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SUSTAINABLE URBAN SANITATION: SIMULATING A DESLUDGING SERVICE IN SENEGAL

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Slow-onset climate-related emergencies such as urban flooding are a growing threat worldwide. This paper presents a recovery-phase project designed to reduce the impact of future flooding on the vulnerable population in Pikine, Senegal. Monte-Carlo analysis was used to evaluate the economic sustainability of a proposed public-private waste transportation service. The analysis showed that the profit margin for a mechanical desludging service ranged from 12% to 52% for a partial tank emptying and -138% to 23% for a full tank emptying at the current market price for the service. The analysis also showed that if a low-cost subscription service is implemented in the area, the commercial service providers will operate at a loss in all cases, unless changes are made in the truck fuel efficiency, the operating hours of discharge sites, and the transportation network.

Keywords: Humanitarian Operations, Transportation, Waste Management

1 Introduction

According to the World Health Organization, diseases related to water, sanitation and hygiene (WASH) account for 4% of deaths worldwide (Prüss, et al., 2002) and to a large extent, the infectious diseases caused by contaminated water and poor sanitation are highly preventable. An issue of particular interest in this paper is the lack of proper sanitation in the informal settlements that surround many large cities in the Global South. Since most of these areas lack sewer systems and robust infrastructure, they rely on commercial or government services to remove the sludge accumulated at the bottom of latrine septic tanks. Within this context, several questions arise. How can desludging be optimized and performed in cost effective ways? Is it possible for private desludging services to be both affordable to the population as well as profitable for private enterprise? How can public awareness of these sanitation issues be improved in an environment of very limited resources and competing priorities? This paper examines possible answers to these questions in the context of Pikine, Senegal.

1.1 Overview of Context

Pikine, a city near Dakar, Senegal in West Africa, is an urban area consisting of both planned areas with modern water and sanitation systems and informal settlements without even basic infrastructure in place. The original communes of Pikine were well planned; however, as Pikine expanded, irregular settlements were built in areas that historically were considered unfit for construction due to the poor sandy soil and the level of the water table, which is very near the surface in some areas. Pikine is subdivided into 16 administrative areas or "Communes d'Arrondissements," and each has both planned and informal areas which are co-mingled. A map of Pikine is shown in Figure 1.

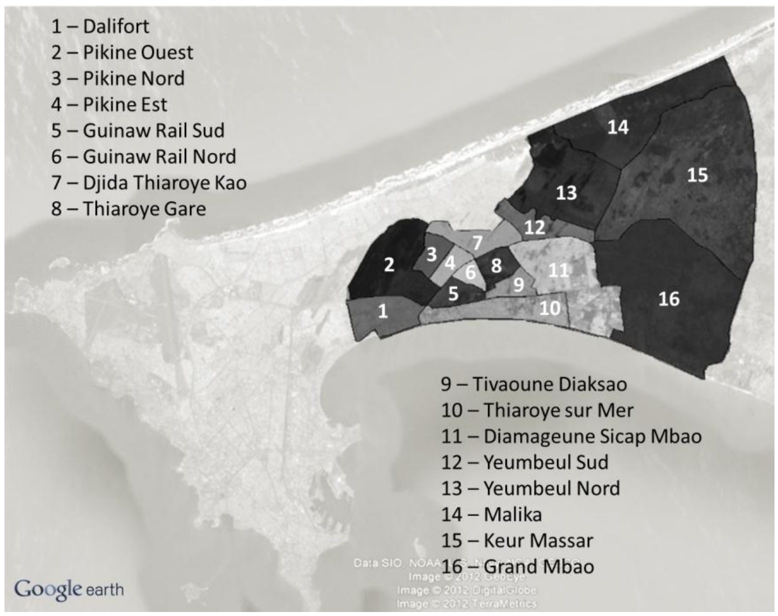


Figure 1: Map of Pikine Communes

Part of the population growth in Pikine was due to migration of poor rural farmers into the city during the 1980s as Senegal experienced drought (Mbow, et al., 2008). However, as rains returned in the late 1990s and early 2000s, the lower lying regions of Pikine began to flood and the government began to pump water out of the Thiaroye aquifer to prevent large scale urban flooding. However, in the informal settlements in Pikine, pumping has not been performed enough due to lack of resources and lack of institutional ownership of the worst affected areas. As a result, the water table is now fully saturated (and polluted) and severe annual flooding occurred in both 2009 and 2010.

1.2 Research Problem

In response to the flooding in 2010, the Bill and Melinda Gates Foundation funded a project implemented by Oxfam America and its local partner *Eau, Vie et Environnement* (EVE) to perform a "Knowledge, Attitudes and Practices (KAP)" assessment of Pikine residents in five of the 16 communes and provide emergency supplies and fuel to pump the water out of the affected areas. After the flooding receded, the Gates Foundation agreed to fund Oxfam and EVE for a follow-on recovery and rehabilitation project which included improvements to the household-level latrines that were the most impacted by the floods of 2010. One of the first steps in the latrine rehabilitation project was the desludging of the latrines to remove the flood water and accumulated solid waste. During this activity, some of the difficulties with the desludging service provision became apparent as both delays and broken contracts with desludging service providers had a significant impact on the project.

In late 2011, the Bill and Melinda Gates Foundation initiated a new sanitation project with the Government of Senegal with the goal of reducing the practice of manual desludging by 90% by the end of the 3-year project. Given the problems encountered in the 2010 latrine rehabilitation project with the desludging service providers, two of the project's financial objectives seemed difficult to achieve in unison: a) Maximum annual household price of the desludging service of 5,000 - 10,000 FCFA (approximately U.S. $10 - $20); and b) Profit margin of at least 20% realized by the private-sector (including revenues from both the desludging service and sludge reuse).

The analysis presented in this paper investigates the potential profitability of a mechanical desludging service in the Pikine communes included in the Oxfam/EVE project and was based on informal interviews and empirical data gathered over several months in Senegal during the 2010 flood response and the 2011 rehabilitation project and subsequent modeling and probabilistic simulation of various desludging operations alternatives that rely on the collected data and interviews.

1.3 Issues with Current System

The context in Pikine is complex and several issues were encountered during the Oxfam/EVE latrine rehabilitation project in Pikine that must be addressed as part of any large scale project. A brief discussion of these issues is included in the following sections.

Technical Issues

The design and upkeep of household-level latrines are contributing factors to the current problems with the sanitation system in Pikine. The most common on-site sanitation installations used in the area are either direct or offset pour-flush pit latrines with concrete slabs and concretelined pits or septic tanks (Harvey, et al., 2002). In this type of installation, the septic tanks must be emptied 1-2 times per year during nominal operations, but in areas subject to flooding, the tanks can fill up much quicker and desludging must be performed more frequently. The height of the raised concrete tanks is also a problem since it is generally below the flood level and water pours into the opening on the top of the tank and in the latrine itself, and additional groundwater seeps into the tank through damaged or non-existent tank bottoms.

