

TRANSFER STATION DESIGN CONCEPTS FOR DEVELOPING COUNTRIES

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INTRODUCTION

Refuse collection represents a significant expenditure for cities in developing countries, often comprising from 20 to 50 percent of local government revenues just for coverage of recurrent expenditures. Collection of solid waste consumes a higher share of income in developing countries than it does in industrialized countries. While labor costs are lower in developing countries, the purchase price of equipment is typically higher, interest rates on credit and customs duties can be markedly higher, and fuel costs more. Also, because spare parts are not commonly available locally, repair and maintenance costs can be higher. For a view of how collection costs vary by country income level, see Table 1.

In nearly every developing country, the capital city has grown to the extent that transfer stations need to be considered. Not only distance to disposal, but travel times (due largely to traffic congestion) have dramatically increased in the past decade. As a general rule of thumb, if the one-way travel distance to disposal is over 20 km and the one-way travel time is over 30 minutes, implementation of transfer stations should be assessed.

This paper outlines alternative design concepts to consider in planning transfer stations. The design concepts are outlined under the stages of a transfer system, as defined below:

- (1) Unloading. Unloading of collection vehicles and, as needed, temporary storage of wastes at the transfer station.
- (2) Loading. Loading systems for transfer vehicles at the transfer station.
- (3) Transport. Bulk haulage in transfer vehicles.
- (4) Discharge. Unloading of transfer vehicles at the disposal site.

**GLOBAL PERSPECTIVE ON
SOLID WASTE MANAGEMENT COSTS VERSUS INCOME**

	LOW INCOME COUNTRY	MIDDLE IN- COME COUNTRY	HIGH INCOME COUNTRY
WASTE GENER- ATION	0.2 m.t./cap/yr	0.3 m.t./cap/yr	0.6 m.t./cap/yr
AVE. INCOME FROM GNP	370 \$/cap/yr	2,400 \$/cap/yr	22,000 \$/cap/yr
COLLECTION COST	10-30 \$/m.t.	30-70 \$/m.t.	70-120 \$/m.t.
TRANSFER COST	3-5 \$/m.t.	5-15 \$/m.t.	15-20 \$/m.t.
SANITARY LANDFILL COST	1-5 \$/m.t.	3-10 \$/m.t.	20-50 \$/m.t.
TOTAL COST	14-40 \$/m.t.	38-95 \$/m.t.	105-190 \$/m.t.
COST AS % OF INCOME	0.8 - 2.2%	0.5 - 1.2%	0.3 - 0.5%

Note:

1. Income based on 1992 Gross National Product data from the World Development Report 1994 published by the World Bank.
2. Costs are for owning, operation, maintenance, and debt service in 1992, assuming no equipment provision through grants.
3. If sanitary landfill can be located with an economic haul distance allowing direct haul in collection vehicles, the cost of transfer can be avoided. An economic haul time for a truck carrying 2 to 6 tonnes is typically 30 minutes one-way from the collection area to the unloading point. Depending on traffic conditions affecting vehicle speed, 30 minute one-way would be 15 to 20 kilometers one-way.
4. \$/m.t. means US Dollars per metric tonne, and \$/cap/yr means US Dollars per capita per year.

Source: Sandra Cointreau-Levine

This paper discusses only truck transfer. Instead of loading trailers which are pulled by truck tractors, as discussed in this paper, transfer stations can also be designed to load containers. Such containers can be loaded on a roll-on tilt frame which is pulled by a truck tractor. They can also be loaded on flat bed freight cars pulled by a locomotive, or on cargo boat or barge.

Transport by rail would be cost-effective only if the closest disposal site is far from the source of waste production (e.g., over 150 km) or inaccessible by any other means, because of the cost to build the special handling facilities required to load water-based and rail-based transport systems and to unload them. Rail systems require more land for the transfer station than truck systems, because it would be infeasible to make more than 2 pick-ups per day of the filled cars, thus requiring a rail spur to park the filled cars while they await pickup. Acquiring open land adjacent to the railroad and within the urban area can be difficult. Similarly, barge transfer requires significant loading/unloading infrastructure and acquiring land along the harbor can be difficult. Also, because the port area of developing countries is typically the oldest part of the city and has the greatest traffic congestion, productivity and cost of the collection system could be adversely affected by locating a transfer station within the port area.

