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Design and management of a sewage pit through discrete-event simulation

Esra Aleisa[1], Mohammad Al-Ahmad[2] and Abdulla M Taha[3]

Abstract

This paper reports two discrete-event simulation studies to model the activities of a residential waste treatment facility and prepare it to accept additional wastewaters through tanker trucks. The first simulation study models the wastewater treatment facility to ensure its ability to handle the planned added capacity arriving through the pit, while the second study simulates various managerial strategies to handle the traffic, testing, and unload procedures of tanker trucks arriving at the facility. The simulation models were statistically validated and the outcomes of the study were implemented in reality. The wastewater treatment facility extension suggested by this study was implemented and launched in mid 2008 to accept residential wastewater tanker trucks. This has saved the environment over 6,000 m^3 daily from being dumped into the open unlined terrestrial landfills. Simulation proved to be an excellent tool in the facility planning effort, as it ensured smooth flow lines of tanker truck load discharge and the best utilization of facilities on site.

Keywords

discrete-event simulation, facilities planning, layout, pit, sewage management, wastewater treatment

1. Introduction

A local wastewater treatment facility was established in 2001 to receive a daily capacity of 27,000 m^3/day of domestic sewage for a city in the State of Kuwait. The facility is connected to nearby residential communities, which are close to the coastal areas (see Figure 1), by the city's central sewage infrastructure that currently pipe around 17,000 m^3/day. However, many of the remote residential areas, army bases, and remote work campuses were not connected to the sanitary system of that water treatment facility. This motivated the population of the remote areas to designate a landfill location to dispense their residential waste. Over 200 tanker loads that accumulated around 6,000 m^3 were dumped daily in the aforementioned landfill. Needless to say, this raised serious environmental, health, and social issues. For instance, the landfill threatened to contaminate the ground waters in the area and had substantially affected environmental habitat and the flora and fauna. In addition, it prevented the open areas around it from being used for recreational purposes and had an effect on the population in the surrounding region. As a response, the local environmental public authority planned to build a sewage pit and attach it to the water treatment facility to receive wastewaters through tankers from sites that are not integrated with the piping system of the facility.[1] To prevent any operational and managerial problems at the pit under consideration, the team has applied discrete-event simulation modeling. Two simulation models were constructed. The first model simulated the water treatment facility to ensure smooth flow of waters due to the added pit extension. The second model simulated the pit activities, including truck traffic, testing, and discharge of waste loads. Data from former dump sites and water

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Figure 1. The location of the wastewater treatment facility under study.

treatment facilities were used to build the simulation. Analyses were conducted during peak and regular hours to identify system capacities, utilization, waiting times, and many other performance measures and system parameters.

The decisions based on simulation have contributed to creating smooth flow lines of sewage tanker truck testing and unloading, which in part resulted in a successful design of a waste disposal facility.

2. Literature review

In the broader literature of facilities planning and simulation, simulation has become an essential tool in complex facility layout projects, because it can incorporate many of the constraints commonly found in large-scale systems.[2] According to Grajo[3] and Aleisa and Lin,[4] layout optimization and simulation are two complementary tools indispensable to any plant layout or productivity task. Simulation is the only methodology that is robust enough to systematically examine the role and impact of process complexity and other key variables on factory performance.[5,6] This is mainly due to the inadequacy of analytical models to consider many of the requirements of material flow, overall flow efficiency and many operational characteristics.[5,7,8]

In the area of wastewater treatment facilities, discrete-event simulation have been applied repeatedly to estimate capacities, analyze and balance effluent water flows, and improve overall performance measures.[9–14] Ceric and Hlupic[15] used simulation to model a solid waste-processing system that is to be installed in Zagreb, Croatia. Printemps et al.[16] utilized simulation to develop a simplified mathematical tool that is able to reproduce and anticipate the behavior of certain wastewater treatment plant discussed in their study. In Glenn et al.,[17] a discrete-event simulation model was created using the General-purpose Simulation System (GPSS) to investigate the batch operation of a poultry-processing wastewater treatment plant. Huang et al.[18] applied simulation on a higher level to assess the potential dynamic evolution of environmental systems caused by various strategies. In addition, Ferrer et al.[19] presented a software tool to design, simulate, and optimize wastewater treatment plants. The program is called DEsign and Simulation of Activated Sludge Systems (DESASS).

3. Water treatment steps

Whether arriving by tanker trucks or pipe lines, residential sewage water undergoes three phases of treatment. These phases are depicted in the process flow chart shown in Table 1 and are explained below.

