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The Turkish Army Uses Simulation to Model and Optimize Its Fuel-Supply System

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Moving military troops, which is critical to tactical success, depends on providing large quantities of fuel. We used simulation to model and analyze the Turkish army's fuel-supply system that consists of sea-going tankers, tank fields, pipelines, and depots. We measured performance of the existing and proposed systems under various scenarios. We developed a simulation optimization model based on a genetic algorithm (GA) to optimize system performance. Based on the results of extensive simulation experiments, we proposed a number of changes. We recommended that the army should open the existing fuel-supply system and that it establish commercial use in peacetime to obtain additional operating revenue. New trigger levels (or fuel-replenishment policies) for wartime allow the fuel-supply system to survive much longer even in the most severe war conditions. These specific recommendations are being considered by the top army officials to obtain benefits worth millions of dollars.

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The Turkish Army's military supply facilities center (MSFC) maintains and manages fuel supplies for the Turkish Armed Forces using a fuel-supply network that consists of sea, pipeline, and highway. Tankers transport fuel processed in Izmir through the Aegean Sea and the Black Sea to two main locations (called A and B). The pipeline system carries this fuel from the main ports to depots throughout the country. Finally, tank trucks transport the fuel from the depots' storage tanks to various military bases. The storage tanks are usually underground and vary in size and capacity (cubic meters) from location to location. The tanks are not on army bases; civilian companies under contract operate them. This pipeline system serves the eastern part of Turkey.

To operate this system effectively to supply enough fuel for the troops, planners must know when to suspend fuel transfers and when to resume them at all locations. We conducted a study to assess the efficiency of the pipelines in both war and peace conditions. We measured the effectiveness of the MSFC's existing operating policies and determined the optimum trigger levels (the minimum amount of fuel a tank must contain for the MSFC to send some to a military facility). We developed a genetic algorithm (GA) to determine the optimum trigger levels. We also examined the tank-assignment problem. We then developed a new assignment procedure to improve system performance. We recommended changes to test in a dynamic and stochastic operating environment.

We found no previous studies in the literature dealing with this exact problem. Hence, our study should be a good example (or case study) of the application of OR/MS methods to such a large-scale optimization problem. Crane et al. (1998) investigated scheduling multiproduct liquid pipelines by applying a GA to the problem of scheduling multiple products in a liquid pipeline. They simulated the movement of products in a pipeline and assessed the relative values of the end states according to preset goals. In another study, DeJong and Spears (1989) developed a GA-based algorithm for pipeline scheduling.

System Considerations

The MSFC assumes that the system has enough fuel of the three main types (diesel, gasoline, and jet) because

	Location A	Location B	Location B
Fuel type	Jet fuel	Diesel fuel	Gasoline
Number of X-type tankers	2	1	0
Number of Y-type tankers	1	1	1
Time the X-type tankers take	4–5 days	5–6 days	0
Time the Y-type tankers take	3–4 days	4–5 days	4–5 days

Table 1: The MSFC assigns two types of ships to transport three types of fuel to two main locations, A and B.

the main refinery has a large capacity (that is, the system has no shortages in input). After the main refinery produces the required fuel, the MSFC must transport it in batches to the main demand locations. Location A stores jet fuel, and Location B stores diesel fuel and gasoline in two separate storage areas. The military uses two types of tankers to transport fuel from the main refinery to the tanks at these locations. One type of ship (X-type) can carry 7,000 cubic meters of fuel and the other (Y-type) can carry 5,000 cubic meters of fuel (Table 1). (We label the Locations A and B to preserve confidentiality.)