Based on the first “Knowledge, Attitudes and Practices” survey conducted by Oxfam/EVE during the 2010 floods, while 96% of households in Pikine had access to latrines, only 39% of those were functioning properly. The survey also showed that of the non-functioning latrines, respondents reported that 87% were not functioning because they were full of water and for those latrines that were functioning; most respondents hadn’t emptied them in the past 3 months (EVE, 2010). Post-flooding, the percentage of non-functioning latrines decreased as the water was either pumped from the latrine tanks or drained naturally into surrounding soil, but there were still a significant number of latrines that were degraded or collapsed. (EVE, 2011)

Logistical Issues

There are many logistical issues which will complicate a desludging program for Pikine. The largest challenge is accessibility of the households to desludging trucks, due to the “maze-like” nature of much of Pikine’s road network. There was no city planning done in the irregular areas, so many of the targeted neighborhoods are only accessible to small 3-4 m^3 tanker trucks. Since the average latrine tank size is 9-10 m^3 (based on a survey of 20 latrines conducted by EVE in July 2011 and corroborated by (CREPA, 2002)) and they tend to fill up with water quickly, several trips would be required by the smaller tankers in order to siphon off the water before desludging can begin.

This creates one of two main problems. If the smaller tanker only visits the house once and takes away 3 m^3 of water, no actual “desludging” takes place and all the service is really doing is taking away the top layer of effluent in the tank, and the fecal sludge remains. On the other hand, if the goal is to empty and desludge the tank entirely, then multiple trips would be required, which could slow the service and increase cost to individual residents.

Another logistical challenge is the distance and travel time between the targeted neighborhoods in Pikine and the waste discharge stations located to the west and southeast.

There are three legal waste treatment facilities in the Dakar region (Cambérène, Niayes, and Rufisque) and they are located between 5-9 km from Pikine and the fuel requirements are high due to the distance and especially the travel time due to extensive traffic congestion problems in the area. The private-sector desludging service providers charge by the rotation (round-trip) between the latrine they are emptying and the discharge site. Due to the access difficulties in Pikine, the time to complete a rotation can be long (45 minutes to 2 hours, depending on traffic) and this reduces the number of rotations in a day and the associated profitability.

Another complicating factor for scheduling of the desludging service is the limited operating hours of the three waste discharge sites. The sites are open from 9 am – 4 pm Monday – Thursday and from 9 am – 1:30 pm on Friday and are closed for the weekend. This fact, combined with the constraints on the size of the tanker due to access issues and the travel time between the Pikine neighborhoods and the waste discharge stations, severely limits the number of latrines that can be desludged during the week per truck, and this in turn, drives up the costs of the desludging service. (EVE, 2011)

Economic Issues

There are two main economic issues that may inhibit successful implementation of a desludging service in Pikine: the affordability/willingness-to-pay of the targeted populations and the economic viability of the subscription price structure for the private-sector service providers. First, while the average fee for a single-use of the larger tankers of ~ $65 is not exceptionally high, it constitutes between 30 – 100% of the monthly household income for the residents of Pikine. (EVE, 2010) Based on preliminary studies leading up to the 2012 Gates project, the team found that a tariff of between $10 - 20 per year would be the amount that targeted populations would be willing to pay for a subscription desludging service. (Bill and Melinda Gates Foundation, 2011)

The second economic issue is related to the ability of the private-sector desludging service providers to meet the Gates-defined objective of a 20% profit margin, including both the proceeds from the desludging service and the possible sale of desludging by-products. For the desludging service, some of the main cost elements to consider are: the cost of diesel fuel used for transport and the operation of the pump; the cost of labor; the cost of maintenance and repair for the trucks and pumps; office costs; amortization; and insurance.

In Pikine, the total fuel used per rotation is higher than in other areas due to the time and distance required to travel between the houses and the discharge stations and the additional time required to find the houses within the neighborhoods. In addition, due to the poor conditions of the roads and the fact that the latrines often contain trash and other non-biological materials (e.g., plastic bags) which can damage the pumps, the maintenance and repair costs would likely be higher than in other more "regular" areas. For these and other reasons, during the Oxfam/EVE rehabilitation project, many private-sector companies would work for 1-2 days and then cancel the contract, claiming that their costs were higher than the $50 – $60 per rotation rate that they were being paid. (EVE, 2011)

Another socio-economic factor that must be considered is the role and impact of the informal manual desludgers (called "Baye Pell" in Senegal) in the overall service scheme. The *Baye Pell*, who manually empty the septic tanks using shovels and buckets and bury the fecal sludge in the concession or in the street, are used extensively in Pikine, and since their price is much less than the formal desludging service providers, they will serve as competition to the mechanical desludging subscription service, unless the government strictly limits this practice.

Cultural Issues

The cultural aspects of sanitation in Pikine have a direct influence on the future success of a subscription desludging service. Cultural preference with regards to latrine placement, convenience, privacy, and appearance dictate the design of the latrine and can make the logistics of desludging much more difficult. In addition, many desludging service providers refuse to use the official discharge sites even when they could afford it and some routinely empty the latrine contents into the rain water network instead of the sewage network. (Massaga, 2011) These behavioral issues need to be addressed through public health promotion and other activities in order to make any desludging service feasible.

Another cultural issue that impacts the desludging service is the reluctance of organizations to talk about the financial aspects of their business, which made gathering cost data for the analysis difficult.

2 Methodology

After gaining insight into the issues, stakeholders and economic conditions in the Pikine area, an extensive literature review was performed to understand what type of research and projects had been done previously to address the sanitation problem. Several organizations have performed previous studies in this area, most notably the "Centre Régional pour l'Eau Potable et l'Assainissement (CREPA)," ENDA GRAF Sahel, and the SANDEC group of EAWAG (Swiss Federal Institute of Aquatic Science and Technology) who has a partnership with the Government of Senegal through the "Office National de l'Assainissement du Sénégal (ONAS)." In addition to the publicly available reports, two unpublished reports from EVE were used extensively in the research, and many informal interviews were conducted with Oxfam and EVE staff, representatives of the Pikine *Communes d'Arrondissements*, commercial desludging service providers and desludging truck drivers.

In order to assess the profitability of the proposed desludging subscription service the following steps were used: a) determine the physical structure of the Pikine desludging service network including the routes and driving distances between the households, waste discharge sites and truck deports; b) identify typical desludging service providers and understand their operating procedures and costs; c) create an analysis tool to calculate the profitability of the current desludging service in multiple scenarios; and d) determine ways to increase the profitability while decreasing the subscription price. These steps are discussed in the sections below.

2.1 Desludging Service Network Map

In order to understand the transportation network for desludging services operators in Pikine, it's necessary to have a highly detailed map that shows the relative distances between the targeted households, the discharge sites and the desludging service providers. While the use of Geographic Information Systems (GIS) tools within the humanitarian community has been expanding rapidly in recent years, the road network for the Pikine area is not well defined, and since most operators use secondary roads to get to the discharge sites and into the informal settlement areas, a simpler approach using Google Earth was used to determine the route distances. This approach had several benefits, including the fact that Google Earth is free and easily accessible to partners in Senegal, the program is easy to use and importing GPS coordinates from the handheld Garmin unit that was used in the data collection was straightforward, and since the satellite imagery for the Dakar region was updated in June 2011, the key landmarks, roads and facilities were easily recognizable.