Table 1. Process flow chart

Process	Symbol
Sewage water received from sanitary system and pumped to the head works	➡
Sewage water received by tanker truck and pumped to pit	➡
Testing a sample of the sewage from each tanker	■
Decide whether the tanker truck content is of domestic sewage type	◆
Unload tanker truck	●
Transfer the sewage through pipes from the pit to the head works	➡
Screening, grit removal and odor control of the sewage in the head works	●
Transporting to the oxidization ditch through pipes	➡
Decompose the organic matter in the oxidation ditches	●
Transfer to secondary clarifiers	➡
Precipitation and separation of the sludge	●
Transfer to sand filter	➡
Remove suspended solids from the treated water	●
Transfer discharge to the back wash storage tank	➡
Addition of chlorine for sterilization	●
Transfer to the ultraviolet system	➡
Chlorine disinfection	●
Transfer to the effluent storage tanks	➡
Store the effluent in silos	▼

1. Primary treatment: this phase is conducted in three steps.

  a. Screening: in screening, solid objects larger than 25 mm (i.e. paper, wood, and plastics) are removed from the sewage water using metal screens. This is used to protect the facility equipment from clogging up and blocking water flow.
  b. Grit removal: in this process, moderately heavy particles, such as grit and sand, are removed. This prevents abrasion of equipment and parts. This also reduces the risk of clogging of piping, as well as reducing the frequency of emptying and cleaning of water-retaining structures.
  c. Odor control: this process removes foul-smelling nuisance gases generated in the previous two processes. This is conducted by running the sewage matter on a bed of activated carbon, where organic and inorganic gases, such as methane and hydrogen sulfide, are absorbed.

1. Secondary treatment: this stage comprises the biological treatment of the matter. It again consists of three steps: oxidation ditches, secondary clarifiers, and return sludge pumps.

  a. Oxidation ditches: oxidation ditches are two long channels that are built side by side and are connected by the two far ends. Propellers are installed at those far connecting ends to stir the content. In the ditches, many pathogenic substances and harmful bacteria are removed to low levels. Oxygen is injected to stimulate the bacterial activity that is used to decompose the organic matter. Figure 2, shows the oxidation ditches at the water treatment facility.
  b. Secondary clarifier: in the secondary clarifier, the sludge continues in the sewage liquor, arriving from the oxidation ditches at the bottom of the clarifiers. Secondary cleaned effluent floats to the top of the tank and moves to tertiary treatment. Part of the precipitated sludge is returned back to the oxidation ditches to enhance the treatment of newly arriving wastewaters.
  c. The remaining part of the participated sludge is pumped to a sludge-handling facility to be further processed and converted to fertilizer.

1. Tertiary treatment: tertiary treatment is the final stage at this particular wastewater treatment facility. It consists of the following steps.

  a. Sand filters (gravity filters): here the secondary treated water is filtered through a special type of rapid filtering sand that separates the suspended solids from water. Chlorine is added for preliminary water disinfection.
  b. Ultraviolet (UV) disinfection system: there are eight channels to disinfect the secondary effluent by using the UV system. It is used to exterminate harmful microorganisms.
  c. Chlorination system: the chlorine system is a standby system that operates when the UV system is not in operation, either due to malfunction or routine maintenance.
  d. Effluent storage tank: four silos are available to store tertiary effluent. Each silo has a capacity of 7,000 m^3.
  e. Effluent pumping station: this station consists of propellants to pump the tertiary treated water from the silos to be shipped and utilized.

Facility machinery are monitored and controlled by a Distribution Control System (DCS). The DCS contains programmable equipment that is used to monitor, control, and adjust the water flows. The flow pipes are made from a ductile iron piping system that ranges between 101.6 and 1,100 mm in diameter. On average, the daily flow of wastewaters throughout the system is around 2,851,455 imperial gallons. These specifications were incorporated in the first simulation model, which is discussed next.

4. The first simulation model: Modeling the water treatment facility

The first simulation model simulated existing wastewater treatment facilities. Then, it exposed the facility to the added water flow that is forecasted to arrive from the new pit, to test the effect of the added volume on the treatment process. The logic of the simulation model was constructed based on the information and process steps and specifications provided in the preceding sections. A snapshot of the discrete-event simulation model using Arena® software is shown in Figure 3.

5. Statistical model validation of the water treatment facility simulation

Statistical model validation provides evidence as to whether or not the model is a legitimate representation of reality.[20] A 95% confidence level was assumed satisfactory as in any typical validation practice. The equality of the real and simulated population variances were tested first. According to result of the equality of variances test, the proper formula for testing the equality of the real and simulated population is selected and applied. Seven replications were conducted for the months provided in Table 2.

