

FLAMAND, KITAWAKI & JENNY

39th WEDC International Conference, Kumasi, Ghana, 2016**ENSURING AVAILABILITY AND SUSTAINABLE MANAGEMENT
OF WATER AND SANITATION FOR ALL****Analysis of faecal sludge collection efficiency
for improvement in developing countries***P. Flamand (Japan), H. Kitawaki (Japan) & H. Jenny (Viet Nam)***REFEREED PAPER 2420**

In most developing countries on-site sanitation, and more specifically septic tanks, will remain the primary sanitation system used for human waste management for many years to come, as the cost of installing sewerage infrastructure remains prohibitive. However, studies have shown that septic tanks are rarely desludged, which reduces their wastewater treatment performance and greatly increases the risk of tanks becoming pollution sources. Furthermore, the systems in place for faecal sludge collection often lack efficiency and the existing services tend to be outside of public sector control and not regulated. To ameliorate this situation, the development of new analysis methods for faecal sludge collection systems is crucial. This paper presents an analysis method adapted from "time and motion studies" in solid waste management and a mathematical model which allows for precise analysis of faecal sludge collection and recommendations to be made to dramatically improve the efficiency of existing collection systems.

Introduction

Despite world-wide efforts towards achieving the new Sustainable Development Goal (SDG) for sanitation of halving the proportion of untreated wastewater by 2030, there is still a long "sanitation ladder" to climb as the cost of installing sewerage infrastructure remains prohibitive. Therefore, for many years to come, on-site sanitation systems, such as septic tanks, and safe faecal sludge management (FSM) will remain an essential component of human waste management. However, these systems are often poorly maintained and managed. Sludge removal is not carried out on a regular basis and numerous surveys conducted in developing countries have found that the majority of households had either never desludged their systems (Harada et al., 2008) or did not know when they were last desludged (Williams et al., 2015). In Viet Nam, septic tanks are rarely emptied or only tended to when blockage or failure occurs (Pham, 2014). Furthermore, the collection of faecal sludge from such on-site systems is often unregulated and inefficient, partly because of the difficulty and time required to access the facilities, which can lead to delays and inadequate practices to increase profitability such as the illegal dumping of sludge into the environment. Therefore, it is crucial to develop new analysis methods to improve faecal sludge (FS) collection efficiency.

Fortunately, analysis methods have already been developed and practiced in the area of solid waste management (SWM), as collection is the most costly component of the SWM process. In SWM, "time and motion studies" are carried out to analyze and improve collection efficiency. In this paper, the method of time and motion studies used in SWM has been adapted, and a mathematical model developed, in order to analyse and make recommendations on the FS collection process. This model was field-tested in Viet Nam where on-site sanitation systems are prevalent and the typical issues mentioned above occur frequently (i.e. septic tanks are currently the predominant means of wastewater management in urban areas and will remain in place for many more years (ADB, 2015) but most are not properly maintained). The field study was conducted in Vinh Long: a medium-size city located in Viet Nam's Mekong Delta.

Methodology

The methodology for this research consisted of the following steps:

1. **Literature review:** a review of the available literature (academic papers, books, donor reports, legislative documents) was conducted to acquire information on the following areas.
 - FSM in developing countries and more specifically in Viet Nam: current situation and issues.
 - Policy and legislation related to faecal sludge management in Viet Nam: Decree 80/2014 and Circular 04/2015.
 - Time and motion study in SWM.
2. **Time and motion (mathematical) model for FS collection:** creation of a time and motion (mathematical) model dedicated to FS collection, which was adapted from the method of time and motion studies commonly used in SWM.
3. **Time and motion field study:** a field study was carried out in December 2015 in Vinh Long: a medium-sized city in Viet Nam with a population of 147,000 (as of 2009).
4. **Efficiency assessment:** from the data collected in the field, a Time and Motion-loading Chart was developed to create a visual representation of each motion in the desludging cycles. Then, the motions of each type of the desludged sites observed in the field were individually compared and analyzed to formulate the recommendations for improvement noted in the conclusion.

