehicles:	20,705,882
Workshop:	153,158
Trailer cleansing facility:	19,439
Sum	**37,339,656**

For continuous work of the compactors a container stock is necessary to have empty containers available in time when no train is at the station. The containers are loaded on the train by movable cranes or stationary cranes with automatically moving locomotives to tug the train and position the wagons under the crane. The train transports the container to the landfill station, where other cranes lift the container onto semi-trailers. Semi-trailers are tugged to the deposit site by tractor units with installed hydraulic equipment to unload the container by pressing the front shield through it. The empty container is brought back to the station and loaded on the train again by crane. This variant is similar to the transfer station in Berlin-Gradestraße which is one of several transfer stations in the world which transport the waste via rail.

Option 3a: 50 m³ containers on semi-trailers

This option builds on the characteristics of option 2a for deliveries to the rail transfer station. The rail transport cannot take place from each transfer station, and the waste needs to be transported to and from the two rail-container terminals.

Option 3b: 30 m³ flexible containers

This option builds on characteristics of option 2b for deliveries to the rail transfer station. In this case, the containers are transported by heavy-duty lifters instead of cranes.

Option 3c: 65 m³ containers fixed on semi-trailers

This option builds on characteristics of option 2c for deliveries to and from the rail transfer station.

Option 4: Open semi-trailer on rail

In this option the waste transport vehicles drive on the railway wagons (railway- owned wagons) via a ramp. When the whole train is loaded it is driven to the landfill. At the landfill other drivers take over the vehicles and drive from the station to the deposit site, unload the vehicles and bring back the empty vehicles to the railway wagons which are driven back to the loading station where the regular drivers take back the vehicles.

In this option the working times of the drivers for the transportation period are saved and only loading and unloading stations without further equipment are needed. The benefit of railroad transport is generally the less environmental impact by reducing noise and pollution and the saving of traffic movements.But the numbers of vehicles increases as well as the number of drivers and the transportation of vehicles cause a loss of payload on the railway wagons.

The comparison of costs will consider not only the investment costs but also the operating costs and other preferences such as ecological reasons.

Table 7. The Operation cost of different transport alternatives (US$) in the year 2019

Cost Items	Option#1	Option#2			Option#3			Option#4
		A	B	C	A	B	C	
Total investment sum:	**37.339.656**	**36.465.951**	**29.737.867**	**31.463.156**	**42.527.728**	**34.644.122**	**41.722.188**	**33.891.071**
Depreciation	3.726.308	3.639.824	2.968.780	3.141.485	3.366.684	3.016.509	3.628.126	3.230.646
Capital Costs	1.306.888	1.276.308	1.040.825	1.101.210	1.488.470	1.212.544	1.460.277	1.186.187
Staff Costs	5.937.750	5.659.875	7.171.125	5.196.750	5.859.750	5.416.125	5.713.500	6.127.875
Repair&Maintenance	2.233.475	2.182.541	1.779.758	1.883.435	2.190.315	1.717.752	2.142.690	1.421.931
Insurance	568.377	727.423	593.178	627.739	585.665	529.551	569.801	494.861
Fuel	123.653	97.020	67.375	77.996	42.732	30.475	34.626	34.752
Tires	3.257.647	2.556.000	1.770.000	2.054.824	1.122.000	800.471	909.176	892.941
Tax	0	0	0	0	0	0	0	0
Rail Transportation	0	0	0	0	24.447.124	40.745.206	24.447.124	42.782.466
Total operation sum:	**17.154.098**	**16.138.991**	**15.391.041**	**14.083.439**	**39.102.740**	**53.468.634**	**38.905.319**	**56.171.660**
Annual cost per Ton:	**5,74**	**5,40**	**5,15**	**4,71**	**13,08**	**17,88**	**13,01**	**18,79**

Therefore an enormous amount of information is required to cover the local situation as exactly as possible and to proof the conditions for each individual transportation system.

If options No. 1 or No. 2 is considered to be implemented, a bypass of approximately 3 km will be needed to avoid crossing small towns in the road. The investment cost of this bypass is estimated at US$ 1,100,000.

Table 7, shows the comparison of costs in 2019 in US$ for different variants. The implementation of a successful waste reduction strategy by 25% would result in

- 20% less investment costs and a 10% increase of the costs per Mg for the transportation system with compaction;
- 25% less investment costs and a 5% increase of the costs per Mg for the road transportation system without compaction, and
- 10% less investment costs and a 5% increase of the costs per Mg for the transportation system by rail

The differences can easily be explained by the different impact of the reduction on the investments and the related operation.

