

Practical Paper

Time and motion assessment of pit-emptying operations in Kigali, Rwanda

Bruce Rutayisire^{a,*}, Dennis Wolter^a, Nicholas Kuria^a and Rachel Sklar^b

^a Pit Pumpers Ltd, Kigali, Rwanda

^b Environmental Health Sciences Division, School of Public Health, University of California, Berkeley, CA 94720, USA

*Corresponding author. E-mails: bruce@pitvidura.com; brucerutayisire@gmail.com

 BR, 0000-0003-0180-5292; RS, 0000-0001-8574-9456

ABSTRACT

To ensure sanitation for all by 2030, fecal sludge collection services in low-income urban areas with no sewer connections need improvement. One of the major issues is the gap between low-income households' willingness to pay and the cost of emptying services in low-income areas. One way of lowering the cost of these services is through process optimization. In this regard, we conducted a time and motion study to better understand the bottlenecks associated with the collection of fecal waste from different types of on-site sanitation facilities. Our results show that emptying pit latrines, which make up 53% of the market for emptying services in Kigali, takes twice as long as emptying septic tanks. 33% of households that requested the service were located in an informal settlement with no access to road and could only be served by a semi-mechanized method which required use of barrels, and a portable pump. In general, interventions related to minimizing trash disposal in pits and septic tanks can go a long way in making the emptying process more time- and cost-efficient. Additionally, developing effective and efficient pumping technologies that are suitable for use in inaccessible areas should be prioritized.

Key words: FSM, on-site sanitation, pit latrines, septic tanks, time-motion study, trash fishing

HIGHLIGHTS

- Pit-emptying process time varies depending on the type of pit and on the type of emptying method used.
- By applying time and motion study, we can improve fecal sludge collection process duration.

INTRODUCTION

With the UN Sustainable Development Goal of ensuring sanitation for all by 2030 (SDG6), the demand for new ways to safely collect, transport, and dispose of fecal waste from household sanitation facilities is increasing (United Nations Publications 2020). This is especially true as traditional sewage infrastructure remains unaffordable for households and governments in most low-income contexts (Dodane *et al.* 2012; Brunner *et al.* 2018). Around 2.7 billion people use on-site sanitation worldwide, where an estimated 1.77 billion use some form of pit latrine as their primary means of excreta disposal (Graham Jay & Polizzotto Matthew 2013; Strande & Brdjanovic 2014).

These systems generally require an emptying service to excavate waste from the full pit or tank, especially when space is limited or the construction cost of a new one is high (Strauss *et al.* 2000). Such services are provided by the private sector using manual emptying (unhygienic emptying), manually driven mechanical systems, or vacuum tankers (hygienic emptying) (Still *et al.* 2012).

In many emerging urban markets, there is a large discrepancy between low-income households' willingness to pay and the cost of delivering emptying services in low-income areas (Burt *et al.* 2019). While manual emptying is less expensive than existing mechanical emptying (Sisco *et al.* 2017), manual emptying is illegal due to unsafe and unhygienic practices that put worker and community health at risk (Thye *et al.* 2011). There is a dire need for affordable and safe emptying services. To date, efforts to make emptying more affordable have focused on the development of new hardware for extracting fecal sludge (Muller & Rijnsburger 1992; Tilley *et al.* 2014). Other research has explored cost subsidizing, clustering, and the

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use of transfer stations to lower the price of hygienic emptying (Mikhael *et al.* 2014; Burt *et al.* 2019). However, less work has been done in optimizing service efficiency to drive down emptying costs (Flamand *et al.* 2016).

Like most cities in developing countries, Kigali is experiencing rapid urbanization with a population of 1.13 million people. Over 60% of this population lives in informal areas (Tsinda *et al.* 2013). As there is no centralized sewerage network, households rely on on-site sanitation systems including pit latrines, septic tanks, and soak pits (Tsinda *et al.* 2013). Emptying full on-site systems is done solely by private sector providers including Pit Vidura which focuses on serving low-income households. Fecal sludge collected by private operators are disposed in a municipal designated dumpsite as there is no fecal sludge treatment plant yet.