5.1. Test of hypothesis of the equality of variances

Let $\bar{X}_i$, s_i, and n_i indicate sample mean, standard deviation, and size of *sample i*, respectively. Similarly, let σ_i^2, σ_i, and μ_i indicate the variance, standard deviation, and mean of *population i*, respectively:

$$H_0 : \sigma_1^2 = \sigma_2^2 \qquad H_1 : \sigma_1^2 \neq \sigma_2^2 \tag{1}$$

After applying the F-Test, the assumption of non-equal variance was validated as α (0.05) is greater than the p-value (0.0002).

Accordingly

$$\bar{X}_1,\text{ actual} = 86102657.1\text{ gallons}$$
$$\bar{X}_2,\text{ model} = 86323285.71\text{ gallons}$$
$$s_1,\text{ actual} = 4424200\text{ gallons}$$
$$s_2,\text{ model} = 668331.932\text{ gallons}$$
$$n_1 = n_2 = 7\text{ replications}$$
$$\alpha = 0.05$$

Comparing the equality of the real and simulated population means using Population Difference Confidence Intervals of Minitab software (two sample t-test)yields

$$-4358796 \le \mu_1 - \mu_2 \le 3917539\text{ gallons}$$

Figure 2. An oxidation ditch consists of a long channel where sewage water is injected with oxygen and bacteria to decompose the waste for around 14 hours.

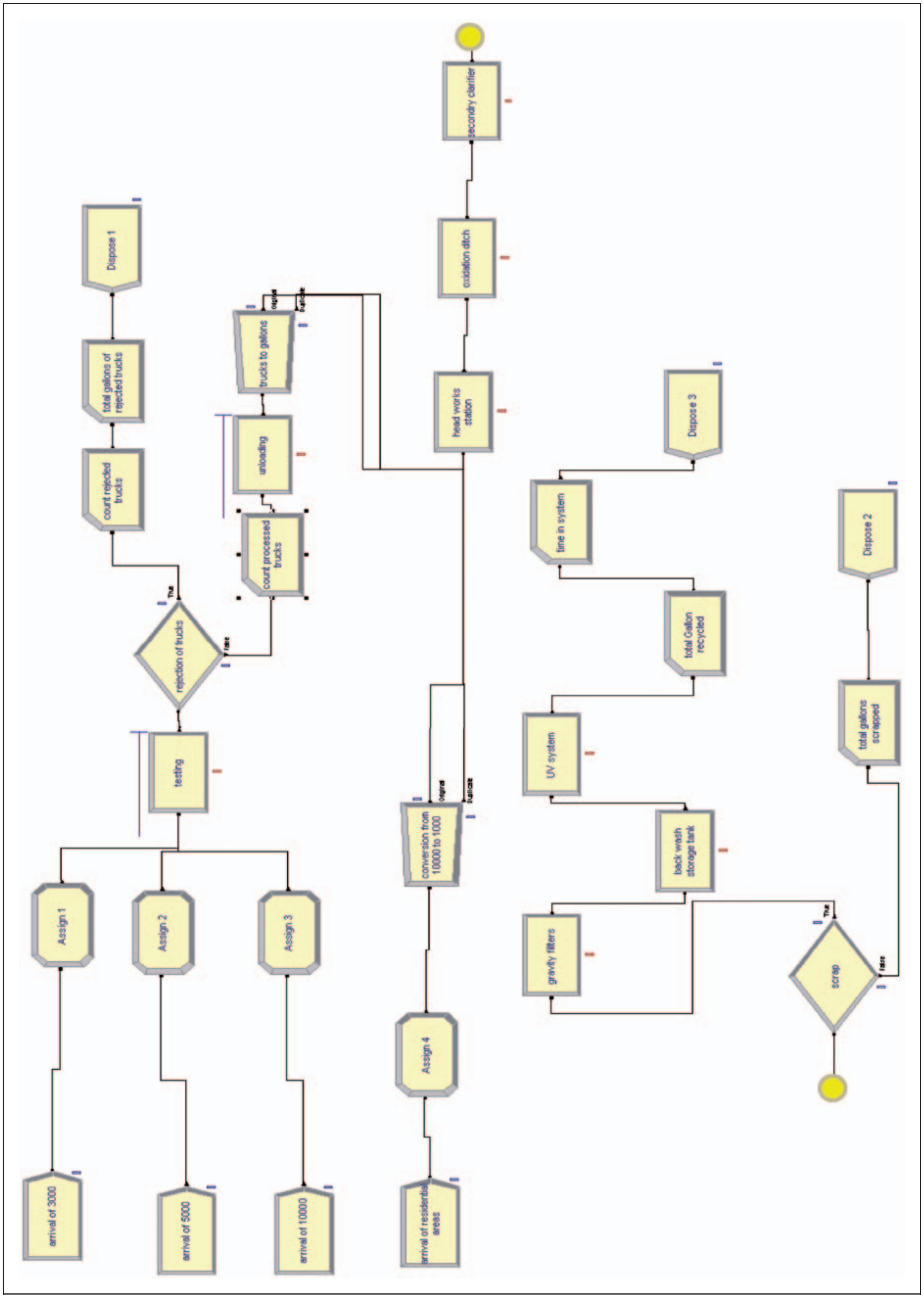

Figure 3. The discrete-event simulation model of the water treatment facility.

