# Evaluation of Management Measures to Reduce Gasoline Queues at Service Stations: A Simulation Approach

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**An analytical simulation model is developed in this study to evaluate gas-line management measures during interruptions in fuel supply. In the model households, vehicles, and service stations are assigned certain attributes to be compatible with their real-world counterparts. Travel activities by vehicle are stratified by trip purpose and simulated on a day-by-day basis. The next-event method is employed to simulate vehicle refilling activities, which takes a microdynamic view of the queueing system at service stations. A sensitivity analysis is conducted for two types of panic behavior during an energy crisis—topping off the tank and arriving early at the gas station. The results show that early arrivals lengthen the waiting time. To prevent this panic behavior, a so-called scattered-refill schedule is proposed. Three management measures are evaluated by the model to determine their effectiveness in reducing wait time per gallon of purchase under a hypothetical 20 percent supply interruption: the odd-even plan, maximum-minimum purchase requirements, and the proposed scattered-refill schedule. The results show that the maximum-minimum plan is an adequate one to prevent tank toppers and the scattered-refill schedule is an effective one to prevent early arrivals. The odd-even plan, although easier to put into effect, is not an effective gas-line management measure.**

During the 1973 and 1979 energy shortages, waiting in line to buy gasoline at service stations was one of the most serious problems that automobile users experienced (1). Many studies (1-5) have indicated that during the past two energy crises, increased waiting time in gasoline stations was used to ration the scarce fuel supplies. However, the gasoline queue is an inefficient gasoline market clearance mechanism. No one benefits from the use of resources employed in queues (2).

When the queueing systems at gasoline stations are under energy supply restrictions, some users are affected by gasoline refilling needs, refilling times, and purchase limits in addition to the operational features of the stations such as station hours and purchase requirements.

The uncertainty about the future terms on which gasoline will be available brings a kind of speculative demand. However, the amount of gasoline that can be purchased in a gasoline station is limited by the capacity of the vehicle's tank. Regardless of the fuel level in the tank, automobile users tend to refill more frequently to maintain enough fuel for travel. This kind of tank-topping behavior, in which there is a high refilling point and small purchase size, causes an increased number of visits to gasoline stations. Thus, more time is spent to purchase the same amount of fuel than would be spent under normal conditions.

The already short fuel supply augmented by panic buying behavior soon depletes the fuel at gasoline stations. Consequently, stations close earlier, which plays an important role in drive-up waiting lines at service stations during an energy crisis. For customers early closure of the gasoline station is a strong indication of a gasoline supply shortage. Therefore, as long as they can find an open station, they refill with as much gasoline as possible if there is no limit on purchases. If after serious searching they still cannot find an open station, an early visit to the gasoline stations the next day is considered. Thus, the shortened station hours severely limit customers' scheduling flexibility in buying gasoline and force them to make early visits to gasoline stations, which result in much longer waiting times for refueling.

Another serious problem during an energy crisis is the preopening arrivals at gasoline stations, which cause extremely long waiting times for the customers. Therefore, a plan to regulate the distribution of arrivals at gasoline stations during a fuel supply interruption so that customer waiting time could be minimized would be an important asset to transportation energy contingency planning.

Daskin et al. (4) made the first model of service station queues during gasoline supply shortages. An M/G/1 queueing model was employed in this study to approximate the queueing system at service stations. The times between customer arrivals (M) were assumed to be exponentially distributed, the service times followed a general distribution (G) described by its mean and variance, and there was only one server in the system (1). Service time in the model was divided into two parts: a fixed time needed by each visitor to the service station and a pumping time, which was a function of the mean size of fuel purchase and the pumping rate. The mean arrival rate was assumed to be constant, independent of time of day. Moreover, the mean purchase size was assumed to be independent of the total amount of gasoline that each consumer demands.

The odd-even rationing plan was tested in the model by assuming a certain reduction of the mean arrival rate. Gasoline purchase requirements (maximum-minimum plan) were evaluated in the model by assuming certain upper and lower limits of the purchase size probability density functions. Tank-topping behavior was also analyzed in the model by reducing the mean purchase size.

There were several drawbacks to the structure of this model. The lack of dynamic feedback in the system is the major one. The waiting time spent at service stations does not have any impact on consumers' refilling behavior. The early depletion of fuel at stations caused by large purchases was not considered in the model. The purchase size was not constrained by the capacity of the vehicle's tank (in this study, it was assumed that the purchase size was independent of the amount of gasoline demand). In addition, the assumption that the mean arrival rate is constant and independent of time of day is not compatible with the real-world situation at service stations, in which peak demands exist at certain periods of the day. Moreover, the early arrivals were not considered in this study.