In this paper, we attempt to understand the full scope of bottlenecks that exist in the fecal sludge emptying process using a time and motion study framework (Barnes 1963; Zandin 2002). By identifying bottlenecks in the process, we ultimately hope to reduce the duration of each job, and thereby increase affordability for low-income households. In doing this exercise, we revealed challenges associated with different types of on-site systems and the performance of emptying methods depending on the type of facility. Lessons from this paper can help to draw interventions that can drive service efficiency, lower overall service costs, and achieve affordability for low-income households.

METHODS

Study context

This study was conducted as a case study of Pit Vidura, a social enterprise that provides hygienic fecal sludge collection and transportation services in Kigali, Rwanda. Emptying services are requested via door-to-door marketing agents or via a call center. The customer is then scheduled based on the availability of the most suitable truck. Households pay a fixed rate for Pit Vidura to remove a set volume from their pits and septic tanks. Because the majority of emptying costs are daily fixed costs, reduced job durations can enable serving more households per day and lowering the cost of serving each household (Burt *et al.* 2019). Figure 1 shows emptying tasks and their order of execution.

Pit Vidura's fleet consists of three types of trucks and associated emptying methods. The truck used for each individual emptying job is determined according to the accessibility of the household. The types of trucks are described below.

- *Flatbed Truck (FBT)* is a flat-bodied truck used to transport up to eighty 50-liter barrels (4 m³) filled with fecal sludge and trash removed from the customer's pit. Emptying jobs done by the flatbed truck require six workers. A portable pump (eVac) is used to empty sludge into 50-liter barrels which are loaded onto the truck. The flatbed truck serves households in areas with narrow paths that are inaccessible to the exhauster trucks. This method is hygienic and considered as semi-mechanized as it utilizes both mechanical emptying via the pump and manual carting of small containers over distances between the truck and the household.
- *Exhauster truck 1 (ET1)* has a 10 m³ tank and vacuum pump. It utilizes three people (one driver and two operators) and provides trash fishing service, carried out by the operators. Once the operators finish trash fishing, the sludge is pumped

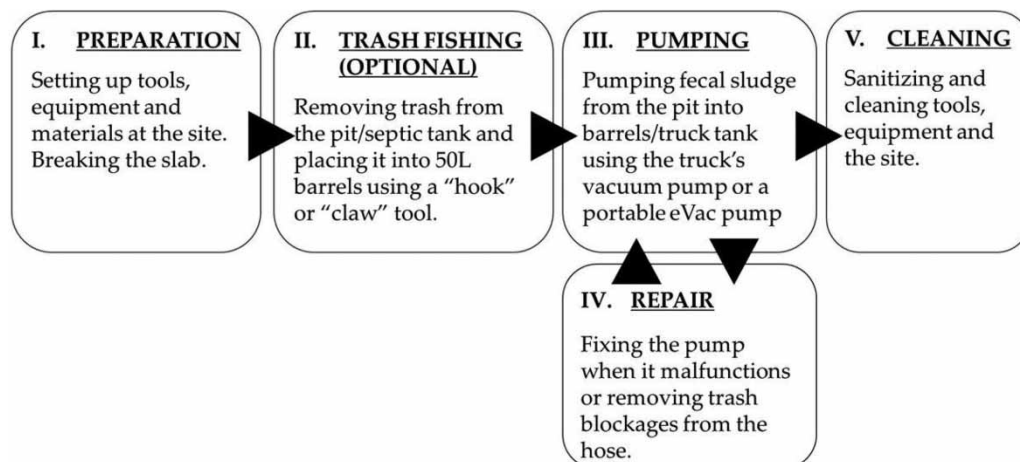


Figure 1 | Tasks comprising a single emptying job.

to the truck's tank by a vacuum pump. It is mostly scheduled to low-, middle-, or high-income residential areas with road access. This method is considered mechanized and is hygienic.