As shown in Figure 2, the key elements of the Desludging Service Network Map are the administrative commune borders, coordinates of the households, service provider truck depot locations, discharge station locations, and the routes between all these points.

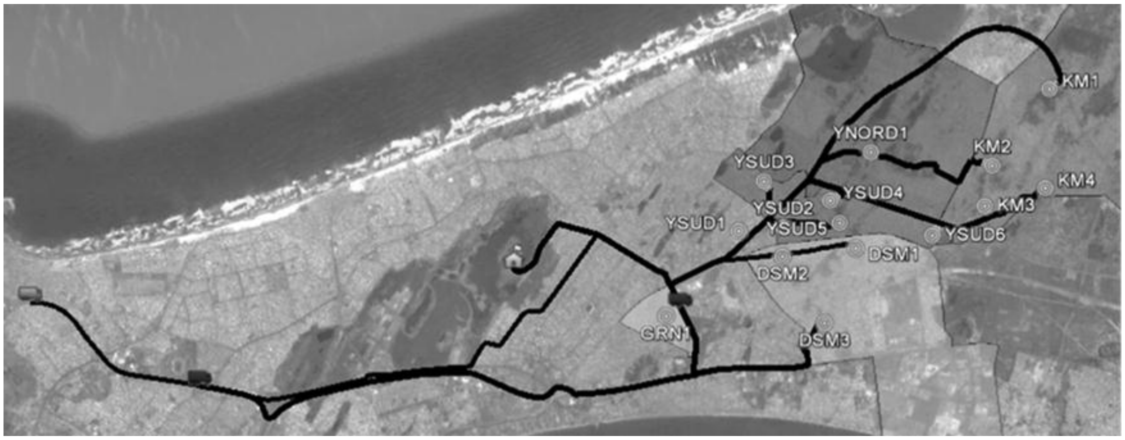


Figure 2: Desludging Service Network Map

Communes and Households

Five of the 16 administrative communes in the City of Pikine were used for this study and they include Keur Massar (KM), Guinaw Rails Nord (GRN), Yeumbeul Nord (YNORD), Yeumbeul Sud (YSUD), and Dimaguène-Sicap Mbao (DSM). The communes were chosen due to the availability of the commune-level demographic data that was gathered during the response and rehabilitation phases. (EVE, 2010) (EVE, 2011) For the Desludging Service Network Map, the existing commune administrative maps were imported into Google Earth and a data file containing the GPS coordinates for 150 households in the targeted communities was imported.

In order to identify routes to be used in the analysis, the 150 household dataset had to be reduced to something more manageable. In order to accomplish this, the households were grouped into clusters based on their location and then the geographic midpoint (or center of gravity) of each cluster was calculated, and this became the "Representative Household" coordinate that was used to calculate the distance between key points. A total of 16 Representative Households were identified using this method.

Locations of Service Providers and Discharge Stations

For the purposes of this analysis, the locations of three representative desludging service providers were chosen. These three providers represent the three main types of organizations active in the Pikine desludging market: the larger formal private sector companies that generally work on the larger government contracts (the location of the Société de Nettoiement Industriel et Chimique (SNIC) which was used as an example in this analysis); the small informal one-truck operators that congregate at the main highway intersection near Dakar's Stadium; and the Municipal Government operators that provide service in their locality at a reduced price (the location of the Mayor's office in Guinaw Rails North (GRN) was used as a reference location).

Currently, there are three legal waste discharge Stations in Dakar: Cambérène; Niayes; and Rufisque. While all three locations are open for waste discharge, most service providers use the Station at Niayes, when they dump legally at least. Normally, the Rufisque Station would be used for the DSM and KM neighborhoods; however, there is a major new toll road being built in the area and the traffic congestion is so heavy that the service provider that was interviewed said that the travel times could be as high as 2 hours. (Cayor_Vidanges, 2011) Therefore, for this analysis, only the Niayes Station was used exclusively.

Identification of Routes and Route Distances

Once all of the key points were identified in the Pikine Desludging Service Network Map, the routes and distances between the points had to be identified and measured. For the simulation model presented in Section 2.2, four key routes are necessary, as illustrated in Figure 3.

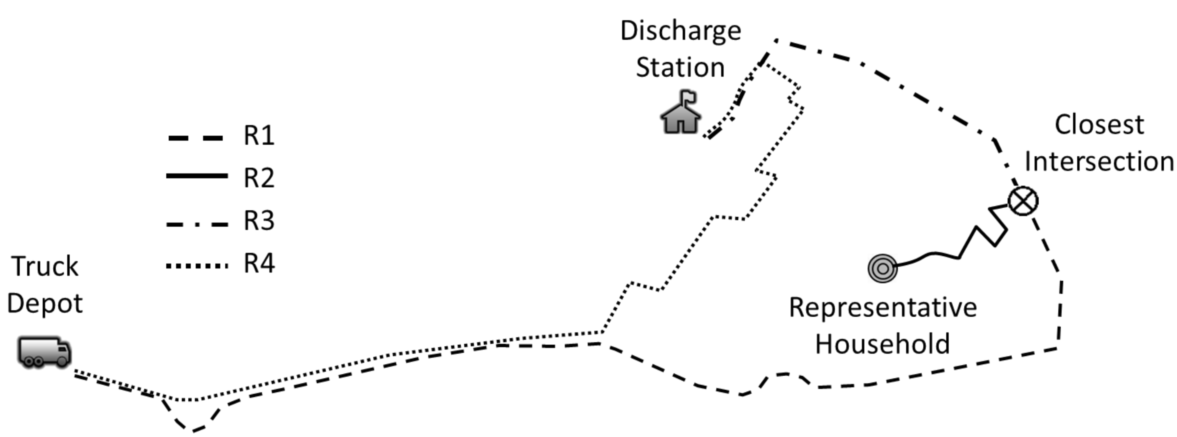


Figure 3: Route Distances

R1 = Route between closest intersection to Representative Household and Depot
R2 = Route between closest intersection and Representative Household
R3 = Route between closest intersection and Discharge Station
R4 = Route between Depot and Discharge Station

The routes were identified by the EVE team based on conversations with a commercial desludging service provider (Cayor Vidanges) and the Mayor of Guinaw Rails Nord (GRN) and two of the drivers working there, as well as their own experience in the area. Once the routes were drawn, the path lengths (in km) were automatically calculated in Google Earth.

2.2 Desludging Service Simulation Model

Given the high degree of variability in the travel times between the various locations in the Pikine Desludging Service Network Map and the desire to understand the average profitability for the commercial desludgers as well as the variance in profit margin, a Monte Carlo method was chosen for the analysis. A Monte Carlo simulation uses a set of randomly generated numbers as input variables into a deterministic model, and then records the outcome for all iterations as the model cycles through 1,000+ runs, or sets of random inputs. This method was also easy to implement in Microsoft Excel, which was seen as beneficial for stakeholder acceptance in Pikine since they already use Excel in their daily business and there would be no additional cost for software.