UNLOADING DESIGN CONCEPTS

There are two design concepts to consider for unloading. Collection vehicles either can unload directly into transfer vehicles or can unload into a storage area, from which waste is later loaded into transfer vehicles, as defined below:

- o Direct Unloading. A direct unloading system involves collection vehicles discharging directly into transfer vehicles or their loading systems. A two-level arrangement is required, wherein the collection vehicles drive up a ramp to the upper level in order to discharge into a transfer vehicle parked or loading system (i.e., conveyors and/or stationary compactors).
- o Unloading-to-Storage. An unloading-to-storage system involves collection vehicles discharging into a storage area. From the storage area, wastes are subsequently loaded into transfer vehicles. The storage area may be a platform on the same level as the unloading level, in which case only a two-level arrangement is required. The storage area may be a pit, below the level of the unloading level, and above the level on which the transfer vehicle is parked, in which case a three-level arrangement is required. The storage area is commonly designed to hold the peak quantity of waste generated in one day.

Direct unloading systems require the most minimal of civil works and stationary equipment facilities, and are thus the lowest cost to implement, but necessarily the lowest cost to operate, as discussed below. The wide applicability of direct unloading systems is indicated by those currently in operation:

- o Collection truck direct to transfer truck, without conveyance or compaction, in Ho Chi Minh City, Viet Nam; Izmir, Turkey; Riga, Latvia; Mexico City, Mexico; and Manila, Philippines.
- o Collection truck to stationary compaction, then to transfer truck, in Singapore; Hong Kong; Jakarta, Indonesia; Sophia, Bulgaria; and Bogota, Colombia.

The direct unloading system requires that the availability of transfer vehicles at the transfer station keep pace with the arrival of collection vehicles, so that no delays are caused in the collection operations. Such coordination is difficult to orchestrate within a large-scale system where there is a steady stream of collection trucks arriving to discharge their loads. Therefore, the direct unloading system is usually implemented only as a small-scale system, i.e., typically where the quantity of waste handled is less than 300 tonnes/day. If it is implemented as a large-scale transfer station, there needs to be adequate provision of discharge hoppers and transfer vehicles to make sure that collection trucks are never kept waiting.

For loading of the trailers in the direct unloading system, use of a knuckleboom crane is recommended. This small crane, mounted on the side of the receiving hopper, costs less than the price of one transfer trailer. The knuckleboom crane is used to distribute the load evenly over the transfer vehicle's axles, so that overloading on any one axle is avoided. Also, the knuckleboom crane can be used to compact the load so that maximum allowable loading is achieved. For optimum results, the trailer would be standing on weight scales which allow the crane operator to continuously observe the weight on each axle, as well as the overall vehicle and load weight.

As noted above, one advantage to the direct unloading system is that it involves the smallest investment in civil works. Because there is no storage of wastes in the direct unloading system, the building size is minimized. Furthermore, investment in systems to minimize odors and insects would be minimal, because such impacts are associated with solid wastes being stored at the station rather than the movement of wastes through the station.

On the other hand, a potential disadvantage to the direct unloading system is that it requires the fleet size of transfer vehicles (and associated loading systems) to be large enough to keep pace with the unloading requirements of the collection fleet. Most collection vehicles must operate only during a limited period of time each day -- usually early in the morning hours. Filling the collection vehicle can take from one to five hours, depending on its capacity and the nature of loading from the collection points. In most cities, collection vehicles arrive at the transfer station within one or two peak hours per shift. The size of the transfer fleet, in a direct unloading system, would have to meet these peak hour demands. For this reason, recently designed transfer facilities for Seoul, Korea and Manila, Philippines included storage capacity.

In the unloading-to-storage system, waste unloaded to a storage platform is pushed by a bulldozer (or wheeled loader) into a hopper or onto a conveyor. Waste unloaded to a storage pit is picked up

by an overhead crane or pushed by a bulldozer to the receiving hopper. The crane or bulldozer operator visually inspects the waste during operation to set aside any wastes which are potentially hazardous or could damage the transfer vehicle during loading.