The pipeline system was built by NATO in 1953 and has three starting points, one at Location A and two at Location B (Figure 1). The capacities of the storage tanks at these points range from 45,000 cubic meters to 2,500 cubic meters (Table 2). The pipelines between

		Tank capacities (m^3)		
Tank number	Tank location	Jet	Diesel	Gasoline
1	Location A	45,000	0	0
2	Location C	20,000	0	0
3	Location B	0	15,000	12,500
4	Location D	0	17,500	0
5	Location E	12,500	8,750	10,000
6	Location F	20,000	15,000	7,500
7	Location K	10,000	5,000	2,500
8	Location M	12,500	7,500	5,000
9	Location N	7,500	5,000	5,000
10	Location L	7,500	7,500	7,500
11	Location G	6,250	7,500	6,250
12	Location H	5,000	6,250	5,000
13	Location I	5,000	15,000	10,000
14	Location J	0	3,750	3,750
Total		151,250	112,500	75,000

Table 2: The 14 main tanks with different capacities in the existing pipeline system. We show the tank capacities in terms of fuel types for each location.

tanks vary in capacity and pumping knots (Table 3). The pipelines can transport the three fuel types without requiring cleaning between fuel types. The remnants of one type stuck to pipeline walls are swept away by the next, and the mixed quantity is usually negligible for diesel fuel and gasoline, but diesel fuel or gasoline contaminated with jet fuel must be discarded. We ignored this small amount in our study.

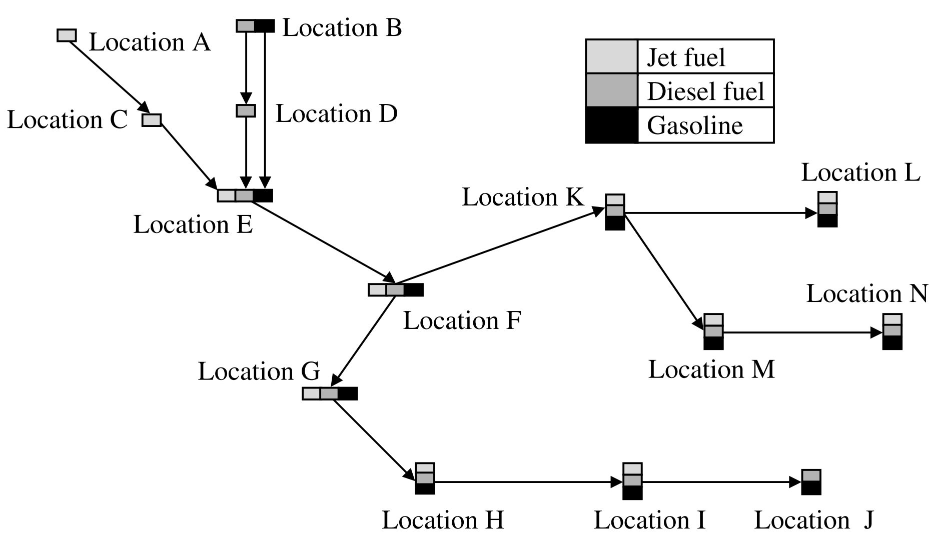

Figure 1: This diagram illustrates a schematic view of the existing system with the location of the main tanks and pipelines.

Number	Pipeline	Pumping capacity	Pipeline capacity
1	Location A–Location C	300–330 (unit/hour)	3,750 units
2	Location C–Location E	300–330 (unit/hour)	5,850 units
3	Location B–Location D	100–120 (unit/hour)	3,200 units
4	Location D–Location E	100–120 (unit/hour)	3,750 units
5	Location B–Location E	100–120 (unit/hour)	6,750 units
6	Location E–Location F	120–140 (unit/hour)	5,500 units
7	Location F–Location G	60–80 (unit/hour)	2,400 units
8	Location G–Location H	60–80 (unit/hour)	4,800 units
9	Location H–Location I	60–80 (unit/hour)	3,400 units
10	Location I–Location J	60–80 (unit/hour)	2,100 units
11	Location F–Location K	80–100 (unit/hour)	2,500 units
12	Location K–Location L	60–80 (unit/hour)	3,300 units
13	Location K–Location M	60–80 (unit/hour)	900 units
14	Location K–Location M (jet)	30–40 (unit/hour)	650 units
15	Location M–Location N	30–40 (unit/hour)	1,150 units

Table 3: The 15 pipelines in the existing system vary in pumping and storage capacities.