During the simulation, the Desludging Service Simulation Model begins by randomly choosing a representative household from the available list and then schedules a single truck to travel to that household, pump the contents of the latrine, travel to the discharging station, discharge the tanker contents, and then return back to the same household or neighborhood, depending on whether the goal is to either partially or fully empty the latrine tank. The location of the household, the volume of the latrine pit, the time to fill or empty the tanker, the waiting time at the household and discharge station and the road travel time for each segment are chosen randomly based on a range of expected values gathered from empirical research and expert opinion from interviews with stakeholders in Pikine. For the purposes of the analysis, it was assumed that all of the input distributions were uniform and calculated through the use of the *randbetween* function in Excel, based on minimum and maximum expected values.

Based on this output, the model calculates the amount of time it takes to do a single rotation, how much sludge is pumped, the distance traveled, the time of the last discharge, the average tank volume and the total job time. These values are recorded for each run (representing one working day) and the model is run to obtain averages based on 100 runs of 260 working days per year (26,000 runs in total). Once these runs are complete, the data is imported into a separate spreadsheet and the model calculates the net profit and profit margin and builds data tables and charts for average values and the range of values over a five year sample.

Input Data and Assumptions

Input data for the Desludging Service Simulation Model came from a variety of sources including published reports, internal Oxfam/EVE reports, empirical data gathered in the field in November 2010 and July 2011, and informal interviews with stakeholders. When data wasn't available assumptions were made on the minimum and maximum expected values and random numbers were generated in the Monte Carlo simulation between these two values. The data and assumptions were gathered in three main areas:

a) The "Data_Routes" table which contains the input data taken from the Pikine Desludging Service Network Map and assumptions for the minimum and maximum travel speeds on the main highway and within the Pikine communes. The Data_Routes table includes the distances between the four key points on the Desludging Network Map (R1-4, as shown in Figure 3) that were measured in Google Earth and assumptions for the minimum and maximum travel speed along those routes. Specifically, the min/max highway speed (e.g., *MinSpeedHwy*) and min/max neighborhood speed was estimated based on conversations with truck drivers and recorded data gathered during travel on the highways and smaller roads in July 2011. During the simulation, the model picks a speed within these two ranges for each travel segment and based on the corresponding travel distance, a segment travel time is calculated. The segment travel times are then added together to generate the total rotation time.
b) The "Data_Truck_Costs" table which includes data on the service provider operating costs, compiled primarily from previously published studies by (CREPA, 2002) and ENDA-Tiers Monde (Toure, et al., 2002) plus data from EVE and interviews with desludging service providers (Cayor_Vidanges, 2011). The cost data was divided into the following areas: office; maintenance; insurance; amortization; salaries; and fuel (driving/waiting/pumping).
c) The "Data_Latrines" table includes empirical data on the typical size of the latrine tanks, which varied from 5-14 m^3. For the simulation model, the latrine size was

generated randomly within this range; however, the distribution of latrine sizes in the model was compared to the actual distribution of the 20-latrine sample and the mean and standard deviation were similar. The average latrine size of 9.4 m^3 was also similar to values from the public literature.

Rotation Time

The rotation time (in minutes) is calculated as follows:

T_{total} = $T_{R1} + T_{R2a} + T_{prep} + T_{pump} + T_{R2b} + T_{R3a} + T_{wait} + T_{discharge} + T_{R3b} + T_{R4}$

where

T_{R1} = *randbetween (R1/MaxSpeedHwy, R1/MinSpeedHwy)*

T_{R2a} = *randbetween ($R2_{HH}$/MaxSpeedHH, $R2_{HH}$/MinSpeedHH)*

T_{prep} = *randbetween (5,30)* for the first visit, and = *randbetween (5,15)* for subsequent visits

T_{pump} = *min (TruckSize, PitSize)/PumpRate*

T_{R2b} = *randbetween ($R2_{HH}$/MaxSpeedHH, $R2_{HH}$/MinSpeedHH)*

T_{R3a} = *randbetween (R3/MaxSpeedHwy, R3/MinSpeedHwy)*

T_{wait} = *randbetween (5,15)*

$T_{discharge}$ = *round (TruckSize/DischargeRate)*

T_{R3b} = *randbetween (R3/MaxSpeedHwy, R3/MinSpeedHwy)*

T_{R4} = *randbetween (R4/MaxSpeedHwy, R4/MinSpeedHwy)*

Note: T_{R3b} = 0 for the last rotation; T_{R4} = 0 for all rotations except the last rotation

Case Studies

In order to understand how the Pikine desludging service system behaves over a range of possible scenarios, three case studies with two variants were created. There were two main differentiators in the cases: first, whether the tank was only emptied to the capacity of the single tanker or whether it was completely emptied, potentially requiring multiple trips; and second, whether the operator was a small informal enterprise, a larger formal enterprise, or a municipal government/commune. This yields six primary cases, as shown in Table 1.

Table 1: Summary of Six Cases

Case	1A	1B	1C	2A	2B	2C
Tank fully emptied?	No	No	No	Yes	Yes	Yes
Type of Desludging Enterprise	Small Private	Medium Formal	Municipal	Small Private	Medium Formal	Municipal

In Case 1, it was assumed that the tanker only makes one trip to each household and empties the latrine to the volume of the tanker truck and leaves the remainder of the latrine volume in place. For example, if the latrine size was randomly selected to be 9 m^3 and the truck size was 6 m^3, 3 m^3 of sludge and waste water would be left in the latrine tank. This case mirrors the current situation in Pikine, and has led to criticism of the desludging service providers who only pull off the waste water layer and leave the hardened sludge at the bottom. This accumulated sludge can contaminate the water table in the area and cause significant health concerns, especially during flooding where the remaining contents of the latrine tank overflows into the household compound and into the streets.

In Case 2, it was assumed that if the tanker truck does not empty the tank on the first trip, they return to the same household until the latrine tank is completely empty. For example, in the case of a 9 m^3 latrine with a 6 m^3 truck, two rotations would be required, and for the fixed price subscription service, the desludging service provider would be paid the same amount as in the one rotation per household case, but would incur roughly twice the cost, and a significant decrease in profitability would result.

In both Case 1 and 2, three types of desludging service providers were modeled: Variant A, a small informal operator with a 6 m^3 truck and no office expenses, insurance or other fees; Variant B, a formal operator with a 6 m^3 truck and standard commercial operating costs; and Variant C, a municipal operator with a 3 m^3 truck and minimal operating costs. The results of these cases and variants are presented in the following sections.

3 Results

In this section, results are presented for each case and variant based on the current price of the desludging service (25,000 FCFA ($50) for the private sector operators and 12,500 FCFA ($25) for the municipal operator), and a parametric analysis of the profitability as a function of subscription price is also shown. Several sensitivity analyses are also presented, showing the effect of different strategies to increase the profit margin while holding the subscription price fixed at the goal of 10,000 FCFA ($20), regardless of the size of the latrine.