Bulldozers are widely available and portable equipment which are relatively easy to operate and maintain. In cities where there is a surplus of such equipment, because of a slow-down in construction activity, there might be merit in contracting for this part of the transfer operation. The overhead crane requires adequate structural support for the overhead track-mounting. Also, the crane operator works from a glass-enclosed air-conditioned room well above the storage pit. If the crane breaks down and spares are not locally available, the station could be shut down to operations. In developing countries, spares for bulldozers are more likely to be locally available than spares for overhead cranes.

The unloading-to-storage system allows the collection system to operate under conditions optimal to its nature. Waste collection is conducted in the mornings so that unsightly waste containers awaiting collection are not visible during the principle hours when residents and visitors are traveling around the city. Also, waste collection is conducted in the morning when the temperatures are cooler and conditions are lighter. With a transfer system, collection vehicles unload during the morning periods when waste collection is commonly most appropriate.

Similarly, the unloading-to-storage system allows the transfer system to operate under conditions optimal to its nature. Bulk transport operations could occur at night when traffic is lightest. The unloading-to-storage systems allows for a longer period of transfer operations than the period of unloading by collection vehicles. For example, even though a collection operations commonly occur between 6 AM to 1 PM with unloading occurring between 8 AM and 1 PM, the transfer operations could occur over a 24-hour period. As a result, the investment in transfer vehicles and any equipment associated with loading and unloading transfer vehicles can be minimized.

LOADING DESIGN CONCEPTS

There are various systems for loading waste into transfer vehicles. The most common loading systems are outlined below:

- o Direct Loading to Transfer Vehicle. Waste discharged from collection vehicles or from the storage area drops by gravity through a hopper directly into an open-top transfer vehicle. A knuckle-boom crane may be mounted at the mouth of the hopper, and used to distribute the load evenly within the transfer vehicle.
- o Loading by Stationary Compactor. Waste drops through a hopper into a stationary compactor which is mounted on the floor of the lower level of the transfer station. The compactor contains a hydraulically driven ram which pushes the waste from the compactor's receiving chamber into the body of the transfer vehicle. The body of the transfer vehicle must be adequately reinforced to take the force of the ram.

- o Loading by Pre-Load Compactor. Waste drops through a hopper into a pre-load compactor which is mounted on the floor of the lower level of the transfer station. The pre-load compactor contains a hydraulically driven ram which pushes the waste from the compactor's receiving chamber into a compaction chamber. The compaction chamber is reinforced to take the force of the ram and sized to make a compacted unit which would readily fit within the body of the transfer vehicle. Once the compacted unit of waste is fully formed, it is extruded from the compaction chamber into the transfer vehicle. Because the transfer vehicle does not receive compaction forces, it does not need to be reinforced to take the force of the ram.

- o Direct Loading to Self-Contained Compaction Vehicle. Waste drops through a hopper into a self-contained compaction vehicle. A movable bulkhead mounted at the front of the body of the vehicle pushes the waste toward the back doors of the body. Compaction is achieved as the waste's void spaces are reduced and forces from the bulkhead are applied. The same movable bulkhead which compresses the waste is also used to push it from the vehicle at the disposal site. The body of the vehicle must be reinforced to take the force of the ram.

Local waste characteristics affect technology choices. For example, the potential for achieving a significant compaction is affected by the density of incoming waste and its potential for volume reduction through compaction. In industrialized countries, compaction typically achieves 3:1 volume reduction. In developing countries, it is more common to experience only a 1.5:1 volume reduction. When the level of income in a country is low, the content of organic putrescibles, moisture, ash and soil in the solid waste is high. Also, the lower the level of income, the less likely there are to be low density packaging materials such as bottles, cans, and cartons. Therefore, for lower income countries, density is higher. In low-income developing countries, loose wastes have a density of about 300 kg/c.m. In middle-income developing countries, loose waste averages 250 kg/c.m. In industrialized countries, it is only about 170 kg/c.m. See Table 3 for refuse characteristics by income level.