Prins et al. (1) developed a simple mathematical model to analyze gasoline-line problems. The allocation of gasoline per day represented the supply side of the system. The demand function consisted of the following independent variables: (a) the cost per gallon of gasoline, (b) the mean waiting time per visit, (c) the expected number of visits to gasoline stations per week, and (d) the average number of hours that gasoline stations are open. The average number of hours that stations are open is a function of automobile population, number of service stations, expected number of visits to service stations per week, and the service station rate (in vehicles per hour). The expected number of visits to gasoline stations per week is a function of the use rate per vehicle per day and the purchase size. The purchase size is a function of the average number of hours that gasoline stations are open, the mean waiting time in line per visit, the expected number of visits to gasoline stations per week, and the level of the gasoline shortage.

The odd-even plan and maximum-minimum purchase requirements were tested in the model. This study concluded that the odd-even plan minimized aggregate wait time as well as wait time per visit more than maximum-minimum purchase requirements. This conclusion is just the opposite of the one made by Daskin et al. The sensitivity analysis of the model showed that the waiting time was not sensitive to the length of time that the stations are open or to the purchase size. This result is not compatible with two findings: (a) early station closures shorten the refilling period (and thus shorten times between arrivals and consequently lengthen waiting times) and cause early arrivals (which lead to much longer waiting times), and (b) the smaller purchase size that results from panic buying (tank-topping behavior) increases the waiting time per gallon of purchase. The inappropriate set-up of these two critical factors in the model (i.e., the length of time that the station is open and the purchase size) might be one of the reasons for those inadequate findings (6). The exclusion of the vehicle's tank capacity and the impact of early arrivals could be the other reasons.

Hobeika et al. (7) have developed a simulation model to evaluate the impacts of several fuel supply restriction measures on gasoline consumption during energy shortages. The major entities in the model are households, automobiles, and service stations. The major components of the model are household attribute assignments, vehicle attribute assignments, station attribute assignments, trip assignments, travel routine, search routine, queueing routine, fill-up routine, and summary routine.

The model was built with a detailed activity simulation approach, where events include all types of travel activities detailed as to trip start time, end time, distance, and speed. This kind of simulation uses a great deal of computer execution time. Because most vehicles do not refill every day, it is not necessary to simulate all trips. Moreover, in this study it is assumed that refilling occurs only at the end of a trip, which is not necessarily true for all users.

## PURPOSE AND OBJECTIVES

The purpose of this study is to develop an analytical dynamic simulation model that can adequately analyze gasoline queue problems and evaluate various gasoline-line management measures for possible use by decision makers before and during an energy crisis. To accomplish this the specific objectives of this study are identified as follows:

1. To provide a better understanding of the quantitative effects of panic behavior (such as tank topping and arriving early) on gasoline queues,
2. To identify an effective scheme that helps to prevent early arrivals during an energy crisis, and
3. To evaluate the effectiveness of several gasoline-line management measures in reducing gasoline queues.

## METHODOLOGY

### Model Entities

The major entities being simulated in the gasoline retail market are the vehicles owned by households and the gasoline service stations in the study area. In most commodity purchase queueing systems the consumers are identified as the entities on the demand side. However, with regard to fuel consumption, a vehicle is more appropriate to work with in a simulation model because it is easier to count vehicles than persons at gasoline stations.

According to Dave Catterton of the Virginia Petroleum Jobbers Association (March 16, 1982) and James Heizer of the Virginia Gasoline Retailers' Association (March 15, 1982), the gasoline at service stations is consumed mostly by vehicles owned by households; the major group of customers at service stations is therefore the household vehicle owners. Also, because household-owned vehicles consume more than half of the motor fuel in this country (8) and their consumption of fuel exhibits greater flexibility than that of other modes, the fuel that can be conserved by vehicles owned by households during an energy crisis deserves more attention than that carried by other modes. Vehicles in this model are assigned certain attributes to meet the characteristics of their real-world counterparts. At the same time they are assigned to specific households to serve the travel needs of a group of people who live together and share the same vehicle. Therefore in this study the household is employed as the unit for travel demand. Each household is assigned certain attributes that would affect the level of travel made by the vehicle or vehicles that it possesses.