3.1 Case 1

In Case 1, each operator is assumed to fill up their tanker truck to its capacity (or to the volume of the tank in the event that the tank is smaller than the tanker) and then drive to the discharge site (Niayes) to discharge the contents. When the operator returns to Pikine, they go back to the same neighborhood, but choose a different house. Therefore, each customer gets one rotation regardless of the size of their latrine tank, and revenues are accumulated based on a fixed price per rotation (e.g., 25,000 FCFA ($50) for a 6 m^3 tanker). This assumption matches the current modus operandi in Pikine, and has significant impacts on the quality of service since the average latrine tank size in Pikine is 9.5 m^3 and the largest tanker truck size is limited to 6 m^3 due to access constraints. Table 2 shows the tabularized results for Case 1 for the three variants.

Case 1A

This case represents the most common form of service provision in Pikine where small independent operators pump out a truckload of sludge/effluent for individual households on a service-on-demand basis. A 6 m^3 truck size was assumed in the analysis since many of the Pikine neighborhoods are not accessible by larger trucks.

For Case 1A, an average of 3.7 rotations was completed each day, which is consistent with previous studies. (CREPA, 2002) This average is across all 16 of the household clusters identified in the Pikine Desludging Network Map (see Section 2.1), and since some Communes are further away from the Depot and Niayes Station than others, fewer rotations can be done for those areas. The impact of household distance from the depot and discharge station is also evident in the Daily Distance and Rotation Time result. Since the “desludging” service in Case 1 only empties the tank to the capacity of the truck, only 63.2% of the tank volume was pumped out on average. This could cause significant public health concerns, especially during flooding.

On average, the profit margin obtained by the small operators was 53% assuming a standard price of 25,000 FCFA ($25) per rotation for a 6 m^3 truck and one driver plus two additional manual laborers on every truck. The Profit Margin Percentage is calculated as *(Revenues-Costs)/Revenues ×100)*. The main reason why this profit margin is so high is that the informal operators pay no taxes on revenue, have no office or office staff to drive up their overhead costs, and they operate with older used trucks, so their monthly payments on equipment is relatively low.

Table 2: Results for Case 1

CASE 1		Average Across 16 Household Clusters						
		Daily Distance (km)	Daily Rotations	Rotation Time (min)	Annual Rotations	Annual Distance (km)	Annual Profit	Profit Margin
1A	Min	45	2.9	97	940	16,438	$ 23,971	51.8%
	Max	83	4.6	178	990	17,363	$ 26,501	54.4%
	Ave	65	3.7	134	966	16,934	$ 25,249	53.1%
1B	Min	51	2.8	103	909	17,764	$ 15,372	34.4%
	Max	87	4.5	189	960	18,675	$ 17,636	37.4%
	Ave	70	3.6	140	934	18,228	$ 16,549	36.0%
1C	Min	39	3.3	72	1,144	15,316	$ 3,420	12.1%
	Max	77	5.9	145	1,195	16,376	$ 5,033	17.1%
	Ave	60	4.5	103	1,171	15,794	$ 4,355	15.1%

Case 1B

In the case, the operator is assumed to be a medium size enterprise that is located near the Yoff airport in Dakar. For the medium formal operator, it was assumed that they were paying taxes, they operated from an office building where they paid rent and utilities, they had an office manager and accountant whose salaries were split over the size of the fleet (5 trucks assumed), and they operated with a newer truck with a higher monthly payment for equipment. The distance between the truck depot and the Pikine neighborhoods is also greater; however, this was not a major factor in the results as it only affected the first segment of the day.

As shown in Table 2, the averages for total distance, number of rotations and rotation time are not significantly different than in Case 1A. However, the profit margin for the larger formal operator is significantly less than that of the informal operator due to the higher operating costs. The distribution of operating costs is shown in Figure 4.

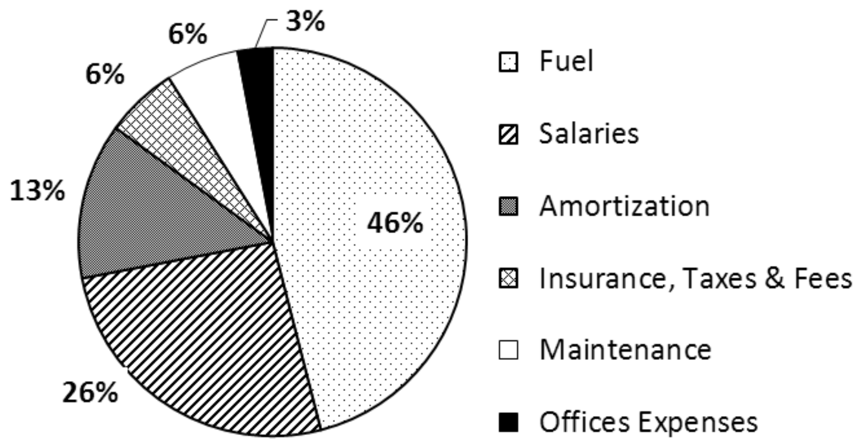


Figure 4: Composition of Total Costs (Formal Medium Size Operator)

Case 1C

In this case, the location of the truck depot was changed to the Mayor's office in Guinaw Rails Nord (GRN), which owns a 3 m^3 truck that was used extensively in the Oxfam/EVE latrine rehabilitation project. Since the Mayor's office is publicly owned, no rent was included in the operating costs and 50% of the office expenses were estimated for the vehicle operations. In addition, a salaried office manager/logistician was covered in the model, but since the truck is a public asset, no amortization was assumed. Truck maintenance, however, was included.

The results shown in Table 1 are as expected. Due to the closer distance between the Depot and the Representative Households, the average total distance traveled in a day is 60 km and since it takes less time to complete a rotation, more rotations can be done in a day on average (4.5 as opposed to 3.6 in Case 1A). The average rotation time of 103 minutes is higher than the average recorded in the sample set provided by EVE for the 20 sample latrines; however, the empirical data set did not include the transfer times to/from the depot at the GRN Mayor's Office, which accounts for 27 minutes on average out of the 103 minutes.

In the model, the tanker only removes 3 m^3 of scum/effluent from each latrine per rotation so the total sludge pumped is only 31.6% of the total tank volume on average. If less than 1/3 of the contents of the tank are being emptied with each annual service, it becomes more likely that flooding will make the tank overflow in the future and it may be necessary to increase the frequency of desludging.

Based on the assumptions used for the operating expenses of the GRN service, the average profit margin is 15.1%. Since the goal of the municipal service is to provide the desludging at a zero percent profit margin, this would seem to be a bit high. However, because the operating costs assumed in the model and bookkeeping by the Mayor's Office do not include depreciation on the vehicle or the salaries of everyone involved, it is likely that the actual costs are higher.

3.2 Case 2

The main difference between Case 1 and Case 2 is the degree to which the desludging service providers actually empty the septic tank. In Case 1, one truckload of sludge/effluent was pumped, even if the volume of the latrine tank was larger than the truck volume. In Case 2, the desludging service provider is forced to empty the entire pit, regardless of whether the job takes one rotation or four, and they are paid the same amount regardless of the number of trips. Obviously, this has a significant impact on the profitability of the service as shown in Table 3.