Table 2. Comparison between the results of the actual and simulated systems

Month	Actual data (imperial gallons)	Simulated system (imperial gallons)
January	84,244,820	85,871,000
February	77,861,300	85,790,000
March	90,399,320	87,022,000
July	90,104,960	87,184,000
August	88,425,920	86,002,000
September	84,100,720	86,840,000
October	87,581,560	85,554,000
Sum	602,718,600	604,263,000
Average	86,102,657.1	86,323,285.71
SD	4,424,200	668,331.932

The 95% confidence interval on the difference between the real and simulation population means includes zero. This result indicates that the means of these two populations are statistically equal at a 95% confidence level. In other words, the simulation is a valid representation of the real system.

Now the simulation model of the real system can be used to test whether the real system can accommodate an additional capacity of 8,000+ gallons per day, while maintaining the desired functionality.

6. The planned pit simulation model

Experimenting with the simulation of the real system with added capacity indicated that the desired characteristics of the tertiary effluent are consistent with that required by the local Ministry of Public Works (MPW).

The second simulation model discussed in this section simulates the activities carried out at the planned pit prior to pumping its content to the wastewater treatment facility. Activities at the pit include conducting tests on the type of content in the tanker trucks arriving at the pit, the tanker truck unloading procedure, parking, maneuvering, record keeping, and leaving the pit area.

6.1. Testing truck and pit content

Wastewater testing at the pit facility includes both preliminary on-site and detailed water testing. The on-site water testing is performed by hand-held probes, which measure temperature, pH, and conductivity. Detailed tests are performed twice every week on samples taken from the pit itself. The detailed tests are conducted in laboratories at a nearby wastewater treatment plant.

6.1.1. Truck load testing (on site). The truck load testing is a relatively quick test that is performed on each tanker truck arriving at the pit. The test will provide an initial indication as to whether or not the tank content is of a residential source. Failure to achieve target ranges for this test indicates that the tank content might not be residential (possibly industrial or medical) and that further investigation is necessary. Non-residential waste, whether industrial or blood contaminated (arriving from hospitals), needs to unload elsewhere. A team of experts estimates that this test can be conducted within 6–9 minutes on average, and can be accomplished using hand-held probes that can provide quick results.

6.1.2. Periodical tests (detailed). Periodical tests are more comprehensive compared to on-site tanker truck testing. These measurements require extensive biological and chemical testing, which typically requires several hours for sample conditioning and other lab work. Periodical tests include measurements such as settleable matter, total suspended solids, total dissolved solids, volatile suspended solids, biological and chemical oxygen demand, sulfates, phosphates, alkalinity, heavy metals, and others.

Detailed measurements include chemical and biological characterization of the pit water. Therefore, due to time constraints, this test will be conducted either periodically or on random tanker trucks failing the on-site testing.

6.2. Tanker truck traffic data

Because the pit project did not exist by the time the simulation was built, required data were obtained by conducting field visits to the original waste dumpsite. At that location, time studies were conducted to calculate tanker truck maneuvering and parking times, tanker truck load discharge times, and record keeping. Previous records of arrival times of tanker trucks were used to estimate inter-arrival patterns and load capacities of tanker trucks. In addition, research on available testing equipment was obtained to estimate time for testing and time until test results are obtained.

6.2.1. Arrival rates, load size and type. Data supplied by a local environmental authority for sewage tanker truck arrival for first quarter of 2008 were used to model inter-arrival times and the amount of sewage waste to be dumped at the facility. Regular and rush hour actual inter-arrival times in minutes were collected over the entire 24-hour period for several months. Data collection indicates a clear rush hour that starts at 8:00 am and ends at 2:00 pm every day.

Figure 4 shows tanker trucks categorized by load capacity and their respective relative percentage. It also shows that the vast majority of tanker trucks are of the size 10,000 gallons (41.67%) and 5,000 (50.56%) gallons.