CONCLUSION

As a result of the comparative transfer analysis the current option should be phased out. The current system does create pollution on the way due to the open semi-trailers, and causes the highest number of vehicle movements through the city.

It has also been shown that the railway option is not recommendable. Firstly, expensive new tracks towards the landfill should be planned. Secondly the transport is several times broken, since waste is to be transported from the transfer stations to a rail terminal by truck and also from the final terminal at the landfill towards the dumping site. Two additional transfer stations with container movement facilities are needed and the need of more containers as buffer or while in the train. This requirement increases the price for the rail option significantly. Finally, the rent for the rail wagons adds up to the higher price of the railroad option.

The transportation by road has as described above has several environmental and social impacts. Those impacts can be reduced by reducing the number of daily trips for the transportation of the waste to the landfill.This will be achieved by compacting the waste prior to loading. The direct compaction into the containers is not recommended since the amount of liquid as a result from the pressing can not be collected externally and has to remain in the container. From the three researched options, two 30 m³container on a truck and a trailer are considered as less favourable: Firstly, the system is less efficient due to higher investment costs and longer loading and unloading procedures. Secondly, this system is different to the existing equipment.

As Fig. 3 and the related tables demonstrate, due to the greater distance from the new landfill to the transfer stations the compaction system is more effective in both terms of capital and operation costs.

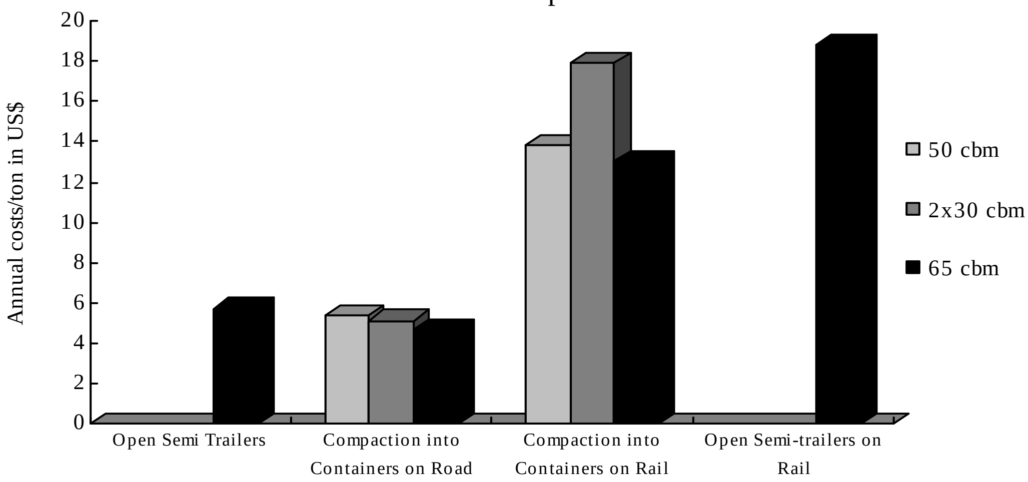

Fig. 3. Annual costs per ton of transferred waste

The lower numbers of vehicles for the compaction alternative and especially the container system result in even less capital costs.

Consequently, the most preferred option is the 65 m³ closed container system attached to semi-trailers with push out blade and pre-load compaction.

In the same way, the 50 m³ container system might be considered as neither the operation nor the cost does not differ significantly. The final price can be determined by the tendering procedure. If the compactors are all of the same made all type of containers should be compatible to the compaction unit. This will, however, depend on the supplier of the material.

The costs for pre-load compaction are estimated at 10 to 15 % of the total investment sum, while the resulting reduction in transportation equipment will be more than 20 to 40 %.

The study in Tehran shows that in the larg cities as the landfills are located in remote areas, optimization of the transport/transfer system can make a great change in the investment and operation costs of the system and it is feasible to introduce innovative technologies for transporting the waste. On the other hand it has been shown that if the transfer stations are so spatially dispersed and there is limited number of railway stations in dense urban areas, it will not be feasible to use railway transport even for very distant landfills. The study shows that implementation of a compaction system would be potentially beneficial to decrease the costs and environmental impacts in such situation.

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