Literature review

Although septic tanks are one of the most common forms of urban improved sanitation facilities in developing countries, many are never emptied and become sources of groundwater contamination (Williams and Overbo, 2015). When septic tanks get overloaded with sludge, hydraulic retention time (HRT) becomes insufficient to remove pathogens (Feachem et al., 1983) and these facilities no longer perform their intended primary treatment (AECOM and Eawag, 2010). A survey in urban Hanoi found that although 90.5% of human waste was flowing into septic tanks, 89.6% of these tanks had never been desludged (Harada et al., 2008). Furthermore, only a few countries have put in place regulations for FS desludging (Williams and Overbo, 2015). In Viet Nam, FSM was clearly advocated for the first time in the new Decree 80/2014 and the associated Circular 04/2015.

In FSM, collection is an aspect that requires improvement. In Viet Nam, septic tanks are often built underneath houses and sealed by a solid concrete base without access covers (Nguyen et al., 2011), which renders location and access very difficult for FS collection while also increasing maintenance time and cost. In addition, infrastructure for treatment and/or disposal is lacking. Consequently, faecal sludge is often disposed of with solid waste in landfills which, in the case of Hanoi and Ho Chi Minh City, are distantly located in a 12 to 15 km-radius from the centre of these cities (Nguyen et al., 2011). As a result, illegal dumping of sludge into drains or waterways from private contractors is common practice. In Hanoi, some companies have multiple options for dumping sites, which reduces the risk of being caught by the police, while enabling further trips to be made thus increasing their income (Nguyen et al., 2011).

The review of literature on the method of time and motion study in SWM (Sakurai, 1990) provided valuable examples of how an analysis method can be used to improve collection systems. This review provided the basis for the time and motion model of this research adapted to FS collection.

Time and motion model for faecal sludge collection

In order to analyze and improve the efficiency of FS collection, each motion of FS collection should be mathematically expressed using variables which can undergo sensitivity analysis. Accordingly, the time and motion (mathematical) model created for this research shows, symbolically through three equations, all of the motions possible in desludging cycles conducted during a full working day. By offering a precise measurement of the time required for each motion, this model allows for the assessment of FS collection efficiency and the identification of the motions that require improvement. Using this model, specific countermeasures with higher success potential can be defined. In addition, it provides a useful tool for comparing the efficiency of various sludge collection alternatives. As a potential shortcoming it can be noted that, although this model worked well in the present case with a typical vacuum truck, additional factors may need to be considered when using other types of sludge collection vehicles/equipment.

The time and motion (mathematical) model developed for this research is as follows. Three patterns for the desludging cycles of a typical full working day have been defined with the differences between the sequences described hereinafter. A visual example is shown in Figure 1.

- **First cycle:** C_1 = Travel from depot to first site to desludge, and transport of collected sludge/waste for discharge to sludge treatment/disposal site (with possible inclusion of idle time).
- **Subsequent cycles:** C_z = Travel from sludge treatment/disposal site to next site to desludge, and transport of collected sludge/waste for discharge to sludge treatment/disposal site (with possible inclusion of idle time).
- **Last cycle:** C_{last} = Travel from sludge treatment/disposal site to last site to desludge, and transport of collected sludge/waste for discharge to sludge treatment/disposal site, followed by cleaning of vacuum truck and return to depot at the end of the day (with possible inclusion of idle time).

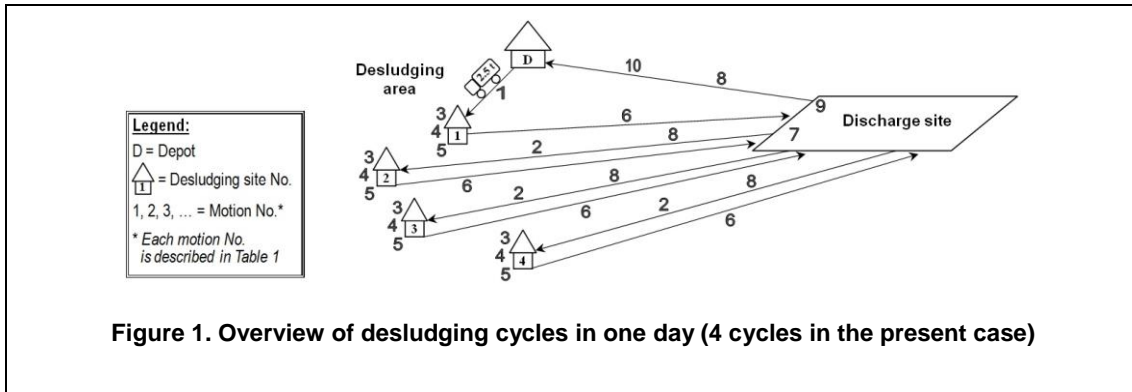


Figure 1. Overview of desludging cycles in one day (4 cycles in the present case)