Statistical fitting software is used to fit inter-arrival times. The fitting indicates that during regular hours, tanker trucks arrive according to the following distribution: $-0.5 + \text{EXPO}(11.7)$ minutes. This translates approximately to having five tanker trucks per hour (5.36 tanker trucks per hour rounded to the nearest integer). On the other hand, during peak hours, tanker trucks arrive according to the following distribution: $-0.5 + \text{EXPO}(3.88)$ minutes. This translates approximately to having 18 tanker trucks per hour (17.75 tanker trucks per hour rounded to the nearest integer). Additional data collected and fitted are categorized as either regular and peak hours, which are shown in Table 3.

6.2.2. Docks and load discharge. Field visits to a nearby site and timed data collection indicates that a gallon requires 0.001581 minutes to unload. For instance, a 10,000 gallon truck tank will require around 16 minutes of unloading time. This time excludes testing and maneuvering for parking at the dock station.

After collecting check-in data and testing, tanker trucks proceed to the unloading area for waste discharge. The initial design of the pit consists of eight unloading docks. In addition, the initial scenario was based on the assumption that trucks will choose the closest empty dock. However, experimentation via the pit simulation showed that this will cause some docking stations to be underutilized while others to be over utilized.

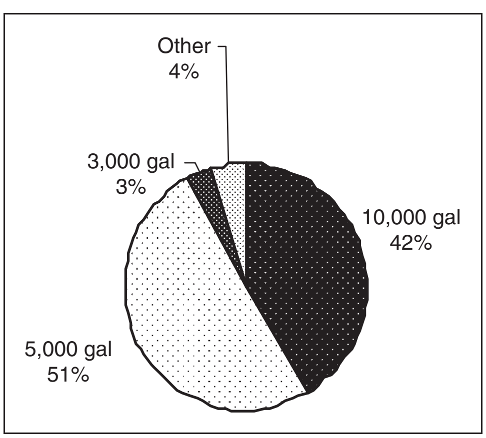

Figure 4. Pie chart of the tanker truck loads in gallons to arrive at the pit.

Table 3. Flow data analysis and fitting of inter-arrival times during peak and regular hours

Measure	Regular work hours	Peak work hours
Hours	00:00–08:00 14:00–00:00	08:00–14:00
Total observations	75	102
Relative percentage	42.4%	57.6%
Ratio	~1:4 tank trucks	
Min	0 minutes	0 minutes
Max	31 minutes	11 minutes
Sample mean	11.2 minutes	3.38 minutes
Sample SD	7.12 minutes	2.71 minutes
Mean tank trucks/hour	5.36	17.75
Distribution	Exponential	
Expression	$-0.5 + \text{EXPO}(11.7)$	$-0.5 + \text{EXPO}(3.88)$
Square error	0.059770	0.031227
p-value	<0.005	

6.3. The simulation model of the pit

Here we conduct the second discrete-event simulation model on the flow of tanker trucks arriving at the pit using Arena® discrete-event simulation software. The simulation was programmed to estimate several performance measures, including the number of tanker truck waiting in the queue, time in the queue, time spent at the facility, average utilization of site officers, average utilization of the docking areas, and average daily amounts of unloaded sewage.

Ten simulation experiments (replications) were conducted, each of the length of a 24-hour day. Each replication simulates a system that consists of the following.

1. Three officers: these officers are assigned to perform the following tasks:

   a. record truck check-in data, which requires 1–2 minutes;
   b. conduct content daily test, which requires 6–9 minutes.

2. Traffic officer: the traffic officer is assigned to monitor traffic and assign trucks to discharge locations to avoid traffic jams during operation hours.
3. Eight unloading docks: the unload time at docks is 0.001581 minutes/gallon. UK gallon measurements are used. Each docking area has one parking spot that can hold an additional tanker truck. Thus, there

