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Developing Efficient Testing and Unloading Procedures for a Local Sewage Holding Pit

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***Abstract*—**A local municipality has decided to build a sewage pit to receive residential sewage waste arriving by tank trucks. Daily accumulated waste are to be pumped to a nearby waste water treatment facility to be re-consumed for agricultural and construction projects. A discrete-event simulation model using Arena Software was constructed to assist in defining the capacity of the system in cubic meters, number of tank trucks to use the system, number of unload docks required, number of standby areas needed and manpower required for data collection at entrance checkpoint and truck tank load toxicity testing. The results of the model are statistically validated. Simulation turned out to be an excellent tool in the facility planning effort for the pit project, as it insured smooth flow lines of tank trucks load discharge and best utilization of facilities on site.

***Keywords*—**Discrete-event simulation, Facilities Planning, Layout, Pit, Sewage management.

I. Introduction

THIS paper comprises a study to escort the design and management of a residential sewage holding pit that is designed to replace an existing waste dump area. The study consists of a discrete-event simulation for predicting performance, capacity, utilization and flow at pit and its support activities. The pit is designed receive residential sewage tank truck loads, hold it temporally, and then pipe daily accumulated loads to a nearby water treatment facility. The pit is designed to have a capacity of 6000m^3 of sewage waste and will be operating on 24 hours basis. Records from an existing waste disposal site indicates that this facility will be receiving a daily average of 200 sewage tank trucks within a 24-hour period with peak hours between 8:00am to 2:00 pm, while the rest of tank truck are distributed along the remaining operating hours.

This study aims to resolve the following issues:

1. Testing of tank truck loads: As indicated earlier, the facility is designed to receive residential waste only. Therefore, a time-efficient-testing procedure needs to be established to avoid industrial waste tank trucks from unloading at the facility. Testing must be conducted based on a valid sampling method that would enable the processing of daily count of approximately 200 tank trucks in timely and smooth fashion.
2. Parking and unloading of tank trucks: The transportation, parking and unloading of sewage tank trucks should be designed to achieve the following:
    a. Maximum utilization of unloading docks.
    b. Minimization of total time that tank trucks need to spend at the facility and in waiting for busy docks.
    c. Ensure smooth flow of tank truck transportation and elimination of bottlenecks and tank trucks deadlock especially at peak hours.
3. Record keeping and analysis: To facilitate smooth tank truck handling and to minimize extensive testing in the future, detailed record keeping for drivers, tank truck number, load content and load origin must be collected for each tank truck entering the facility. Records show that these data are already collected in a similar waste disposal site. However, this data, together with test results must be routinely analyzed and used to improve the facility management on the long run.

II. Background

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. According to Grajo [1], layout optimization and simulation are two complementary tools indispensable to any plant layout or productivity task. Such that 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 [2]. This is mainly due to the inadequacy of analytical to consider many of the requirements of material flow, overall flow efficiency and many operational characteristics[3, 4]. In addition, simulation models can capture many of the requirements and attributes of real life problems that are difficult to consider using analytical models of the facility layout problem [5, 6]. According to Eneyo and Pannirselvam [7], simulation is used in facilities layout to estimate system parameters associated various layout activities including: placement of a new facility or department, relocation of department or activities within an existing facility, capacity analysis, and the effect of capacity extension

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on the facility, problem diagnostics and identification of bottleneck, improvements of material handling systems [8], material flow, and work in process, etc.

In addition within the facilities planning context, simulation was mainly used to:

1. Develop series of improved layouts that has been generated using traditional layout algorithms [9]
2. Contrast different layout configurations [2, 10-14].
3. Justify the embracement of certain manufacturing concepts such as Group technology and flexible manufacturing systems[15-18].
4. Identify system parameters such as facility utilization, flow-time and buffer sizes [19-23].
5. Identify potential problems and bottlenecks in proposed layout structures prior to implementation [24].
6. Evaluate various strategies for the operation of the system [25].
7. Compress or expand time, which gives the analysts the convenience to studying the layout in the long-run or under specific short-term scenarios.
8. Incorporate any stochastic behavior and uncertainty by incorporating the probability distribution that best describes the activity [13, 26, 27].
9. Simulation model were used to generate random flow volumes to be subsequently supplied to traditional facility layout algorithms [28].