In the existing system, tanks at 14 locations are connected to the pipeline. The troops get fuel from these tanks. The fuel stored in the tanks at Locations A and B is pumped onward to the inland locations as quickly as possible so that the MSFC can order new batches from the main refinery. The procedure the MSFC uses is a typical continuous-review procedure. The reorder point for Location A is 38,000 units. That is, when the level of jet fuel at Location A drops to 38,000 units, Location A orders a batch of fuel from the main refinery, and the main refinery assigns fuel to be transported on an available ship. The reorder point for both diesel fuel and gasoline at Location B is 8,000 units. The fuel tank facilities at Location C and Location D also pump the contents of their fuel tanks onward so they can take on fuel from the main locations as they reach their order points.

The pipeline systems between the locations are not identical, so the capacity and the pumping capacity differ throughout the system. The facilities on the pipeline system after Location E use single pipelines to transport three different types of fuel. Thus, fuel transfer between any source location and any destination location must be conducted in a systematic way. Any pipeline between two locations can contain the three types of fuel in different amounts at the same time. Deciding on the type of fuel to transport from a source location to a destination location depends upon the percentages of the fuel tanks that are full at the destination locations (for example, Location G is a source location for Location H, but a destination location for Location F). First, managers determine the percentages of each type of fuel in the destination location tanks. At each location there are more than three tanks, each devoted to one of the three fuels. Once they find the lowest of these percentages, they order fuel from the source location, and the source location begins to pump a batch of that fuel if it has enough to do so. Thus, if the destination location's holding of diesel fuel is the lowest compared to its storage capacity for diesel fuel when compared to the other two types, it orders diesel fuel, and the source location supplies it if it has enough. If the source location does not have enough diesel fuel, managers at the destination location order the fuel of the remaining two that it most needs. If the fuel tank at a destination location is 95 percent or more filled, the source location tank does not send the fuel. Moreover, a source location is considered to have enough fuel to supply locations down the line if it has 10 percent of the tank full (that is, it cannot supply fuel if its fuel level is less than 10 percent of its storage capacity). This percentage is also called the trigger level. Once a facility's tank of a particular fuel type drops below its trigger level, the facility suspends the flow immediately and resumes it only when the fuel level again exceeds the trigger level by one batch. Thus, the system must meet two conditions to transfer fuel between two locations; the destination tank must contain less than 95 percent of its capacity and the source tank must contain more than its trigger level. During a war, fuel can flow through the pipeline 22 hours a day, losing two hours for maintenance activities.

It is a common belief in our army that fuel demand during the first 30 to 40 days of a war is about 15 times greater than peacetime demand. One of our objectives was to test whether the MSFC can really meet such huge demands for the three types of fuel. If it can, for how long can the system keep on providing the same amount of fuel? If it cannot, what alterations must the MSFC make to the system (for example, by constructing additional tanks or by assigning some tanks to different types of fuel) to avoid shortages? Turkey has not been at war since the pipeline system was constructed in 1953. Thus, no one knows whether the trigger levels would be effective. According to existing policy, the MSFC suspends transfers from any fuel tank falling below 10 percent full until it contains a batch size plus the trigger level. This policy might work well if destination facilities ordered fuel in amounts proportional to fuel tank capacities, but this is not the situation in practice. One of our objectives was to determine trigger levels for each type of fuel tank at each facility so that it could meet demands and so that the whole system could maintain operations for longer time periods in war conditions. We also considered random breakdowns interrupting pipeline flows. Because it is difficult to model pipeline leaks, we assumed that the destination tanks did the leaking. We also assumed that ships transporting fuel to the main ports have no major breakdowns.