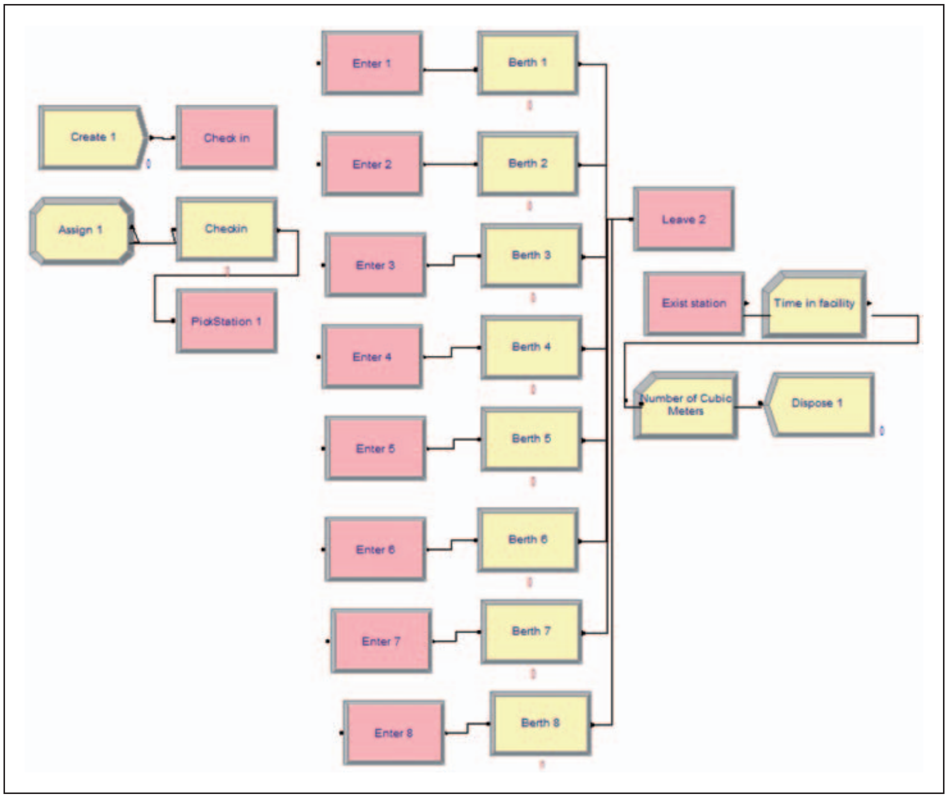

Figure 5. The simulation model of the planned sewage pit.

exist a total of eight waiting areas, one opposite each discharge dock.

4. One pit: the pit can hold a maximum of 6,000 m^3. The pit is emptied continuously to a nearby treatment facility.

Trucks arriving at the facility are first checked in by one of the facility officers (1–2 minutes). Then, it proceeds to the pit area. Time to reach the pit from the officer and parking requires 4–5 minutes. The truck content is tested (6–9 minutes). The time to discharge varies by gallon content and is around 16 minutes for a 10,000 tanker truck. The truck requires 1–2 minutes to maneuver and leave the facility.

The coding of the discrete-event simulation in Arena® software for the planned pit is shown in Figure 5. A snap shot of the animation of that simulation is shown in Figure 6.

6.4. The planned pit simulation model results

A simulation model was constructed based on the characteristics described in the previous section. As discussed earlier, the results are based on 10 replications, each of the length of 24 hours. The system is assumed to start empty and idle and data statistics are initiated at each replication.

The simulation analyses indicate the following.

1. The daily average discharge is 6,104.4 m^3. In the worst case scenario it could reach up to 7,253 m^3.
2. The distance between the pit entrance and the highway entrance should accommodate at least five trucks.
3. At most, four parking spots from the planned eight ones to be built opposite the docks will be utilized. The rest can still be implemented but used for truck cool down.
4. Engine cool down: heavy tanker trucks that arrive from relatively remote areas will sometimes stay at the pit site for a period of time to allow for the engine and tires to cool down. Cool-down delay is estimated to occur in approximately 10% of heavy tanker trucks. The facility can accommodate this situation, by allowing trucks to park in the available eight parking spots. This is possible, because the simulation study showed that even during peak hours only four out of the available eight waiting areas will be used to hold trucks in the queue. Thus, the