The time and motion mathematical model includes the following equations.

$$C_1 = \frac{LDH}{S_{i1}} + TP_{i1} + \frac{V_{i1}}{PS_{i1}} + TE_{i1} + \frac{LHDS_1}{S_1} + \frac{V_{i1}}{DS_{i1}} + TI_1$$

$$C_z = \frac{LDSH_z}{S_{iz}} + TP_{iz} + \frac{V_{iz}}{PS_{iz}} + TE_{iz} + \frac{LHDS_z}{S_z} + \frac{V_{iz}}{DS_{iz}} + TI_z$$

$$C_{last} = \frac{LDSH_{last}}{S_{ilast}} + TP_{ilast} + \frac{V_{ilast}}{PS_{ilast}} + TE_{ilast} + \frac{LHDS_{last}}{S_{ilast}} + \frac{V_{ilast}}{DS_{ilast}} + TC_1 + TI_{last} + \frac{LDSD}{S_{ilast}}$$

Where:

C_z : Time required for z^{th} desludging cycle (hour) ($z = 1^{st}$ to last: possible cycle numbers in one day)
 z : Desludging cycle number

LDH : Distance from depot to 1^{st} site to be desludged for 1^{st} cycle (km)

S_{iz} : Speed of desludging equipment l for z^{th} cycle (km/hour)

l : Desludging equipment (ex. vacuum truck, etc.)

TP_{iz} : Preparation time for sludge collection from sanitation alternative i for z^{th} cycle (includes localization of sanitation alternative i , floor breakage, desludging pipe and hose layout preparation, etc.) (hour)

i : Sanitation alternative (ex. septic tank, etc.)

TE_{iz} : Ending time of the desludging operation of sanitation alternative i for z^{th} cycle (includes desludging pipe and hose storage, payment/contract signing and receipt transmission) (hour)

V_{iz} : Volume of sludge stored in sanitation alternative i at the time of collection for z^{th} cycle (L)

PS_{iz} : Pumping speed of the sludge removed from sanitation alternative i depending on sludge collection equipment l for z^{th} cycle (L/hour)

DS_{iz} : Discharge speed of the sludge removed from sanitation alternative i depending on sludge collection equipment l for z^{th} cycle (L/hour)

$LHDS_z$: Distance from desludged site to sludge discharge site for z^{th} cycle (km)

TI_z : Idle time, including lunch and other break times for z^{th} cycle (hour)

$LDSH_z$: Distance from sludge discharge site to next site to be desludged for z^{th} cycle (km)

LDSD : Distance from sludge discharge site to depot for last cycle (km)

TC_1 : Cleaning time of desludging equipment l (hour).

Time and motion field study

During the field study that was conducted in Vinh Long, a team of 2 desludging operators from the Vinh Long Public Work Company Limited (the sole company conducting desludging in the city) was followed and observed during a full working day. Each motion of the work executed by the municipal operators was individually timed and recorded. The data gathered that day for each motion is listed in Table 1. Each motion is numbered from 1 to 10.