The compacted densities achieved in low-income countries are typically higher than those in industrialized countries -- 450 to 600 kg/c.m. in developing countries versus 350 to 500 kg/c.m. in industrialized countries -- because of their waste's higher moisture content and inerts content. Moisture contents in wastes in developing countries range from 45 to 85 percent, versus moisture contents in industrialized countries of 20 to 30 percent. Developing countries have more inert fines, because of poor confinement of wastes at the source and inclusion of ash from cooking and heating activities. See Table 3 for refuse characteristics. (Note: In industrialized countries, cities with high rates of recycling, such as Minneapolis, Minnesota, USA, are now experiencing significantly elevated densities within their compaction vehicles - sometimes exceeding their design capacity of 1,000 lb. per cu. yd., or 590 kg/c.m., and thus necessitating vehicle design changes or only partial filling.)

Load bearing limitations and maximum vehicle dimensions specified in local and national design standards for roads and bridges affect the choice of loading technology. In the USA, central government design standards for government-built bridges limit gross vehicle weight to 36.4 tonnes and 5 axles, with no axle carrying more than 7.7 tonnes. However, some of the states in the USA allow heavier vehicle weights on their roads and bridges, with gross vehicle weights as high as 53.9 tonnes allowed on 7 axles in the state of Michigan.

**GLOBAL PERSPECTIVE ON
REFUSE DIFFERENCES**

	LOW INCOME COUNTRY	MIDDLE INCOME COUNTRY	HIGH INCOME COUNTRY
KG/CAPITA/DAY	0.4 to 0.6	0.5 to 0.9	0.7 to 1.8
PUTRESCIBLES %	40 to 85	20 to 65	20 to 50
PAPER %	1 to 10	15 to 40	15 to 40
PLASTIC %	1 to 5	2 to 6	2 to 10
METAL %	1 to 5	1 to 5	3 to 13
GLASS %	1 to 10	1 to 10	4 to 10
RUBBER,MISC.%	1 to 5	1 to 5	2 to 10
FINES %	15 to 60	15 to 50	5 to 20
MOISTURE %	40 to 80	40 to 60	20 to 30
DENSITY KG/C.M.	250 to 500	170 to 330	100 to 170
LOWER KG/KCAL	800 to 1100	1000 to 1300	1500 to 2700

Notes:

1. Country categorization by income is based on 1992 GNP data from the 1994 World Development Report published by the World Bank. Waste data based on a wet, "as received", condition (i.e, not oven dried).
2. Compaction trucks achieve load densities of 400 to 500 kg/c.m. in both developing and industrialized countries, based on their hydraulic mechanism designs. Higher densities result from high soil and water contents present at high levels in the wastes of some countries.
3. For self-sustained incineration, a year-round minimum of 1300 kcal/kg lower calorific value (i.e., as received) is needed. For waste-to-energy plants, 2200 kcal/kg is the minimum calorific

value desired.

4. Some Eastern European cities within middle income countries have marginally suitable levels calorific value for incineration of 1300 to 1600 kcal/kg.

Source: Sandra Cointreau-Levine

Many developing countries have a central government standard for road and bridge design which is comparable to the USA standard, and thereby limit gross vehicle weight to 40 tonnes on 5 axles, with no axle carrying more than 8 tonnes. Early in the process of planning a transfer station, the designer needs to determine what vehicle weight standard exists, whether bridges and roads along the route are actually designed to meet the standard, and whether the standard is enforced.

If the maximum size of transfer vehicle can be filled to achieve allowable load limits without compaction, there is probably little economic justification for compaction. The owning and operating costs of larger transfer vehicles for hauling uncompacted waste need to be compared with the costs of smaller vehicles hauling compacted waste. Also, the incremental cost for compaction needs to be added to the owning and operating costs of the fleet hauling compacted wastes.

Total system costs for loading and transport need to be analyzed in order to choose the most cost-effective system. Apparently small differences in cost might prove to be significant if the travel time from transfer station to disposal site is substantial. Countries which are largely dependent on imported fuel and subsequently have higher fuel costs might have a greater need to maximize vehicle productivity by compacting loads, if there are road restrictions on vehicle size, or by using larger capacity vehicles. Similarly, countries where the salaries of drivers for transfer vehicles are relatively high, as in industrialized countries, might have a greater need to maximize vehicle productivity by compacting loads.