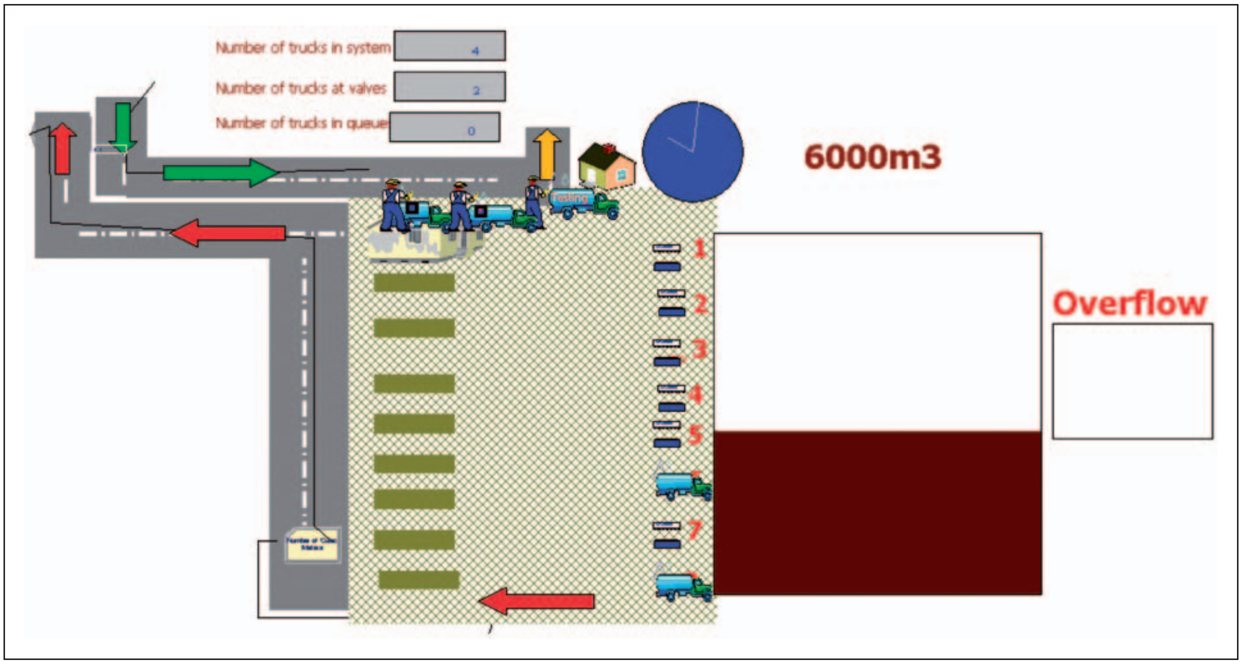

Figure 6. A snapshot of the animation of the discrete-event simulation of the planned pit.

remaining waiting areas are sufficient to handle overheated tanker trucks.

7. Statistical model validation of the planned pit simulation

As discussed earlier, model validation indicates whether or not the model is a legitimate representation of reality. This is conducted by statistically comparing real system output (μ_1) with the simulation system output (μ_2). Then, either hypothesis testing is applied for comparing the two population means, or the confidence interval is used to identify the difference between the two population means.

Hypotheses testing or confidence intervals require data points to be random, independent, and normally distributed.

The system starts empty and idle and replication statics are initiated with each run, which indicates that it is fair to assume that the data points are independent. The default random generation seed of Arena® software assures that the data is identically and randomly distributed. The output file of Arena® software automatically investigates for data correlation. In all aspects tested, no correlation was evident. There were between seven and 10 samples for each simulation, each sample containing around 200 data points (trucks). It is reasonable to assume that the normality assumption required for confidence intervals and hypotheses testing is valid via applying the central limit theorem.

In either case, in order to accomplish validation, we need to compare two population variances (the real and simulated) by drawing random samples from each population. Depending whether or not the sample sizes and variances are equal, different formulas need to be used.

Again, recall that $\bar{X}_i$, s_i, and n_i indicate the mean, standard deviation, and sample size of sample i, respectively. Sample values form the real system (1) for the number of daily tanker truck arrivals are:

$$\bar{X}_1 = 178.6 \text{ trucks}$$
$$s_1 = 21.9 \text{ trucks}$$
$$n_1 = 9$$

Sample values form the simulated system (2) for the number of daily tanker truck arrivals are:

$$\bar{X}_2 = 194 \text{ trucks}$$
$$s_2 = 12.8 \text{ trucks}$$
$$n_2 = 8$$

To conduct a statistically sound validation, the equality of two population variances needs to be verified, prior to checking the equality of means.

Since σ^2 is unknown we need to verify whether or not $\sigma_1^2 = \sigma_2^2$, using hypothesis testing:

$$H_0 : \sigma_1^2 = \sigma_2^2$$
$$H_1 : \sigma_1^2 \neq \sigma_2^2 \tag{2}$$

The F-distribution statistic will result in

$$F_0 = s_1^2/s_2^2 = 2.93$$
$$\text{Reject if} : F_0 < F_{1-\alpha/n_1-1,n_2-1} \text{ or } F_0 > F_{\alpha/2,n_1-1,n_2-1}$$
$$F_0 < F_{0.975,9,8} \rightarrow F_0 < 0.244$$
$$F_0 > F_{0.025,9,8} \rightarrow F_0 > 4.36$$

Therefore, with 95% confidence we *fail to reject* that the two variances are unequal. Now, we can proceed with conducting hypothesis tests on the equality of means:

$$H_0 : \mu_1 = \mu_2$$
$$H_1 : \mu_1 \neq \mu_2 \tag{3}$$

From the sample data:

$$\bar{X}_1 = 178.6, \ \bar{X}_2 = 194$$

The spooled variance sp^2 is calculated as follows:

$$sp^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2} = 311.93 \tag{4}$$

The t-distribution statistic will result in

$$t_0 = \frac{\bar{X}_1 - \bar{X}_2}{sp\sqrt{1/n_1 + 1/n_2}} = -1.767 \tag{5}$$

Reject if: $|t_0| > t_{\alpha/2,n_1+n_2-2} \rightarrow |t_0| > t_{0.025,15} \rightarrow |t_0| > 2.131 \rightarrow$ fail to reject H_0

The statistical analysis indicates that at a significance level of 95% we fail to reject the null hypothesis. In other words, we fail to reject that the two population means are unequal. Hence, the simulated model is a valid representation of reality.