The Model

We developed a simulation model of the existing pipeline system using Automod (AutoSimulation, Inc. 1999) software suited to modeling distribution systems. Automod has a GA-based built-in optimization procedure that we used to find optimum trigger levels. The source code for the simulation model consists of about 3,000 lines, including process definitions, order lists, variables, counters, and functions defined in the experimental frame.

We verified the simulation model using the techniques suggested by Banks et al. (2001). Specifically, we employed debugging, input-output control, and animation to make sure that the code represents the logic defined in the conceptual model. Any simulation model is only an approximation of the actual system and embodies a set of required performance measures. In the validation process, we first sought face validity by asking people knowledgeable about the system to check the simulation results. We had long conversations with the experts—the engineers and managers that work at the tank facilities and report to commanders—who manage the actual system. In general, they accepted our model and thought it had a high degree of face validity. We also sought data validation. The data we used in the model came from the historical records of the operating system. We carefully examined the conditions under which this data was collected and analyzed it to ensure its appropriateness. Finally, we sought statistical validity. We compared the output of the simulation model with the actual performance data to make sure the behavior of the model resembled the behavior of the real system. Specifically we used the confidence-interval approach recommended by Law and Kelton (2000). We found no statistically significant difference between the actual system and the simulation model. Hence, we accepted the validity of the model and used it to make inferences about the actual system.

Experimental Settings

In analyzing the system in war conditions, we considered the worst-case scenario. In other words, we assumed that most of the troops, who all obtain their fuel from the pipeline, would be affected. We further assumed that the war began unexpectedly, and that any point in the steady state of the system in the current peace condition could be the beginning of a war. In the worst-case scenario, the Turkish army would have to fight with a large number of enemy forces for fairly long distances along the borders of Turkey. Also, we assumed that the demand for fuel from the pipeline would increase enormously.

Naturally, the commanders of the pipeline want the system to provide all types of fuel for their troops for the longest time possible. The system is considered to have collapsed when any one of the fuel tanks at a facility can no longer provide fuel to troops. For that reason, the simulation model is a terminating simulation type (Law and Kelton 2000); it stops when the system collapses. (If a tank has a trigger level of X percent, it suspends transfer when it falls below this level.) Thus, more fuel can be drawn from the tanks with low trigger levels than the tanks with high trigger levels.

MSFC personnel commonly believe that the 10 percent trigger level is the best for our system in war conditions. Because Turkey has not been at war since 1953 when the army began construction of its pipeline, no one actually knows whether this level is suitable for the entire system. Because the tank capacities at different locations and their demands vary, the trigger levels should also vary. In other words, we would expect the trigger levels to differ for different tanks

Fuel type	Mean duration	Standard deviation	Tank location to collapse first
Jet fuel	9.6	1.13	Location H
Diesel fuel	14.5	2.41	Location K
Gasoline	85.3	4.47	Location B

Table 4: The system survives for various numbers of days for the three fuel types.

if the army is to ensure that the system will survive for the longest time possible. The system collapses, not because of ineffective transportation, but because of insufficient fuel. Thus, we had to determine how much fuel at each location could be transported to the next tank and the trigger level for each tank.

Simulation Results

Even though our primary objective was to analyze the system in wartime, we also measured its performance in peace conditions. Simulation results showed that the pipeline system is usually idle in peacetime. Hence, we suggested that the Ministry of National Defence make the system available for civilian use and thereby generate an estimated million dollars of revenue.

Scenario 1: 10 Percent Trigger Levels for All Tanks

We first evaluated the existing trigger level of 10 percent to find out whether it was suitable for all the tanks (Table 4). First, we found that supplying jet fuel creates a serious problem in the system. Since the daily demand for jet fuel is higher than for the other two types of fuels, the jet-fuel tanks hit 10 percent levels relatively quickly. Diesel-fuel demand is also quite high, while gasoline demand is quite low and the gasoline in the system will last for 85.3 days.