Skill levels necessary and spare parts locally available to keep the loading system operating reliably need to be considered. In general, loading systems which provide compaction require a higher level of skill to operate and maintain and more careful inventory planning of spare parts which need to be imported. This can be a deciding factor in some developing countries, especially where there are importation restrictions due to limited foreign exchange.

The stationary compactor makes a densified waste load for hauling. With a more densified load, the size of the transfer vehicle could be minimized. However, because the body of the transfer vehicle must be reinforced to take the force of the ram compactor, it weighs more. Therefore, within any constraints of gross vehicle weights imposed by local road and bridge design standards, the maximum allowable load would be less in a vehicle which weighs more.

Like the stationary compactor, the pre-load compaction system makes a densified waste load for hauling. However, because the load is formed in a compaction chamber and then extruded into the body of the transfer vehicle, the vehicle does not have to be strongly reinforced to take compaction forces. Vehicles used with the pre-load compaction system are similar in design to vehicles used with the non-compaction systems of loading by bulldozer or crane, except that they do not need to have an open top for gravity loading.

Most transfer stations with storage areas continuously provide visual inspection of waste before loading, in order to avoid dropping heavy items (such as engine blocks and batteries) which might cause damage to the floor of the transfer vehicle. The stationary compactor and pre-load

compactor are the only loading systems wherein waste is dropped into a receiving chamber rather than into the body of the transfer vehicle. Therefore, damage to the floor of the vehicle is minimized by these loading systems.

The self-contained compaction system has the compaction mechanism mounted on the transfer vehicle. Therefore, the weight of the transfer vehicle is heavier than with any of the other loading systems. Self-contained compaction systems might be appropriate in areas where there are many small neighborhood transfer stations being served by the fleet of transfer vehicles, and where compaction is justifiable but not at each station. Also, self-contained compaction systems could be used at small transfer stations which do not have any power source for operating a stationary ram compactor or pre-load compactor. As with all of the compaction systems, the mechanisms require special maintenance skill and stocking of spare parts so that down-time is minimized.

To evaluate which system is most cost-effective, factors other than cost are also taken into consideration. These factors require a qualitative judgement regarding their value relative to cost. For example, Seoul, Korea, is including pre-load compactors in its first transfer station which being built this year. The waste coming into the plant has a relatively high density (i.e., 270 kg/c.m. after source separation of the coal briquette ash) and pre-load compactors will probably achieve a compaction ratio of only 2 to 1 (i.e., to 550 kg/c.m.). Because Seoul has restrictions on the allowable size of transfer vehicle (i.e., 67 c.m. maximum allowable trailer capacity), as well as strict load limitations on gross vehicle weight (i.e., 40 tonnes), use of the pre-load compaction system has a comparable cost to use of direct loading into open-top trailers. Concerns expressed by residents over potential noise, dust, and odor impacts of the proposed station led the city to choose pre-load compaction over the direct loading system, because it provides more enclosure and might lessen these impacts.

To evaluate which system is most cost-effective sometimes requires looking beyond the transfer system to the disposal system. For example, Singapore has included stationary compactors in its newest transfer station, even though the incoming waste is already well compacted within collection trucks. The incoming compacted waste loses about 10 percent of its density during unloading (i.e., density is reduced from about 500 to 450 kg/c.m.). Therefore the stationary compactor achieves a compaction ratio of only 1.2 to 1 (i.e., 450 to 550 kg/c.m.). Because Singapore has very little land available for disposal by sanitary landfill, most of its waste must be incinerated. The stationary compaction improves the calorific value to the waste for incineration by squeezing out some of the waste's moisture. Moisture levels in refuse coming into the transfer station average 50%, whereas moisture levels after compaction at the transfer station average 40%.

TRANSPORT DESIGN CONCEPTS

This paper discusses transfer stations in which collection trucks discharge their loads to large capacity hauling trucks. Small neighborhood transfer depots, wherein collection workers with hand push carts or donkey carts transfer waste into an open tipping truck, are not discussed in this paper.