8. Analysis of simulation runs of the pit simulation

Two simulation scenarios were proposed; the results are provided in Table 4. The results indicate the following:

1. Increasing the number of officers at peak hours to five officers will not significantly affect the total number of trucks served per day. However, it will reduce the average time a truck spends at the facility from 30.6 minutes to 27 minutes. In addition, on average, the time spent in the facility can reduce from 63 minutes to 55 minutes during peak hours, which constitute a 12.6% reduction.
2. Three officers are mostly utilized. The fourth and fifth officers will be utilized for around 35–42 minutes during the eight-hour peak period. However, the addition of the officers will in fact reduce the time in system by around 12%.
3. The original pit site dimensions will cause jams during peak hours. The number of waiting areas required can be dictated from the number waiting in the queue.
4. The distance between the highway entrance to the facility and the facility check-in point should accommodate at least five tanker trucks. This is to avoid long queues on the highway during peak hours.

Table 4. Results for discrete-event simulation categorized by regular and peak hours

Model	Scenario 1		Scenario 2	
Description	Testing conducted by 3 officers		Testing conducted by 5 officers in peak hours and 3 otherwise	
Criteria	Average	Maximum /peak hours	Average	Maximum /peak hours
Number of tankers served daily	194	223	189	222
Dock utilization per dock	22.4%	100% (peak hours)	22.4%	100% (peak hours)
Officer utilization	21%	100% (peak hours)	31%	100% (peak hours)
Time in facility (minutes)	**30.6**	**63**	**27**	**55**
Cubic meters of daily waste (m^3)	5584	6104.4	5899	7153
Waiting time in dock queues (min)	–	1–16	–	19.2
Waiting times in checking areas (min)	–	1–4.8	–	24.6
Number of trucks waiting at check-in point	0–1	0–5	0–1	0–8

Figure 7. Unloading docking station for the sewage pit as prescribed by the simulation study.

Figure 8. The planned pit is open to receive wastewaters using tanker trucks.

Based on the simulation results, the experts on the project decided to hire three officers during regular hours and five during peak hours of operation. In addition, the experts decided to supply hand-held probes to the officers and test the content of the truck while it is waiting at the dock, not at the check-in area. The location of the pit was moved around 100 m from the highway to accommodate a maximum length of five large tanker trucks that could possibly be queuing during peak hours. A pit design of eight unload docks and eight waiting areas is sufficient to handle unload queues and engine cool down.

9. The pit implementation

The planned sewage pit was constructed according to the specifications prescribed by the preceding two simulation studies. The pit opened to receive tanker truck loads in mid 2008 and operated as indicated by the simulation model. The docking stations for the tanker truck loads discharge is provided in Figure 7, while the pit is shown in Figure 8. This project saved the open areas of the environment from dumping a daily amount of 7,000 m^3.

Conclusions

Two discrete-event simulation models were constructed to imitate sewage pit activities that were planned to replace a residential wastewater landfill. The first simulation modeled the water treatment facility itself in order to predict its ability to handle the additional capacity pumped from the new pit. The simulation showed that the facility was ready to receive the additional capacity coming from the pit with minor modifications. The second simulation modeled the pit activities, which included tanker traffic and maneuvering, tank load testing, and discharge docks. This simulation aimed to predict the total timing, efficiency, performance, capacity, operator headcounts, utilization, and flow of tanker trucks at the pit. The simulation indicated that eight discharge docks and eight standby waiting areas are sufficient to accommodate the facility needs during peak hours. The pit was successfully constructed and is now receiving wastewaters. The construction of the pit was of particular importance, as it planned for the pump daily accumulated waste to be recycled at a nearby water treatment facility rather than polluting the desert and areas around it. Almost 6,000 m^3 of wastewater from over 200 water tanker trucks was saved and recycled by accomplishing this project. The use of simulation proved to be an excellent planning tool that predicted all bottlenecks before actual line stoppage and pit construction. This eventually resulted in preventing the expensive cost of modification that could accumulate to tens of thousands of dollars had it been the case that pit project was built without simulating the flow of traffic, particularly during peak hours. The success observed in the smoothness of the flow of trucks and waters when the actual pit was constructed was a true validation of the system models created and a true validation for the value of simulation.

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