Case 2A

Case 2A models a small informal operator that is based in the Truck Depot near the Dakar Stadium. As shown in Table 3, the total distance traveled and the average number of rotations completed in a day is close to the result in Case 1A, but the number of customers, which is the basis upon which the revenues are based, is much lower than the number of rotations. While the average rotation time is basically the same whether the operator is emptying the same septic tank for a second or third time or starting with a new septic tank each time, as was the case in Case 1A, the number of customers served in a day depends on the size of the tank, the size of the truck, and on the traffic conditions between the nodes in the network map.

When the average annual Profit Margin is computed for Case 2A, the results show a decrease in profits by more than half as compared to Case 1A. This is due primarily to the fact that, in Case 1A, one trip per household is completed and in Case 2A, multiple trips may be required to fully empty the latrine. In both cases, the price paid per household remains the same, but the operator's costs change significantly. However, the average profit margin is still shown to be 20.4% which does meet the Gates project goal (not including possible resale of sludge by-products).

Table 3: Results of Case 2

		Average Across 16 Household Clusters							
		Daily Distance (km)	Daily Customers	Daily Rotations	Rotation Time (min)	Annual Rotations	Annual Distance (km)	Annual Profit	Profit Margin
Case 2A	Min	46	1.8	2.9	95	544	16,705	$ 4,394	16.4%
	Max	83	2.8	4.8	177	594	17,505	$ 6,851	23.4%
	Ave	66	2.2	3.8	130	572	17,121	$ 5,749	20.4%
Case 2B	Min	51	1.8	2.8	100	538	17,770	$ (2,534)	-10.9%
	Max	87	2.7	4.6	189	577	18,873	$ (989)	-4.0%
	Ave	70	2.1	3.6	137	561	18,345	$ (1,659)	-6.9%
Case 2C	Min	39	1.3	3.3	71	417	15,321	$ (14,190)	-138.3%
	Max	77	2.1	5.9	145	466	16,184	$ (12,871)	-112.2%
	Ave	61	1.7	4.5	103	442	15,790	$ (13,585)	-125.0%

<u>Case 2B</u>

In Case 2B, the medium size formal operator is based at the Truck Depot near the Yoff Airport in Dakar. All other factors, including the included taxes and office overhead costs remain the same as in Case 1B. The results, shown in Table 3, are similar to Case 2A and show a modest increase in the distance traveled and the rotations per day. However, as was the situation in Case 2A, the number of customers is a bit more than half the number of rotations, indicating that between 1-2 rotations are required per customer in order to completely empty the septic tank. This is consistent with an average tank size of 9.4 m^3 and a truck size of 6 m^3.

The average Profit Margin shows a loss of 6.9%, which is due to the high cost of operations coupled with the payment based on the number customers. During the Oxfam/EVE rehabilitation project, several desludging service providers stopped their service claiming that they were not making a sufficient profit to cover costs. The analysis in Case 2B appears to agree with this position.

<u>Case 2C</u>

As shown in Table 3, the results in Case 2C show some very interesting trends. First, because the GRN truck volume is only 3 m^3, many trips are required in order to empty out the septic tank completely. This leads to a high number of rotations per day (4.5 per day on average) but a low number of customers per day (1.7 per day on average). While the rotation time is shorter than the other Case 2 variants due to the closer proximity of the GRN Mayor's office to Niayes, the lower price charged (12,500 FCFA per customer, not rotation) makes the service very unprofitable.

The average Profit Margin in Case 2C is -125%. This means that the cost of providing a desludging service that completely empties the latrine tank using a small 3 m^3 tanker is not a feasible, or programmatically sustainable, venture.

Prior to initiating any future sanitation program in the Dakar region, the stakeholders should agree on whether a full desludge is required or whether a partial emptying of the latrine tank will suffice. This decision will have a significant impact on the profitability of the subscription desludging service, as explained in the next section.

3.3 Parametric Analysis of Subscription Price

In Case 1 and 2, the price of the rotation/customer trip was set at 25,000 FCFA ($50) for Variants A and B and 12,500 FCFA ($25) for Variant C. It is also important to understand how the profitability changes for different subscription prices. As shown in Figure 5, all operators are showing a loss at subscription prices below 10,000 FCFA, which is the upper limit of the target price set by the Gates project. It is also possible to solve for the "break even" point where there is a 0% profit margin and for the subscription price that yields a 20% profit margin, as shown in Table 4.

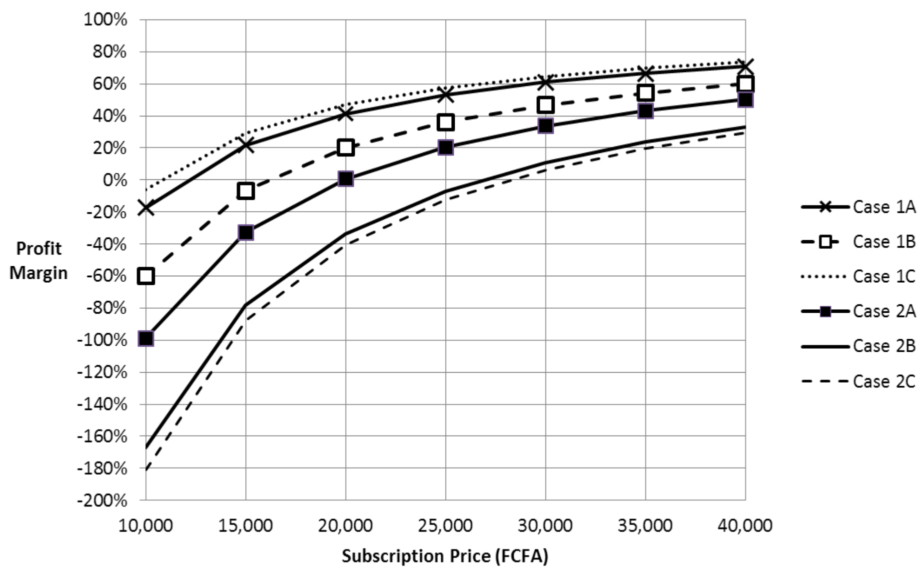


Figure 5: Profit Margin as a Function of Subscription Price

Table 4: Subscription Prices for Break Even and Profit Margin Goal

	Break Even (PM=0%)	Gates Goal (PM=20%)
Case 1A	11,726 FCFA ($23)	14,657 FCFA ($29)
Case 1B	16,002 FCFA ($31)	20,002 FCFA ($39)
Case 1C	10,612 FCFA ($21)	13,264 FCFA ($26)
Case 2A	19,892 FCFA ($39)	24,865 FCFA ($49)
Case 2B	26,715 FCFA ($53)	33,394 FCFA ($66)
Case 2C	28,108 FCFA ($55)	35,136 FCFA ($69)

When there is a fixed subscription price that is collected on a monthly basis, the net profit is less variable than in the pay-per-service case, as shown in Figure 6. Currently, the model does not take seasonal variations in demand into consideration, which can be substantial. A subscription service will allow the operators to get through the low demand months assuming the revenues are managed well, but could also create problems if the operators spend the larger profits in low demand months and then realize lower profits or losses when the demand (and associated costs) is high. Since the management of the subscription service schedule and financial aspects will require a higher skill level in fleet management than the smaller private operators and municipal providers are accustomed to, training in these areas should be provided as part of the larger project.