The transfer vehicles discussed herein are truck tractors pulling trailers of various designs, as outlined below:

- o Open Top Trailers. These trailers are open at top and have doors at the back. After filling, the waste is covered (i.e., by tarp) so that it doesn't blow out during transport. Open top trailers are loaded from the top by gravity feed through a hopper. They also can be loaded from the back by the pre-load compaction loading system.
- o Closed Top Trailers. These trailers have side walls and roofing, and doors at the back. Closed top trailers are loaded by pre-load compactors. The untied bale of waste is extruded from the compactor into the body of the trailer.
- o Compactor-Compatible Closed Top Trailers. These trailers have side walls and roofing, and doors at the back. Compactor-compatible closed top trailers are loaded by stationary ram compactors. Unlike the light-weight trailer described above, the siding and roofing is reinforced to be able to receive the forces of the ram.
- o Self-Contained Compaction Trailers. These trailers are closed at the top, except for an opening to receive waste near the front of the top. They have side walls and roofing, and doors at the back. The movable bulkhead is mounted at the front of the trailer and pushes waste from the front toward the closed back doors. The side walls, roofing, and back doors are reinforced to be able to receive the forces of the movable bulkhead. The movable bulkhead is also used for discharging the waste at the disposal site and operates by pushing the waste out the back when the doors are opened.

The allowable load limit used in design of roads and bridges is different from country to country. It commonly is set between 36 and 46 tonnes gross vehicle weight. The most typical value used in developing countries is 40 tonnes gross vehicle weight. For a 40 tonne limit, the average truck tractor able to pull this gross vehicle weight would weigh about 7 tonnes. This means that the weight of the loaded trailer could be as much as 33 tonnes.

The weight of the trailer depends on the material with which it is made and on the extent of reinforcing provided. Most trailers used to transfer refuse have vertical side wall bracing. When the trailers are subjected to compaction forces, the spacing of the bracing may be closer than when the trailers are loaded by gravity feed from the top. Also, when the trailers are subjected to compaction forces, they have horizontal side wall bracing in the areas receiving the greatest force.

Trailers commonly are made of steel or aluminum. The aluminum trailers weigh 15% to 20% less than comparable steel trailers. For example, an empty 75 c.m. open top aluminum trailer weighs about 5.5 tonnes, while an empty open top steel trailer of the same size weighs about 7 tonnes.

Similarly, an empty 75 c.m. compactor-compatible aluminum trailer weighs about 6.5 tonnes, while

an empty compactor-compatible steel trailer of the same size weighs about 8.5 tonnes.

A self-compacting steel trailer would weigh significantly more than an empty compactor-compatible steel trailer of the same size. For example, a 75 c.m. self-compacting steel trailer would weigh about 14 tonnes, compared to a weight of about 8.5 tonnes for an empty steel trailer which is compactor-compatible.

There is a new light-weight steel being used for trailer manufacture in the USA. With the new light-weight steel, the weight difference between aluminum and steel could be reduced by half.

Lighter aluminum trailers, because of its lighter weight, can haul more waste within road and bridge road limits. However, aluminum trailers cost 40% to 60% more than steel trailers. Also, aluminum trailers are more costly to repair, because they are more difficult to weld and materials are more costly. Furthermore, aluminum is more rigid than steel and more likely to dent, crack or tear. Steel, because it is a more flexible material and is easier to repair, was the material of choice in both the recent Hong Kong and Singapore transfer systems.

In order to determine whether aluminum is cost-effective, the additional vehicle productivity of the aluminum trailers must be weighed against their higher purchase price and operation/maintenance cost. Also, refuse characteristics are a factor. For household refuse, there is limited potential for damage during loading; whereas, heavy bulky materials present in commercial, industrial, or construction/debris might preclude consideration of lighter weight trailers. There are few developing countries with local ability to manufacture aluminum trailers, while a number of developing countries have local ability to manufacture steel trailers. Cost-effectiveness analysis would therefore also consider the availability and cost of foreign exchange for purchasing aluminum versus steel trailers, as well as the cost of shipping and customs duties.