III. Data Collection

Data collection for this project was obtained from:

1. Field visits and time studies to similar sewage dump sites.
2. Records from an existing waste disposal site.
3. Testing procedures and test durations were obtained form experts working at water treatment facilities.

A. Tank Truck Arrival, Size and Content Data

Data supplied by the sewage authority for sewage tank truck arrival for first quarter of 2008 were used to Model inter-arrival times and amount of swage waste to be dumped at the facility.

Regular and rush hours, actual inter-arrival times in minutes were collected over the entire 24-hours period. Note that lower inter-arrival times indicates faster arrival rate. In other words, the lower the level shown in Fig. 1, the faster trucks enter the station. The Figure shows that a clear rush hours that starts at 8:00 am (lower inter-arrival, higher arrival) and ends and 2:00 in the after noon.

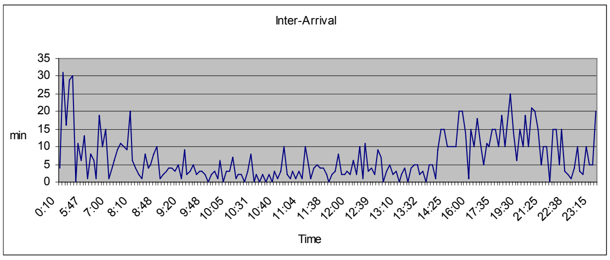

Fig. 1 Inter-arrival pattern of tank truck to waste disposal

Table I shows tank trucks categorized by load capacity and their respective numbers and relative percentage. It also shows that vast majority of tank trucks are of size 10,000 gallons (41.67%) and 5,000 (50.56%) gallons.

TABLE I
COUNT AND RELATIVE PERCENTAGES OF DIFFERENT TANKER TRUCKS LOAD CAPACITIES

Counts of Capacity	Percentage of Capacity
75 Nos. of 10000 Gal	41.67%
91 Nos. of 5000 Gal	50.56%
1 Nos. of 2000 Gal	0.56%
6 Nos. of 3000 Gal	3.33%
1 Nos. of 3300 Gal	0.56%
1 Nos. of 6000 Gal	0.56%
2 Nos. of 4000 Gal	1.11%
1 Nos. of 8000 Gal	0.56%
2 Nos. of 12000 Gal	1.11%
Total	**100.00%**

B. Analysis of Tank Trucks Flow into and the Facility

The data illustrated in Fig. 1 was supplied to data fitting software and was fitted using the statistical chi-squared test. The test results are illustrated in Table II. These were incorporated in the simulation study.

The fitting indicates that during regular hours tank trucks arrive according to the following distribution: -0.5 + EXPO(11.7) minutes. This translates that approximately having five tank trucks per hour (5.36 tank trucks per hour rounded to the nearest integer). On the other hand, during peak hours, tank trucks arrive according to the following distribution: -0.5 + EXPO(3.88) minutes. This translates that approximately having eighteen tank trucks per hour (17.75 tank trucks per hour rounded to the nearest integer).

TABLE II
FLOW DATA ANALYSIS AND FITTING OF INTER-ARRIVAL TIMES DURING PEAK AND REGULAR HOURS

Measure	Regular Work Hours	Peak Work Hours
Hours	Midnight – 8:00 am 2:00 pm – Midnight	8:00 am – 2:00 pm
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 Std Dev	7.12 minutes	2.71 minutes
Mean tank trucks/hour	5.36	17.75
Distribution	Exponential	
Expression	-0.5 + EXPO(11.7)	-0.5 + EXPO(3.88)
Square Error	0.059770	0.031227
p-value	< 0.005	

The resultant hourly arrival schedule of tank trucks over the 24-hours period is shown in the schedule of Fig. 2.