Motion #	Description	Symbol	Desludging sites			
			1 st site ¹⁾	2 nd site ²⁾	3 rd site ²⁾	4 th site ³⁾
1	Travel from depot to 1 st site	$\frac{LDH}{S_{11}}$	13 min. 15 sec.	-	-	-
2	Travel from sludge discharge site to next site to desludge	$\frac{LDSH_{iz}}{S_{iz}}$	-	12 min.	22 min.	21 min.
3	Preparation time ⁴⁾	TP _{iz}	61 min.	29 min.	13 min.	7 min.
4	Pumping time	$\frac{V_{iz}}{PS_{ilz}}$	31 min.	17 min.	12 min.	12 min.
5	Ending time ⁵⁾	TE _{iz}	29 min.	25 min.	7 min.	6 min.
6	Travel from desludged site to sludge discharge site ⁶⁾	$\frac{LHDS_z}{S_{iz}}$	21 min.	21 min. 30 sec.	26 min.	22 min.
7	Discharge time	$\frac{V_{iz}}{DS_{ilz}}$	3 min.	7 min.	4 min.	3 min.
8	Idle time (for breaks) ⁷⁾	TI _z	47 min.	0	0	0
9	Time for vacuum truck cleaning	TC _i	-	-	-	13 min.
10	Travel from sludge discharge site to depot	$\frac{LDSD}{S_{last}}$	-	-	-	17 min. 45 sec.
Required time for desludging cycles		C _z (No. 1-10)	205 min. 15 sec.	111 min. 30 sec.	84 min.	101 min. 45 sec.
Grand total		C ₁ -C _{last}	502 min. 30 sec. = 8 hr. 22 min. 30 sec.			

Notes:

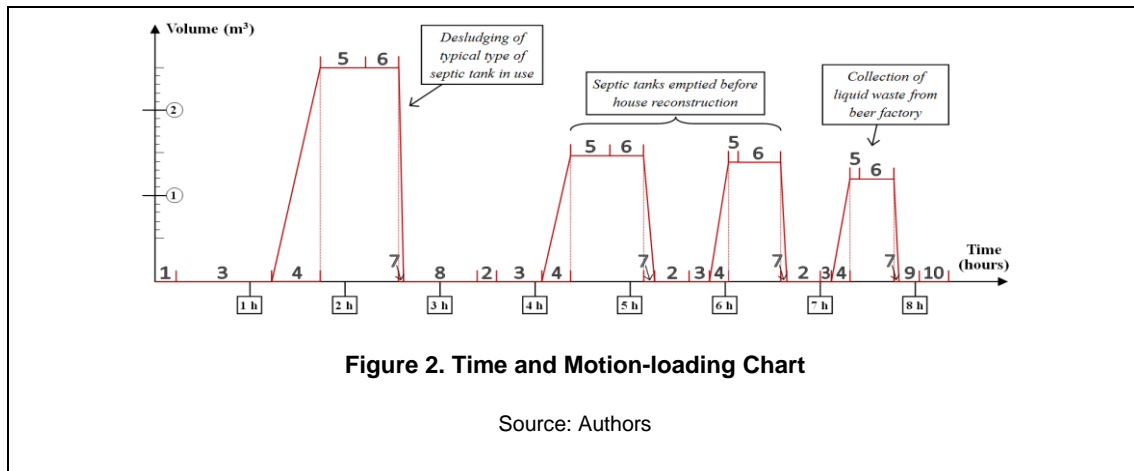
- 1) The first desludged facility was a septic tank of more than 2.5 m³ constructed under a house with 5 users.
- 2) The second and third desludged facilities were on sites where the houses had been dismantled. The septic tanks needed to be emptied before the installation of new tanks and construction of the new homes.
- 3) The fourth site was at a beer factory.
- 4) The preparation time comprises any task required prior to pumping, which includes the time needed to access the septic tank or facility to desludge and the time for assembling sucking pipes and hoses.
- 5) The ending time comprises all activities to be completed after pumping, which includes the dismantling and storage of the sucking pipes/hoses in the vacuum truck, payment for desludging operations, and signing of relevant documents.
- 6) The collected faecal sludge and liquid waste were discharged at the municipal landfill used for solid waste.
- 7) The idle time includes lunch and breaks taken during the working day.

Efficiency assessment

Assessment process

The following Time and Motion-loading Chart (Figure 2) was created using the data recorded in the field, and gathered in Table 1, and shows the four desludging cycles observed during the survey. In this chart, each motion is labelled with a number, which corresponds to the number attributed in Table 1. Each motion is also delimited by two indexes, more or less distant from each other depending on duration. The Time and

Motion-loading Chart provides a detailed yet clear visual representation of the motions conducted in each desludging cycle and identifies the motions that required the longest time and improvement.



Results and discussion

The observation of a full working day of the desludging operations in Vinh Long provided a comprehensive overview of the different types of desludging sites and facilities, and an insight into the issues commonly encountered during desludging operations in Viet Nam, as highlighted below.