Second, we found that the first tank to collapse is always the jet-fuel tank at Location H. It also causes the system to collapse quickly. Because Location H is midway through the network, there seems to be a serious scheduling problem. The jet-fuel tanks at Location I are almost half full at the end of the 10th day. We suggested that Location H should not transport as much jet fuel to Location I, and instead it should store more fuel for itself. This means that MSFC should increase the jet-fuel trigger level at Location H. For the same reason, it should also increase the diesel-fuel trigger level at Location K. The supply of diesel fuel drops more rapidly at Location K than it does at any other location because it has a small storage tank and transports fuel to both Locations M and L. However, the demand for gasoline is not high, and all the gasoline tanks could meet demand, but because the costs for road transportation are high, the gasoline tank transports its contents to the next tank, and the main tank for gasoline then becomes the first tank to collapse.

Third, we concluded that using the same trigger level for all fuel types caused some of the pipelines to carry almost equal amounts of the three fuel types, but the system needs to deliver greater amounts of jet fuel. For example, instead of transporting the same amount of fuel from Location G to Location H that it does from Location H, the MSFC should increase the trigger levels for diesel fuel and gasoline at Location G so that Location G stores more of these fuels.

Scenario 2: Optimum Trigger Level for All Tanks

Having seen that using the 10 percent trigger level causes very poor performance, we decided to test other trigger values (Figure 2). We found that the MSFC must use the same trigger level for all the tanks regardless of fuel type; a 25 percent trigger point seems to be the best for the system. By using a 25 percent trigger point, it would increase the supply duration to 17.2 days (a 79 percent improvement over the existing system with a 10 percent trigger point).

Optimizing System Performance Using a Genetic Algorithm

After finding that the MSFC would greatly improve system performance by setting appropriate trigger levels, we sought optimal settings for the tanks. With the three fuel types and possible trigger levels between zero percent (empty) and 100 percent (full), the potential solutions numbered about $100 * 100 * 100 = 1{,}000{,}000$. Because it would be impossible to completely enumerate and evaluate all these alternatives in the search space, we used a GA to search a subset of the space in a clever way.

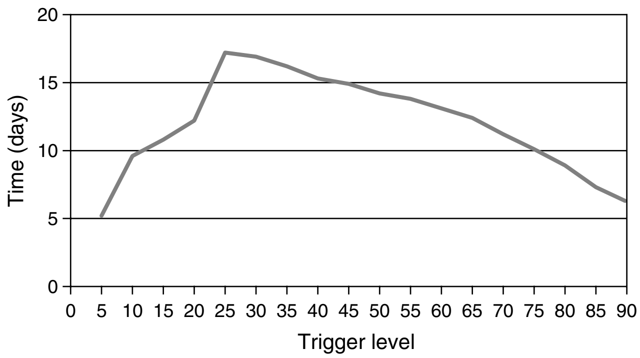

Figure 2: Different trigger levels in the surveillance system differ in their effect on the time periods for which the system can supply fuel. A 25 percent trigger point provides fuel supply for 17.2 days, a 79 percent improvement over the existing 10 percent trigger point.

GAs are search algorithms based on the mechanics of natural selection and natural genetics. In natural genetics, the presence or absence of genes and their order in the chromosome decide the characteristic features of the individual species in a population. The different traits are passed on from one generation to the next through different biological processes that operate on the genetic structure. This process of genetic change and survival of the fittest produces a population well adapted to the environment. Similarly, in using GAs, we use a finite-length string coding to describe the parameter values of each solution of the search problem under consideration. Each string corresponds to an individual, and each individual acquires its power in the survival process through its fitness value. The greater the fitness value, the better the individual performs in the evolution process. A fixed number of individuals corresponds to a generation. GA is an iterative algorithm; in every generation, first, parents are selected depending on their fitness values, and then through some genetic operators, the strings of children are produced, each with its calculated fitness value. We repeat this procedure until we meet some stopping criterion. As in natural genetics, as the generations proceed, the fitness of the whole population (average fitness) increases. We used simulation-optimization methodology to integrate GA with simulation modeling in calculating the fitness values. For every individual of a particular generation, we used simulation results to assess its fitness. We formulated the fitness function (objective function) as follows:

$$\text{Maximize}[\text{minimum}(J, M, B)],$$

where J is the time to the first collapse of a jet-fuel tank, M is the time to the first collapse of a diesel-fuel tank, and B is the time to the first collapse of a gasoline tank. We implemented the optimization process by using the built-in GA algorithm in AutoStat. Specifically, we used the following steps:

(1) We randomly created the first generation of children (solutions).

(2) We made the runs for each child.

(3) Based on their fitness scores, we picked the best N children to use as parents for the next generation, where N is the number of parents per generation.

(4) We created each child in the new generation using the standard mutation and crossover operators of the GA.

(5) We repeated Steps 2 through 4 either until we met the termination criteria or until we stopped the runs.

Scenario 3: Different Trigger Levels for Different Fuel Types

First, we optimized the trigger levels for the three types of fuel using the GA. We terminated after 50 generations or when there was not at least a three percent improvement between the best score of the current generation and the best score of the 10 previous generations. We assigned each fuel a single trigger value between five and nine percent. We set these limits by considering technical issues (compression and expansion of fuel in the line). We set the parameters such that we obtained a maximum of five replications per solution and three parents per generation. We ran the algorithm with these parameters, stopping after 2,310 runs and 22 generations. We obtained optimum trigger levels for the three fuel types; for jet fuel, 23 percent; for diesel fuel, 38 percent; and for gasoline, 71 percent (Table 5).

With these trigger values, the system can supply fuel for 24.8 days. The optimum trigger level for jet fuel that we found in this case is very close to the

Name	Optimum trigger level (%)	Mean duration (days)
Jet-fuel trigger	23	24.8
Diesel-fuel trigger	38	25.1
Gasoline trigger	71	65.3

Table 5: This table summarizes the optimum trigger levels of each fuel type for Scenario 2.

value obtained in the previous scenario. By changing the trigger levels for diesel fuel and gasoline and pumping more jet fuel into the system, we improved the supply of jet fuel. The source locations pump fuel based on the percentages of the destination locations. Once we determine the fuel type having the minimum percentage at the destination location, the source location supplies that type of fuel to equalize the percentages. With the new system, gasoline would always have higher percentages than the other two fuels. Thus, source locations of those fuels are lower than gasoline.

Scenario 4: Different Trigger Levels for All Tanks

As the next step in our investigation, we conducted simulation experiments to determine the optimum trigger levels for all the tanks. We obtained results that show that the MSFC can extend the fuel supply (the performance measure) by about 63 percent from 24.8 days to 40.5 days.

To find out whether the results are logically true, we ran the simulation model with these new trigger levels with 10 replications for 100 days and recorded which tanks collapsed first for each type of fuel. The jet-fuel tank at Location C was the first jet-fuel tank to be unable to provide jet fuel for troops, the second was the jet-fuel tank at Location E, then the jet-fuel tank at Location F, and so on (Table 6).

In the experiments, we did not see a direct relationship between the locations and the trigger levels. To discover whether the trigger level should increase or decrease as we go from the main locations to the end locations in the network seems to be impossible because the tank sizes and the demands for these tanks are all different. Also, the pipelines between different locations carry different fuel types. For example, the pipeline between Location C and Location E carries only one type of fuel, jet fuel. The pipeline between Location I and Location J carries two types of fuel, diesel fuel and gasoline; and the pipeline running from Location G to Location H carries all three types of fuel. The pipelines also differ in transportation capacity and pumping rate characteristics. Thus, the interaction between tank sizes, demands, and pipeline characteristics makes it very difficult to establish a relationship between trigger levels and the locations of tanks. A very simple observation is that the locations with larger tanks and higher demand rates for a fuel type have lower trigger levels for that fuel type than locations with smaller tanks and lower demand sizes. But this may not be true for all the tanks.