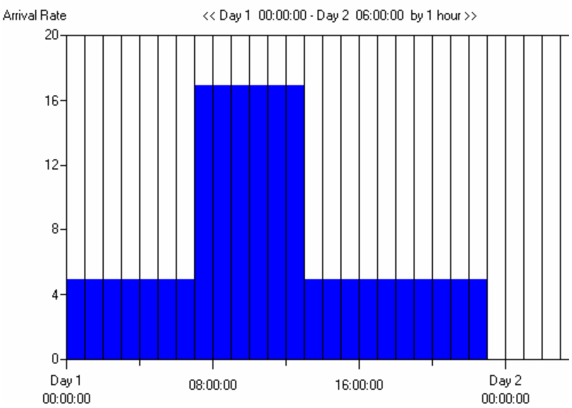

Fig. 2 Hourly arrival schedule of tank trucks

IV. TESTING TANK TRUCK CONTENT

After consulting with the team of experts, two types of tests will be conducted at the facility: daily and periodical tests.

A. Daily Tests

Daily tests measure temperature, PH and conductivity for each incoming tank truck. This test is a relatively a quick one that will provide initial indication to whether the tank content is residential. Failure to achieve target ranges for this test, indicates that further investigation is necessary. A team of experts estimates that this test can be conducted within 6 to 9 minutes on average, and can accomplished using hand held probes that will provide quick results. Fig. 3 shows a sample of a hand held probe that is used to conduct daily tests.

B. Periodical Tests

Periodical tests are more comprehensive compared to daily teat, but will require several hours to measure extent of toxicity. These tests will require over four hours of sample conditioning and lab work. Therefore, due to time constraint, this test will be conducted according to the following basis:

1. Periodical random sampling: This test will be conducted on random basis on tank trucks that were never tested with respect to this test in the past. Test results will be recorded in the tank truck and driver's file and its origin company.
2. For tank Trucks failing the daily test: Tank trucks failing daily test, by scoring values beyond daily acceptable test ranges will be subject to further investigation by using the periodical test.

Fig. 3 Sample of a hand held probe to conduct daily tests at the sewage facility

V. TANK TRUCK SEWAGE LOAD DISCHARGE

After collecting check-in data and testing, tank trucks proceed to the unloading area for waste discharge. The pit designed consists of eight unloading docks. The initial scenario was based on the assumption that trucks will choose the closest empty dock. However, simulation provided that this will cause some docking stations to be under utilized while other over utilized. To have a more uniform distribution of dock usage, we have assumed that discharge movement will be guided by one the pit officers. This proved (through simualtion) to improve the smoothness of the flow at the facility.

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 unloading time. this time excludes testing and maneuvering for parking at the dock station.

VI. The Simulation Model

Here we conduct a discrete-event simulation study on the flow of tank trucks arriving to pit is using the Arena® software. The simulation estimates the following performance measures:

1. The Number of trucks arriving to the station
2. Number of trucks waiting at testing areas
3. Number of trucks awaiting discharge
4. Time a truck spends at the facility
5. Time truck waits in each queue
6. Average utilization of site officers
7. Average utilization of docking areas
8. Best management policy to assign trucks to unload docks
9. Space requirements (measured in number of truck spaces) for testing
10. Truck flow management policy
11. Average daily dump amounts

TABLE III
Results for Discrete Event Simulation Categorized by Regular And Peak Hours

Criteria	Min	Average	Maximum (peak hours)	Half Width
Number of tank trucks served daily	182	194	223	8.7
Dock utilization per dock	-	22.4%	100% (in peak hours)	0.01
Officer Utilization	-	21%	100% (in peak hours)	0.01
Number of tank trucks per dock per day	20	24	29	-
Time in facility (minutes)	15	25	48.3	0.01
Cubic Meters of daily waste (m3)	5584	6104.4	7253	349.4
Simultaneous tanks at pit	-	2	8	0.12
Simultaneous tanks at waiting areas	-	0.05	4	0.02
Simultaneous tanks in system	-	2.4	16	0.2
Waiting times in dock queues (min)	-	1	1-16	-
Waiting times in checking areas (min)	-	-	1-4.8	-
Number of trucks waiting at check-in point	-	0-1	5	-

A. *The Simulation System Characteristics*

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

1. Three Officers: These officers are assigned to:
   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 office hours
3. Eight unload docks: 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 tank truck. Thus, there exist a total of 8 waiting areas opposite to each discharge dock.
4. One pit: The pit can hold a maximum of 6000 m^3. The pit is emptied to a nearby treatment site once everyday.