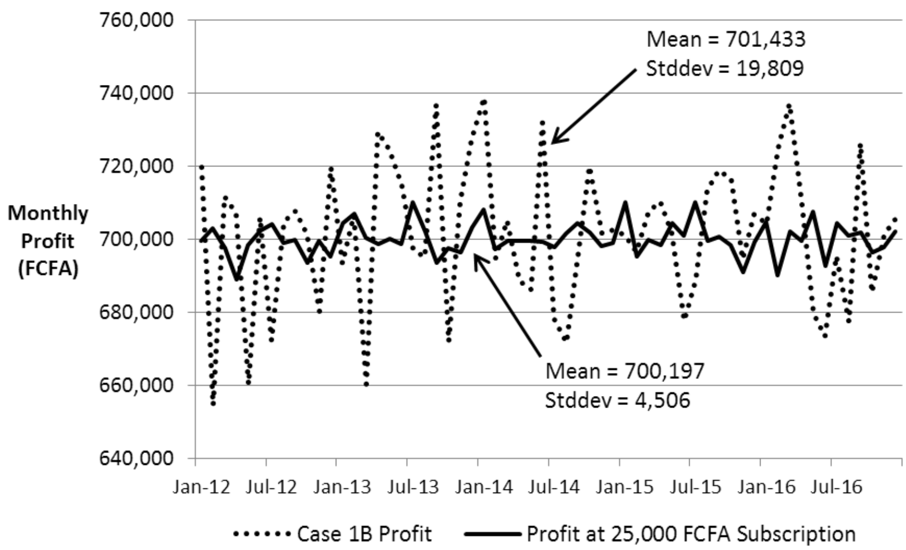


Figure 6: Variance in Monthly Profit (Case 1B as an Example)

3.4 Sensitivity Analysis

Based on the results of Cases 1 and 2 and the parametric analysis, several key drivers to profitability were identified. First, as shown in Figure 4, the cost of fuel constitutes 46% of the total operating costs and changes in the price per liter of fuel and/or truck fuel efficiency could have a significant impact on the profitability. Second, the limited operating hours at the Niayes discharge site was an important driver, since it limited the number of rotations that could be completed in a day. In order to meet the project's goal of a 20% profit margin at a subscription price of no more than 10,000 FCFA ($20), changes in both fuel efficiency and operating hours at Niayes may be necessary, and improvements in traffic congestion, especially along the route to the Rufisque discharge station, may also be beneficial.

Change in Profitability as a Function of Fuel Prices

The fuel cost impact on the overall profitability is clear when reviewing previous reports dealing with desludging in Senegal. For example, when the *PROGEBOUE* report was written in 2002, the cost of fuel was 375 FCFA/liter (CREPA, 2002). While the trends on distance, number of rotations per day, and rotation time are consistent with the findings of this study, the profitability results are quite different, due in large part to the discrepancies with the cost of fuel. Since the price of fuel has doubled since 2002, previous studies of this nature must be updated, especially if they are being used as inputs to profit margin goal setting on the Gates project and other efforts.

A parametric analysis was performed by ranging the price of fuel from 400 – 1400 FCFA (actual price in July 2011 was 752 FCFA/liter) and keeping the other assumptions the same as in the baseline cases presented in Table 2 and Table 3. As shown in

Figure 7, there is a linear relationship between the fuel price and profit margin and the magnitude of the decline in profitability with increasing fuel price is higher for those cases where more rotations are required in order to empty the latrine tank (e.g., Case 2). This is expected since the driving distance and volume of waste pumped drives the fuel consumption, which in turns drives the profitability.

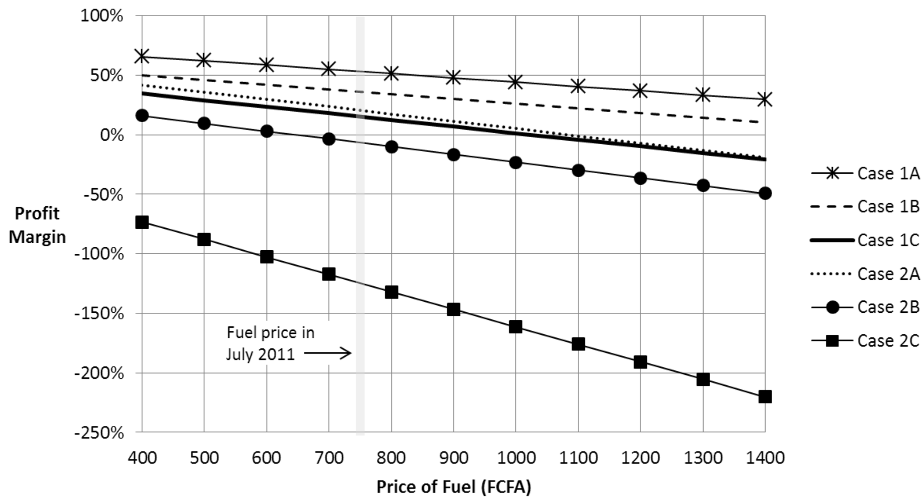


Figure 7: Change in Profit Margin as a Function of Price of Fuel

A potential increase in price of fuel should be considered a risk factor when deciding upon a fixed subscription price that leads to the 20% profit margin goal. For example, in Case 1B (medium size formal operator who removes one truckload of sludge/effluent), if the subscription price is set at 20,002 FCFA ($39), which is the minimum price required to achieve a 20% profit margin based on current fuel prices, and then there is a 50% increase in the price of fuel, the profit margin will be zero. This is illustrated in Figure 8. In order to prevent too significant of a decline in profitability, the subscription price should be reevaluated each year based on fuel price forecasts.