Tank location	Jet fuel	Diesel fuel	Gasoline
Location A	0	0	0
Location C	1	0	0
Location B	0	2	1
Location D	0	1	0
Location E	1	2	1
Location F	2	1	2
Location G	2	0	1
Location H	1	2	0
Location I	2	0	2
Location J	0	1	2
Location K	1	2	2
Location L	2	1	2
Location M	1	1	0
Location N	2	2	2
Total	15	15	15

Table 6: We summarize the survival performance of tanks for each fuel type under Scenario 4. We measure the survival performance of a tank as the number of times the tanks collapsed first for each type of fuel.

Scenario 5: Further Improvement of the Solution by Experts

In most OR/MS applications to real-life problems, the solutions mathematical models produce are suggestive in nature. Thus, decision makers may need to modify them to obtain workable solutions in practice. In our case, we made some logical alterations to the tank assignments for the fuel types to improve the system's performance. When we analyzed the existing system carefully, we saw that we needed to reassign tanks to increase the storage capacities for jet fuel and diesel fuel and improve their duration times (Table 7).

Gasoline tank locations	Current capacity	Proposed capacity	Assigned amount for jet fuel	Assigned amount for diesel fuel
Location B	12,500	11,250	0	1,250
Location E	10,000	7,500	1,250	1,250
Location F	7,500	6,250	1,250	0
Location G	6,250	5,000	0	1,250
Location H	5,000	3,750	1,250	0
Location I	10,000	7,500	1,250	1,250
Location J	3,750	3,750	0	0
Location K	2,500	2,500	0	0
Location L	7,500	6,250	1,250	0
Location M	5,000	3,750	0	1,250
Location N	5,000	3,750	1,250	0
Total	75,000	61,250	7,500	6,250

Table 7: In general, the results of mathematical models should be considered as suggestive rather than exact step-by-step procedures to be implemented in practice. Because not all the features of real systems are incorporated into the models, some human interventions to the solutions may be necessary. In our case, modifications by human experts in the tank-assignment decision greatly improved system performance.

After making these modifications, we used GA to find better solutions. We executed 10,605 runs and 101 generations. The best score we obtained was at the 95th generation, 44.4 days for jet fuel, 45.3 days for diesel fuel, and 60.3 for gasoline. In general, the gap between jet fuel (the fuel with the minimum duration) and gasoline (the fuel with the maximum duration) is lower in this scenario. Thus, the system can supply fuel to the troops for a longer period now. Also, the new trigger levels for gasoline tanks are lower. The jet-fuel triggers are between 18 and 35 percent, the diesel-fuel triggers are between 21 and 37 percent, and the gasoline triggers are between 36 and 49 percent. In summary, as shown in Figure 3, we improved the performance of the existing system from 9.6 days to 44.4 days at the end of the fifth scenario (about 359 percent improvement).

Changing Batch Size

Another important issue was that the MSFC needs a batch size of 100 units (cubic meters) throughout the system. Although some of the engineers in the MSFC say that using smaller batch sizes would be difficult for technical reasons, we wanted to see how batch size affected system performance. We ran 10 replications of the simulation model of five scenarios for batches of 50, 75, 150, 200, and 300 units, in addition

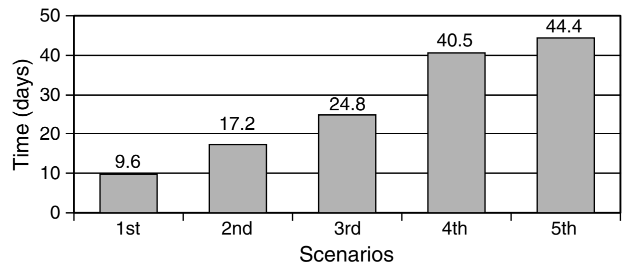

Figure 3: This figure shows how different scenarios for resupplying tanks have different effects on the time periods for which the system can supply the fuel. With the proposed changes in fuel trigger levels, we improved the performance of the existing system from 9.6 days to 44.4 days.