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

A snap shot of the discrete-event simulation model is provided in Fig. 4. Results for the model are provided in the next section.

VII. The Simulation Model Results

A simulation model was constructed based on the characteristics described in the previous section. The simulation consisted of ten replications, each of the length of 24 hours. The system is assumed to start empty idle and data statistics are initiated at each replication. Table III contains average simulation results and when applicable the half width of the confidence interval at a 95% level of significance. Data in the Table III are also organized according to average and peak values that could occur at rush hours between 8:00 am and 2:00 pm. This would assist management to assign resource based on needs during regular and peak hours respectively.

The simulation analyses indicate:

1. The pit capacity of 6000m^3 might not accommodate all waste discharge received in a 24 hours period. In fact, the daily average if discharge is 6104.4 m^3. In worst case scenario it could reach up to 7253 m^3.
2. In addition, since waste will be piped to a nearby waste management facility, the pumps horse power pressure should be purchased to accommodate this need.
3. The provided site dimensions will cause jams in peak hours. An alternative plan must contain by passes and look similar to what is proposed by the

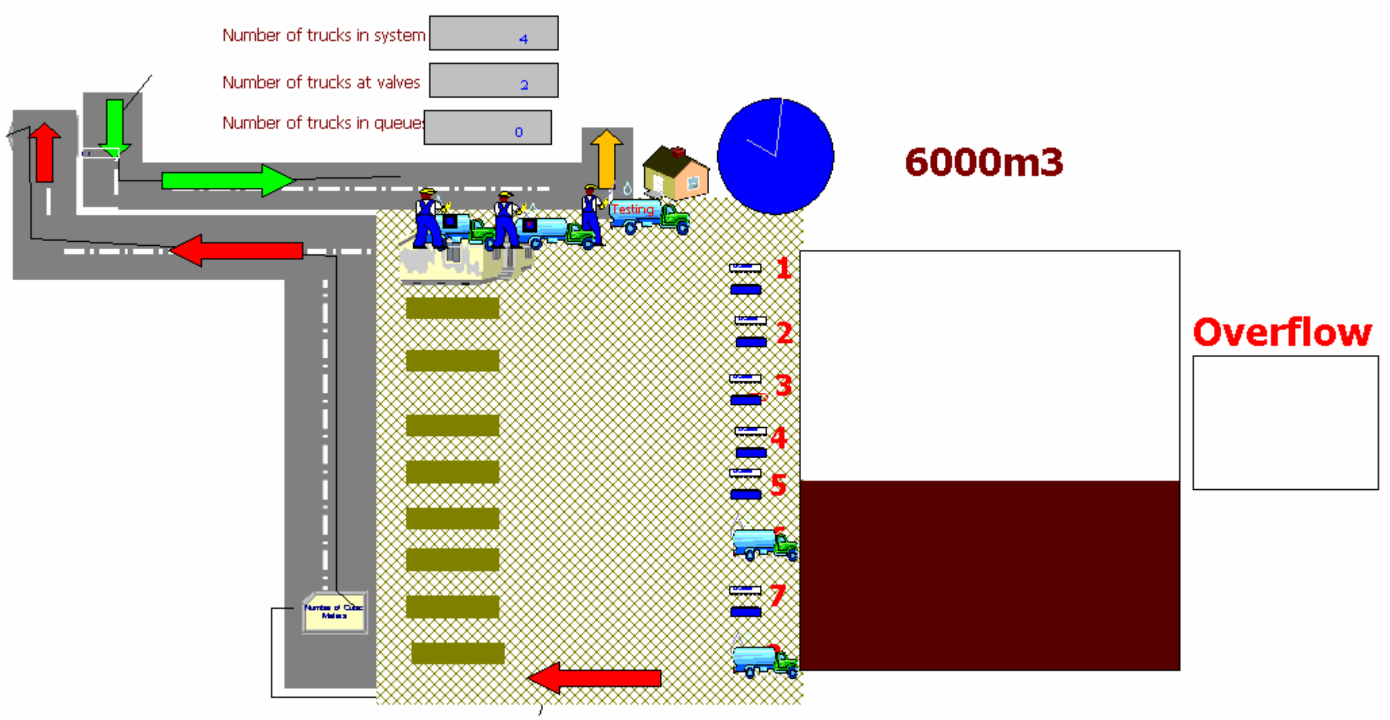

Fig. 4 Snapshot of the pit simulation conducted using the Arena Software

simulation (see Fig. 4).