- *Exhauster truck 2 (ET2)* has a 20 m³ and employs two staff (one driver and an operator). Here, the emptying method is the same as a conventional vacuum truck. It serves institutions (i.e. schools, commercial buildings, religious institutions, health centers/hospitals) and residential places with easy road access and no need for trash fishing. This method is considered mechanized.

Data collection

Service monitoring began on 12 November 2019 and ended on 2 December 2020. For each job carried out during the sampling period, one member of the emptying field team recorded the start and end times of each task. Datasheets were digitized by the operations manager and quality checks were conducted regularly to ensure the validity of the data collected from the field.

In addition to the time to complete each task, other information was collected such as the type of sanitation facility (pit latrine versus septic tank), location, the volume of sludge versus solid waste removed from the pit, and the type of truck used.

Statistical analysis

In this study, we assessed the task durations for each job measured across each type of sanitation system and emptying method (truck type). We also assessed the impact of trash fishing on emptying duration by comparing jobs that required trash fishing to those that did not.

RESULTS AND DISCUSSION

Emptying methods by facility type

Pit latrines are most often emptied by the flatbed truck as most pit latrines are in areas that are hard to access by the exhauster trucks. On the other hand, septic tanks are almost exclusively serviced by the two exhauster trucks.

Figure 2 shows that only 39% of pit latrines were served by an exhauster truck while 99% of all septic tanks and 96% of all soak pits were serviced by exhauster trucks. This pattern highlights the well-documented issue of accessibility when it comes to emptying pit latrines in low-income areas (Still *et al.* 2012). The vast majority of pit latrines in our study, 61%, were served by the flatbed truck system, a semi-mechanized system which relies on the use of a portable pump to empty waste into barrels that are carried from inaccessible households to the nearest place to park the flatbed truck. The development of a fully mechanized technology to reach these areas is needed to increase the efficiency and the lower costs of servicing hard-to-reach and low-income areas.

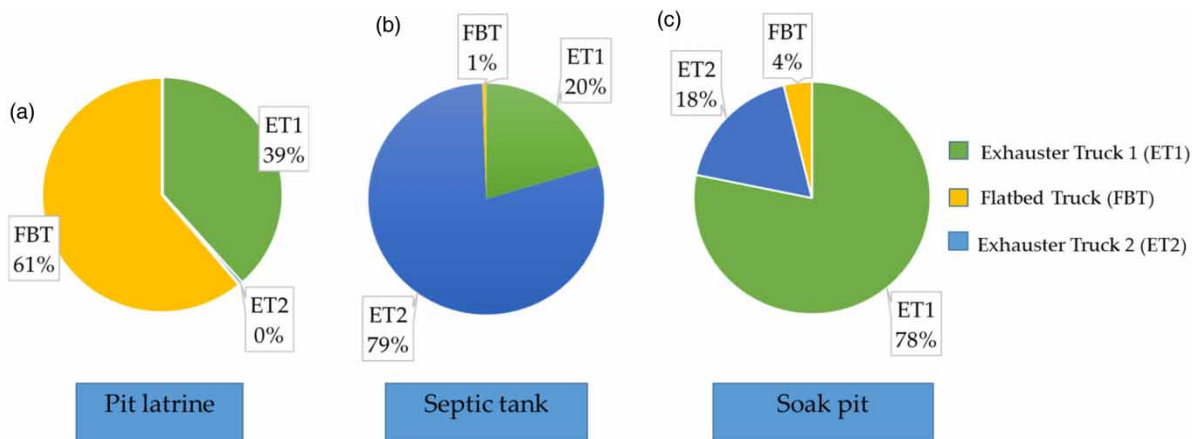


Figure 2 | Use of different truck/emptying methods by type of facility emptied. (a) Pit latrine emptying method; (b) Septic tank emptying method; and (c) soak pit emptying method.