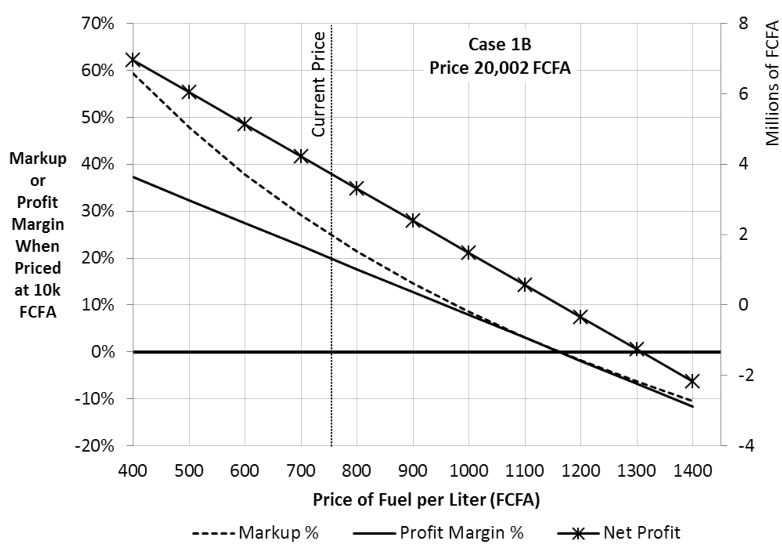
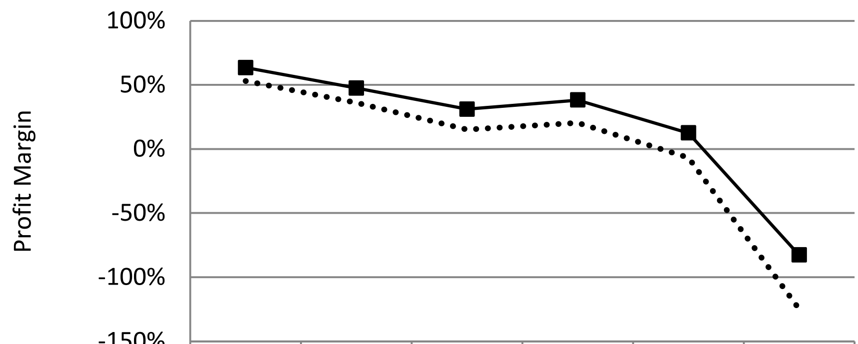


Figure 8: Impact at Fuel Price Increase on Profitability for a Fixed Subscription Price

Change in Profitability as a Function of Fuel Efficiency

Since the cost of fuel plays an important role in the overall profitability, it is also important to consider the fuel efficiency of the desludging trucks. In the model, the fuel efficiency was set at 6 miles per gallon (39.2 liters/100 km), which is typical for older vehicles driving in difficult terrain. If newer, more fuel efficient vehicles were bought, the increase to the profit margin would be increased by 10 to 42%, as shown in Figure 9.

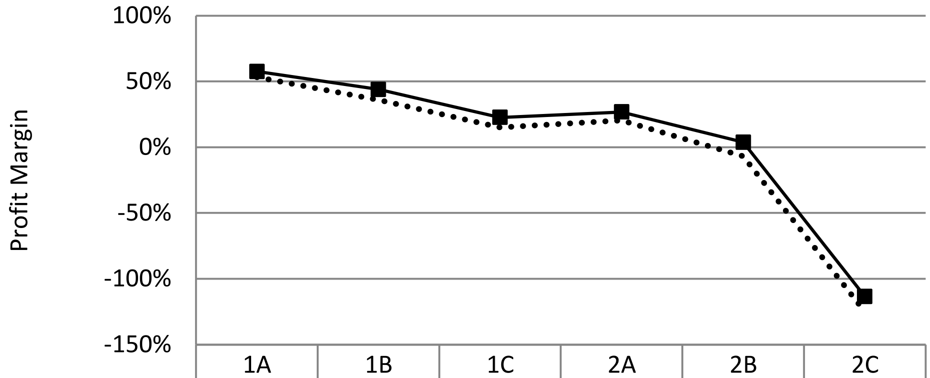


	1A	1B	1C	2A	2B	2C
6 mpg	53%	36%	15%	20%	-7%	-125%
12 mpg	63%	47%	31%	38%	12%	-83%

Figure 9: Profitability as a Function of Fuel Efficiency

Change in Profitability as a Function of Closing Time

Currently, the Niayes site is only open on Monday – Thursday from 9:00 am until 4:00 pm and on Friday from 9:00 am – 1:30 pm. In the simulation model, the desludging service providers start work between 8:30 – 9:30 am and continue doing rotations until they get to within one hour of the Niayes closing time (3:00 pm). If the previous rotation finishes shortly before 3:00 pm, they return to the neighborhood to try to complete another one; otherwise, they return to the truck depot and end work for the day. Based on this logic, in the baseline cases, the operators arrived after closing 23 – 29% of the time, in which case they were assumed to dump the truck contents into a drainage ditch or open field, which is the current practice. However, if the closing were extended to 6:00 pm, the profit margin would be increased by 5 – 12%, as shown in Figure 10.



	1A	1B	1C	2A	2B	2C
4:00 PM	53%	36%	15%	20%	-7%	-125%
6:00 PM	58%	44%	23%	27%	4%	-113%

Figure 10: Profitability as a Function of Closing Time at Niayes

4 Summary and Conclusions

Based on the current desludging system in Pikine, it is not likely that the private sector providers will be able to achieve a 20% profit margin at a subscription price of 10,000 FCFA or below. In the best case with a municipal operator who only partially emptied the latrine tank, (Case 1C) the price point to achieve a 20% profit margin was 13,264 FCFA. If the tank was fully emptied, the small informal operators could achieve a 20% profit margin for a price of 24,865 FCFA, which is the current price for a desludge-on-demand.

Several changes could be implemented that would improve the Profit Margin, including increasing the fuel efficiency of the trucks and extending the operating hours of the discharge sites. However, a full cost-benefit analysis must be performed in order to understand the total costs of these improvements. In addition, since the price of fuel is highly variable, the subscription price should be re-evaluated on an annual basis to make sure that the business case for the private sector operators still closes; otherwise the program will not be sustainable.

From a sanitation perspective it is highly desirable that latrines and associated tanks be completely emptied (with exception of a small residual to rebuild the bacteria population) as shown in Case 2. In order to be profitable under such a scenario, the service price must either be made proportional to the tank size, which could make the service too expensive for many households in Pikine, or the tanker truck would have to be larger, which could cause access problems in many areas. A semi-collective system placed in an easily accessible area directly adjacent to a main road may be a possible solution to this problem, but needs to be examined more fully in future studies.

In conclusion, the current sanitation system in Pikine does not meet the needs of its residents and recent flooding has made a long-standing developmental crisis even more acute. While a mechanical desludging service subscription plan will help maintain the existing pit latrines and septic tanks in the area, it must be part of a larger scale effort to modernize the sanitation infrastructure. Flood risk reduction projects in Pikine, such as canalization of waterways, pumping of the Thiaroye borehole, construction of new raised latrines and voluntary relocation of the worst affected residents should be put at the forefront of government policy. If new infrastructure projects are required to make the subscription service more profitable (such as semi-collective installations), they should be included early in the project planning so that their associated maintenance costs can be in including in the life-cycle modeling.

Future research should include: a comprehensive survey of the commercial desludging service providers and the municipal operators to add more precise and updated cost data; an assessment of the impact of traffic congestion, especially as it relates to use of the Rufisque discharge station; a study of how seasonal variations in demand will impact desludging operations; and a cost-benefit analysis of adding communal latrines in the Pikine neighborhoods. In addition, the Google Earth-Monte Carlo simulation approach developed in this study could be applied to other contexts, such as water trucking optimization in relief operations and assessing the potential impact of disaster risk reduction projects in urban areas.

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