4. The Highway entrance should be at a distance from the facility entrance. To avoid jams at highway
5. The distance between the pit entrance and the highway entrance should accommodate at least 5 trucks.
6. Optional bypass to high way can be accomplished to move rejected trucks that failed daily toxicity tests.
7. At most, four parking spots from the planned eight to be built opposite to the docks will be utilized. The rest can still be implemented but used for trucks cool down (discussed below).
8. Engine cool down: Heavy tank trucks that arrive from relatively remote areas will sometimes stay at pit site for a period of times to allow engine and tire cool down. Cool down delay is estimated to occur in approximately 10% of heavy tank trucks. The facility can accommodate this situation, by allowing trucks to park in the available 8 parking spots. That is because; even during peak hours only four of these spots will be utilized at most.

VIII. Model Verification

Model verification indicates whether or not model is working as intended. Analysis of intermediate and final simulation results verifies that model is coded properly and as planned. The Arena software debugging and animation options capabilities facilitated and supported this conclusion

IX. Model Validation

Model validation indicates whether or not the model is a valid representation of reality. This is conducted by statistically comparing real system output (μ_1) with the simulation system output (μ_2). Then, by either applying hypothesis testing for comparing the two means, or confidence interval on difference between the two means.

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

Let $\bar{X}_i$, s_i and n_i indicates mean, standard deviation and sample size of sample i respectively.

Sample values form the real system (1) for number of daily tank truck arrival:

$\bar{X}_1 = 178.6$ trucks

$s_1 = 21.9$ trucks

$n_1 = 9$

Sample values form the simulated system (2) for number of daily tank truck arrival:

$\bar{X}_2 = 194$ trucks

$s_2 = 12.8$ 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 s^2 is unknown we need to verify whether or not $s_1^2 = s_2^2$, using hypothesis testing:

$$H_0 : s_1^2 = s_2^2$$
$$H_1 : s_1^2 \; 1 \; s_2^2$$

The *F*-distribution statistic will result in:
$F_0 = s_1^2 / s_2^2$ =2.93

Reject if: $F_0 < F_{1-a/2, n_1-1, n_2-1}$ or $F_0 > F_{a/2, n_1-1, n_2-1}$

$$F_0 < F_{0.975,9,8} \rightarrow F_0 < 0.244$$
$$F_0 > F_{0.025,9,8} \rightarrow F_0 > 4.36$$

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

$$H_0 : m_1 = m_2$$
$$H_1 : m_1 \; 1 \; m_2$$

From the samples' data:
$\bar{X}_1 = 178.6, \bar{X}_2 = 194$

The spooled variance, sp^2 is calculated as follows:

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

The *t*-distribution statistic will result in:

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

Reject if: $|t_0| > t_{a/2, n_1+n_2-2} \rightarrow |t_0| > t_{0.025,15} \rightarrow |t_0| > 2.131$
$\rightarrow$ 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 the two population means are un equal. Hence, the simulated model is a valid representation of reality.

X. Conclusion

A simulation study was conducted as part of a facilities planning effort for creating a pit site for residential waste management and disposal. Data from a similar facility were analyzed during peak and regular hours to identify system capacities, utilization, waiting times and many other performance measures and system parameters. The simulation of the new pit was created using Arena discrete-event simulation software. The results of the model were verified and validated. Simulation indicated that eight discharge docks and 4 standby waiting areas are sufficient to accommodate the facility needs during peak hours. In addition, the simulation study indicated that the initial plan of creating a 6000m^3 pit is insufficient to handle the daily waste. The pit size should be at least of size of 7253m^3. The decisions based on simulation, have contributed in creating smooth flow lines of sewage tank trucks testing and unloading which in part, resulted in a successful design of a waste disposal facility.

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