- **Travel from depot or discharge site to 1st or next desludging site (motions No. 1 & 2):** In the first two desludging cycles observed, the septic tanks to desludge were difficult to access due to the narrow alleys leading to the houses, which did not allow the passage of the 2.5t vacuum truck used that day. The distance between the streets where the vacuum truck could be parked and the houses was about 100m, which impacted the preparation time.
- **Preparation time (motion No. 3):** As mentioned above, the long distance between the septic tanks and the vacuum truck in two of the observed sites required the assembly of approximately 100m of pipes and hoses, which took over 20 minutes to prepare. Although difficult to precisely evaluate, the distance also affected the pumping speed, which took about 30 minutes in the case of the first septic tank. In addition, it was not possible to reach the septic tank without breaking the floor in the first site as this facility was constructed under the house without any means of access (cap or cover). There was also no indication of its location under the house. The breakage of the floor and then the upper wall of the septic tank necessitated long and painstaking efforts during more than 30 minutes, in hazardous conditions, as both operators both conducted this labour with bare hands/feet. The long time required for such operations has also been mentioned in other Vietnamese cities, like Hanoi (Nguyen et al., 2011). As shown in the Time and Motion-loading Chart in Figure 2, the preparation time for desludging at this site was one of the longest steps of the day. This motion required more than an hour and was the main reason why only one site could be desludged during the morning. An increase in the number of such septic tanks during a work day would therefore drastically reduce the number of desludged households per day and have a negative impact on the efficiency of FS collection. During an interview with the operators, it was determined that this type of septic tank was actually the most common type of facility they worked on.
- **Pumping time (motion No. 4):** When it is necessary to open a hole in a septic tank for access, gravel and stones may fall into the tank during the process, which is usually carried out with a bull point chisel. During the observed day, this problem was at the origin of the blockage and necessitated the interruption of sludge pumping of the third desludged septic tank.

Conclusion and recommendations

The mathematical model based on time and motion in SWM developed for this research enabled the collection of useful data for analysing the efficiency of the FS collection system tested in the field in Viet Nam. The following are recommendations for improvement of the problems observed during the field study and other common issues in FS collection:

- Preparation time could be substantially reduced by developing and maintaining a record keeping system, including information such as septic tank location on site, size and desludging history; by requiring the installation of caps or covers on old systems after floor breakage to allow easy access for future desludging; and, by incorporating easily accessible covers in septic tank design and construction when installing new systems. In addition, the piping system of the vacuum truck for sludge pumping should be improved to reduce setup time.
- Installing caps or covers for septic tank access, when first installed, would also eliminate the risk of gravel and debris entering the septic tank during breakage for access.
- In large cities where there is traffic congestion and discharge facilities are located far from the city centre, by introducing local transfer stations (local storage tank facilities), transportation times could be reduced and collection efficiency maximized by decreasing the time required for transport, which would also increase profitability for the private sector and discourage negative practices such as illegal dumping. Sludge could then be transported from transfer stations to discharge facilities by local municipalities at optimum times when traffic is light.

By using the time and motion model developed for this research, FS collection efficiency could be optimized, which would ultimately reduce the negative impact poorly maintained on-site sanitation facilities and inefficient FS collection systems have on public health and the environment.

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Note

*The views expressed in the paper are those of the authors and do not necessarily reflect the views of ADB.

Contact details

Pierre Flamand
Japan Sanitation Consortium
Intelligent Bldg. Yushima Iyasaka 5F
3-26-9 Yushima, Bunkyo-ku
Tokyo 113-0034, Japan.
Email: pierre@jsanic.org
www.jsanic.org

Hidetoshi Kitawaki
Toyo University
5-28-20 Hakusan, Bunkyo-ku
Tokyo 112-8606, Japan.
Email: kitawaki@toyo.jp
www.rds.toyo.ac.jp/~kitawaki/

Hubert Jenny*
Asian Development Bank
Viet Nam Resident Mission
Cornerstone Building
16 Phan Chu Trinh Street
Ha Noi, Viet Nam.
Email: hjenny@adb.org
www.adb.org/viet-nam