Table 1 | Average task duration according to type of facility

Facility type Sample size (N)	Pit latrine		Septic tank		Soak pit	
	494		353		78	
Tasks	Mean [SD]* (Minutes)	% Job duration	Mean [SD]* (Minutes)	% Job duration	Mean [SD]* (Minutes)	% Job duration
Preparation	48 [39]	19%	30 [48]	18%	40 [39]	20%
Trash fishing	81 [60]	32%	50 [45]	30%	57 [49]	29%
Pumping	80 [50]	31%	52 [34]	31%	65 [38]	33%
Cleaning	41 [43]	16%	26 [27]	16%	34 [29]	17%
Repair	4 [19]	2%	8 [24]	5%	3 [7]	1%
Average emptying duration	240 [110]	100%	120 [82]	100%	160 [79]	100%

[SD]* stands for standard deviation.

Job duration by facility type

The time spent performing a task varies according to the type of facility that is being emptied (Table 1). Across all types of facilities, pumping and trash fishing make up more than 60% of the total job duration while preparation, cleaning, and repairing account for less than 40% of the total job duration.

Within the jobs examined in this study, 53% were pit latrines, 38% were septic tanks, and 9% were soak pits. Emptying pit latrines was found to be the most time-consuming compared to emptying other types of facilities. In general, emptying a pit latrine took 33% longer than a soak pit to empty and twice as long as a septic tank to empty. As pit latrines are the most common form of on-site sanitation in developing countries, improving their serviceability should be prioritized.

During the preparation task, activities such as breaking the concrete slab to allow the pump hose access to the sludge as well as fetching water for cleaning (if not available from the household) resulted in long delays in many cases. Coordination with the facility owner to assist with those tasks before the truck arrival can help eliminate these sub-tasks.

The trash-fishing task was revealed to be time-consuming for all types of facilities, especially pit latrines. Pit latrine design and the absence of a systematic solid waste collection system in areas that primarily use pit latrines may contribute to the disposal of solid waste inside the pit (Portioli *et al.* 2021). To reduce trash fishing duration, interventions should be implemented such as behavior change communication and the placement of trash bins inside the facility (Yeasmin *et al.* 2017). Improving the affordability and reach of solid waste collection systems in low-income areas of Kigali is needed to facilitate long-term viability of affordable emptying and liquid waste management solutions.

The sludge pumping task in pit latrines has a higher mean duration than pumping soak pits and septic tanks. As the eVac portable pump was used for 61% of pit latrine emptying jobs, this points to the need to improve the portable technology to be as effective as the pumps used for exhaustor trucks.

Regarding cleaning duration, reducing the amount of preparation and trash fishing required will directly affect the cleaning duration.

Although the average repair time was the lowest duration of all tasks, its standard deviation was three to four times its average duration. To reduce the variation in the repair time, emptying service providers need spare parts on hand. Reliable supply chains for spare parts is currently a huge gap for Pit Vidura and important spare parts are currently imported from Europe and Asia where shipping times are long and unpredictable. Training the team on preventative maintenance can also alleviate the risk of growing repair durations as the equipment ages.

Job duration by truck type

Pit Vidura uses two types of trucks – conventional exhaustor trucks which use completely mechanized emptying methods and flatbed trucks which use semi-mechanized emptying methods (barrel-based). The overall job duration for the flatbed truck was found to be 40% longer than the exhaustor truck 1 (10 m³) and 60% longer than exhaustor truck 2 (20 m³).

Although exhaustor truck 2 is the most time-efficient truck, due to its large size it does not serve households in low-income areas with limited road access. On the other hand, exhaustor truck 1, which has a smaller tank, served more customers than

Table 2 | Tasks duration per truck

Truck type	Number of workers	Facility type	Number of empties (N)	Average job duration (SD)* (minutes)
Exhauster Truck 1 10 m ³	3	Pit Latrine	190	169 [53]
		Septic Tank	72	150 [85]
		Soak Pit	61	171 [81]
		Sub-Total	323	170 [87]
Exhauster Truck 2 20 m ³	2	Pit Latrine	2	63 [35]
		Septic Tank	279	109 [79]
		Soak Pit	14	106 [37]
		Sub-Total	295	110 [77]
Flatbed Truck 4 m ³	6	Pit Latrine	302	278 [101]
		Septic Tank	2	111 [33]
		Soak Pit	3	167 [67]
		Sub-Total	307	280 [102]

*SD, Standard Deviation.

any other truck in the Pit Vidura fleet (Table 2). In addition, pit latrines emptied by exhauster trucks have lower process times than those emptied by the flatbed truck. This shows the potential for exhauster trucks to serve pit latrines when they are accessible to the truck and if a trash fishing task is incorporated into the process. The flatbed truck, along with the portable pump and barrels, was used when both exhauster trucks could not access the household.