DISCHARGE DESIGN CONCEPTS

A discharge system may be either self-contained (i.e., mounted on the transfer vehicle) or external (i.e., located at the disposal site). The discharge systems discussed in this paper are self-contained, except for one external system which is called the mobile-tipper. The main types of discharge systems are defined as follows:

- o Push-blade. The push-blade discharge system is a single tilted blade sized to fit within the full cross-sectional area of the trailer body and pushed from front to back, in order to push waste out the back. The blade is pushed by one or two hydraulic cylinders mounted between the blade and the front of the trailer. To discharge its load, the transfer vehicle is driven onto the landfill area, backed up to the working face, its back doors are opened, and the load is pushed out the back by the push-blade. The push-blade system is compatible with closed top trailers which have been loaded by stationary compactor or pre-load compactor systems.

- o Live-floor. The live-floor discharge system is a series of slats mounted on tracks which run from front to back along the trailer floor. These tracks move sequentially to "walk" or "shuttle" the load out of the trailer. Three hydraulic cylinders mounted below the floor actuate the walking motion. To discharge its load, the transfer vehicle is driven onto the landfill area, backed up to the working face, its back doors are opened, and the load is walked out the back by the live-floor. The live-floor system is compatible with open top and closed top trailers, and with loading by direct, stationary compactor or pre-load compactor systems.

- o Frame-mounted Tipper. The frame-mounted tipper discharge system involves two hydraulic cylinders mounted on the frame of the trailer. These cylinders lift the front of the trailer body so that the tilt angle of the body and the weight of the load under gravity causes the load to fall out the back. To discharge its load, the transfer vehicle is backed up to the working face, its back doors are opened, and the trailer body is then tipped and the load falls out the back opening. The tipping system is compatible with open top trailers which have been loaded by direct dumping from collection vehicles into the trailers and with closed top trailers which have been loaded by pre-load compactor.

- o Mobile-tipper. The mobile-tipper is not a self-contained discharge system, unlike the systems mentioned above. The mobile-tipper is a track-mounted machine which is located at the working face of the landfill for the purpose of lifting transfer vehicles and discharging their loads. A transfer vehicle is driven onto the mobile-tipper and the vehicle's back doors are opened. Two hydraulic cylinders lift the front of the tipper's platform (and the front of the transfer vehicle which is parked on that platform) and the weight of the load causes it to fall out the back of the trailer. A bulldozer at the back of the mobile-tipper pushes the discharged load away, making room for discharge of the next load. The mobile-tipping system is compatible with open top trailers which have been loaded by direct dumping from collection vehicles and with closed top trailers which have been loaded by pre-load compactor.

The push-blade discharge system takes up more space within a trailer than a live-floor system. Within a 75 c.m. trailer, a push-blade discharge system would occupy about 7.5 c.m. (10 percent) of the trailer's space. On the other hand, a live-floor system would occupy less than 1.5 c.m. (2 percent) of the trailer's space.

The push-blade discharge system weighs more than the live-floor system. Push-blade systems are made of steel or aluminum. A steel push-blade, sized to fit a 75 c.m. trailer, would weigh about 3 tonnes, whereas an aluminum push-blade system would weigh about 2 tonnes. An aluminum live-floor system, sized to fit a 75 c.m. trailer, would weigh about 1.5 tonnes, whereas a steel live-floor system would weigh about 2 tonnes.

There is little difference in the unloading cycle times of the push-blade versus the live-floor discharge systems. Both unload within several minutes. The live-floor system has an advantage over the push-blade system in terms of minimizing space occupied within the trailer and weight added to the trailer, which makes it a popular unloading system in the USA and Canada. However, the push-blade system is easier to maintain and repair, which makes it popular in developing countries. Both Hong Kong and Singapore elected to use push-blade systems in the transfer systems which were recently implemented.

Manufacture of push-blade systems occurs in a number of developing countries, whereas the live-floor system is not presently manufactured within any developing countries.