to the existing size of 100 units (Figure 4). In general, the time the system would last with wartime demand decreases as the size of the batch increases. When we evaluated batch sizes for Scenario 5, we found that the system would hold up for 45 days with batch sizes of 50 but for 35 days for batch sizes of 300. The reason is twofold. First, when a destination location demands all three types of fuel at the same time (that is, when the percentages of the three types of fuel at the destination location drop below 95 percent), the source facility can pump one batch of the fuel type with the lowest percentage and then evaluate the new percentages. The elapsed time from the beginning to the end of the batch depends on the batch size.

In general, the smaller the batch size, the shorter the time. While one fuel is being transported, the other two types have to wait, and their percentages

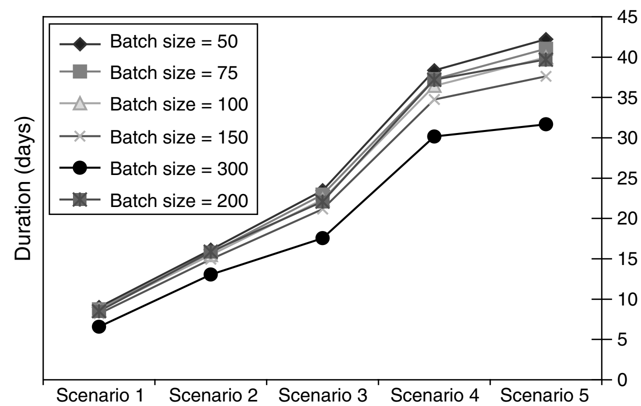

Figure 4: We show the effect of varying batch sizes on the system survival rate. The results indicate that small batch sizes are preferable over large batches.

continue to drop until the next fuel transfer. Second, when the fuel in the source tank drops below the trigger level, the facility suspends the fuel transfer and waits to resume pumping until its percentage is more than one batch size over its trigger level. The waiting time between suspension and resumption of pumping also depends on the batch size. In short, we concluded that keeping batch size as small as possible improves the system performance unless batch sizes are smaller than 100 units.

Concluding Remarks

We systematically analyzed the Turkish Army's transportation of fuel through the pipelines constructed in 1953 by NATO. We examined the use of the pipelines and storage tanks in peacetime and improved the performance of the system in anticipation of war conditions by optimizing the trigger levels. Turkey has had no wars since the pipeline system was constructed; hence its performance during wartime is not known. We used simulation to examine this system under various peacetime and wartime conditions to make long-term decisions on improving use of the system. We developed a fairly accurate simulation model of the system. We investigated the main operating rule of the existing pipeline system and the concept of trigger levels for the tanks. We found that in peacetime the system is idle most of the time. Hence, the military could make some of the system capacity (two ships and much of the pipeline capacity) available for civilian or commercial use to save millions of dollars each year. Army top officers are evaluating this alternative.

In war conditions, we found that the existing system would keep up with demand for a very short period of time (less than 10 days). However, by implementing our proposed changes in the existing system and using the optimum trigger levels determined by the genetic algorithm, the army could extend the duration of the fuel supply (to over 40 days), an improvement that is more important than any monetary benefit. High-ranking officials expect to implement this new policy as part of a new logistic planning system developed by Turkish army scientists. The simulation model we developed is flexible enough to examine several other what-if questions in the future. The MSFC also has another pipeline system called the South Pipeline System. The commanders are considering the possibility of connecting the two pipeline systems. Our simulation model will be used to analyze the entire combined system and determine optimal trigger levels.

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