Although the flatbed truck serves hard to reach low-income households, it is more costly due to the longer process, increased labor demand, and its ability to serve only one customer per trip to the dumpsite (limited volume capacity). Thus, there is a need to improve the efficiency of services delivered by the flatbed truck in order to continue serving low-income households efficiently and affordably.

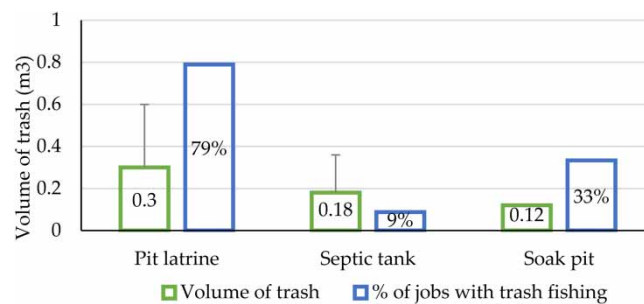
Even though septic tanks have proven to be less time-consuming to empty than other facility types, they have a high standard of deviation, especially with the use of exhauster truck 2. Streamlining the emptying process as mentioned in the previous section would help alleviate this variation and make a positive impact on job planning and logistics.

Trash fishing

Currently, there is a habit of low-income Rwandans to deposit trash in their pit latrines. While this behavior is changing, trash fishing remains a necessary component of emptying in the near term future. In this study, we assessed the average volume of trash removed per type of facility. Figure 3 shows the volume of trash for different types of facilities. It also shows the percentage of facilities that required trash fishing for each type of facility.

In this study, trash fishing was found to be one of the most time-consuming tasks and was shown to increase overall job duration by at least 30%.

79% of pit latrines emptied required a trash removal task with an average 0.3 m³ of trash volume removed. Because pit latrines are used by lower-income residents and those that live in informal settlements, measures to reduce/eliminate it should be prioritized. Though Kigali has put in place and implemented comprehensive solid waste management across

**Figure 3** | Average trash volume per type of facility.

most areas of the city (Rajashekar *et al.* 2019), household behavior still includes trash disposal in pit latrines. More behavior change campaigns and financial incentives/discounts for emptying may be needed to prevent this practice from continuing. Establishing collection points for households, especially in informal areas, may be key to improving solid waste collection in those areas which can, in turn, improve fecal sludge management from the same areas.

CONCLUSION

One limitation of this study was its limited scope – we did not assess the role that transportation factors such as routing between jobs and traffic affect overall job durations. Future research needs to assess this part of this process as there is a huge potential to streamline driving activities leading to more customers served per day and lower cost for low-income households.

In this study, we found trash fishing and pumping to be the most time-consuming tasks. Research should prioritize engineering innovations that specifically target these tasks. Such innovations may include new pumping technologies with trash shredding capabilities and longer pumping ranges, new latrines designs or add-ons that prevent trash from entering the pit, and behavior change campaigns/financial incentives for trash-free pits.

Since trash removed from pits consists mostly of normal solid waste (such as bottles, pieces of clothes, and plastic bags), improving solid waste management systems especially in informal settlement areas should be prioritized. Some of the options to explore can be establishing collection points for a group of houses on the neighborhood level, placing regularly collected trash bins inside the toilet and placing *educational materials* including stickers and signs that discourage trash disposal within the pit on the households' level.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information. Deidentified data on the tasks analyzed for this study are available in a separate file.

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First received 5 May 2021; accepted in revised form 17 November 2021. Available online 30 November 2021