The self-contained tipping system does not appreciably add weight to or consume space within the transfer vehicle. However, unless the ground conditions at the working face of the landfill are relatively dry, level, and compacted (a condition which seldom exists in most developing countries' landfills), the self-contained tipping system is potentially dangerous. Many landfill operators in developing countries report that large tipping trucks tend to tip over during wet seasons when there are high winds, heavy rains, and muddy landfill conditions. This issue would be less relevant to the mobile-tipper discharge system because it involves a heavy machine which is track-mounted and has outriggers at each end to provide stability.

The mobile-tipper enables maximum loads to be transported in a transfer vehicle, because the vehicle doesn't have any weight added or space occupied by a self-contained discharge system. The cost benefits of being able to transport more waste per vehicle must necessarily be weighed against total owning and operating cost of the mobile-tipper. Mobile-tippers appear to be economically justifiable only in situations where the travel time to the landfill is very high (well over an hour each way) and where the load limits of the roads and bridges are low and strictly enforced.

For any potential cost-effectiveness of the mobile-tipper discharge system to be assured, there must not be any queuing of transfer vehicles at the disposal site -- waiting to the mobile-tipper to discharge their loads. It takes an average of 6 minutes cycle time for a trailer to be driven onto the mobile-tipper, have its contents discharged, and be driven off the tipper. Therefore, a typical mobile-tipper can accommodate 10 transfer trailers per hour. Unfortunately, transfer vehicles do not commonly arrive at the disposal site at even intervals of every 6 minutes.

One way to avoid any queuing by transfer vehicles is for a shuttle system to be put in effect, whereby the tractor truck leaves a fully loaded trailer at the disposal site and takes an already emptied trailer. The loaded trailers are then connected to an off-highway tractor (also called a yard goat) to be shuttled to the mobile-tipper for discharge of the loads. Cost of operating the mobile-tipper would need to take into consideration the added cost of the off-highway tractors, as well as some spare trailers, so that there are always empty trailers waiting for incoming truck tractors to the transfer vehicle.

There does not appear to be a substantial difference in the maintenance and repair requirements of

the various discharge systems. All systems are based on moving parts which either tip, push, or walk a load out of a trailer, and the moving parts are driven by the engine power take-off and hydraulic pumps and cylinders.

CONCLUSIONS.

The purpose of implementing transfer systems is to save money.

Transfer stations should be implemented only when the cost of direct haul in collection vehicles would outweigh the cost of supplemental haul in large bulk-haul transfer vehicles plus the cost of the supporting transfer system infrastructure at the transfer station and disposal site.

A collection vehicle in a developing country commonly carries a load of 2 to 5 tonnes and has a crew of 1 driver and 3 workers, whereas a transfer vehicle carries a load of 20 to 25 tonnes and has a crew of only 1 driver. Clearly, the haul costs per tonne/km. for bulk transport should be markedly less than the cost per tonne/km. for direct haul. To the extent that the transfer costs lead to savings in collection system costs, depends not only on transport costs -- but also all associated infrastructure costs for the transfer unloading, storage, loading, and discharge systems.

Every part of the station needs to be designed in light of the objective of saving money. Local conditions will significantly determine which systems would be most cost-effective. The density and moisture content of incoming waste will clearly effect decisions about whether to have a loading system which provides compaction. The number of collection vehicles arriving during peak hours and the overall traffic from the transfer station to the disposal site will affect decisions about whether to have a storage system. The distance to disposal and the local costs of fuel and driver salaries will affect decisions on whether to spend more for lighter weight trailers and discharge systems which enable higher load weights.

In summary, it is essential to analyze the costs of owning and operating alternative transfer station design concepts. The various costs of alternative systems for unloading, loading, transport, and discharge need to be brought down to the common denominator of total owning and operating cost/tonne in order to find the system which will save the most money under local conditions.

Table 3 provides an abbreviated example of such an analysis for unloading systems, with the assumptions about labor costs, fuel costs, equipment prices, and incoming waste characteristics varied for each scenario analyzed. As Table 3 indicates, in developing countries where labor costs are relatively low, fuel costs are relatively high, equipment prices are relatively high, and incoming waste is relatively dense, less mechanized and less capital intensive systems are favored. As indicated in the table, the economics vary with distance of travel.