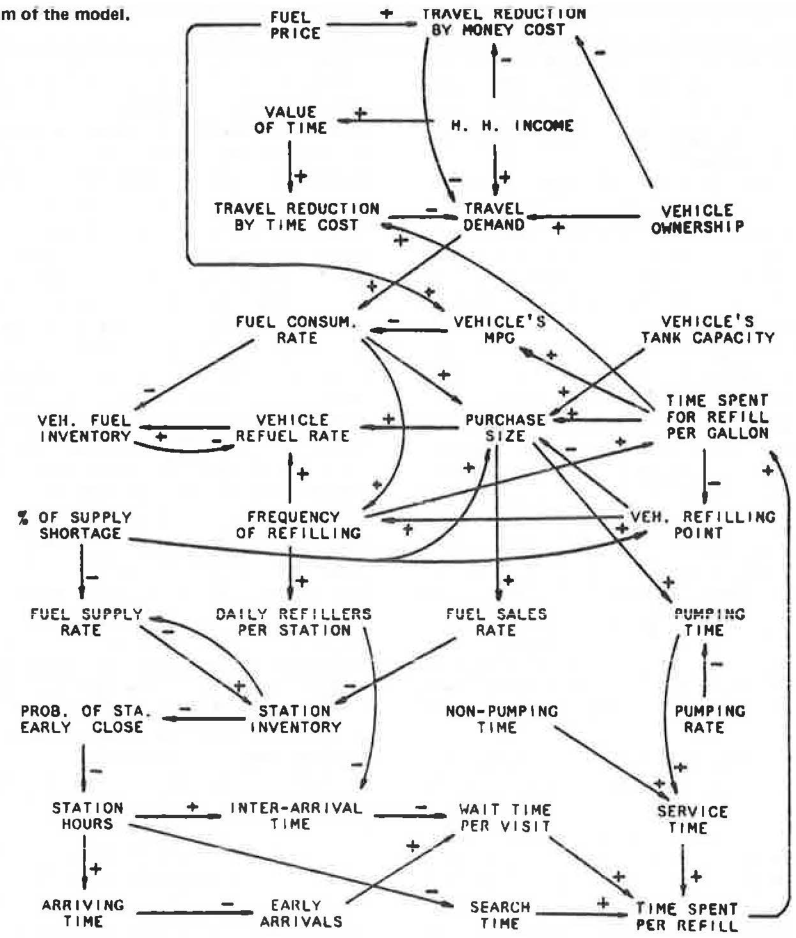
Similarly, service stations are established in the model that represent the supply side of the system and have characteristics compatible with those of their real-world counterparts. A ratio of stations to household-owned vehicles is identified for the region under study. It is then multiplied by the number of household-owned vehicles in the model to estimate the number of stations that should be established. These stations are designed to have the ability of carrying out the various station-related gasoline-line management measures under investigation.

Household-owned vehicles are not the only arrivals at service stations. Other vehicle types are also considered in the simulation model, which includes their number, size, and fuel consumption characteristics. The fuel consumed by these vehicles is then subtracted from the total to indicate the remaining fuel available for consumption by household-owned vehicles.

### Events

In a simulation model the status of the system changes when an event occurs. The changes associated with the travel-related events are the changes in time, fuel, and the number of customers in service stations that occur when any event is promoted from the next event to the current event. Only the critical events are considered in the model to minimize the complexity of the system. Because most vehicles do not refill every day and because the refillings do not necessarily take place at the end of a trip, it is not necessary to simulate all trips in a day. Therefore, only refilling-related events are simulated in the model by the next-event approach. By this approach, the simulation model keeps track of the times at which each distinct status-changing event will occur. It then chooses the time at which the next event will occur, moves forward in the simulation to that time, and alters the status of the system in accordance with the conditions dictated by the occurrence of that event. The basic concept underlying this approach is that there is no need to

Figure 1. Conceptual causal diagram of the model.



view the system at times other than those at which critical events occur. In this research, the next-event approach is only used to simulate the events associated with the refueling activities. All the travel activities are simulated on a day-by-day basis.

## Station Hours

Gasoline station service hours played a significant role during the past energy crises in limiting the refueling flexibility of customers and in causing panic behavior among vehicle drivers with regard to the severity of the shortage of fuel. Thus, the station hours in the model are designed to reflect gasoline depletion or early closure conditions or both.

The major causal relationships in the model are summarized in Figure 1. In this diagram the direction of the linkage represents the direction of the influence. A positive sign (+) is used when changes in both variables are in the same direction (both increasing or both decreasing). A negative sign (-) implies that changes in both variables are in opposite directions (one increasing and the other decreasing, and vice versa).

The relationships between variables are briefly described as follows. A high fuel-consumption rate leads to low fuel inventory in a vehicle's tank, which leads to a high vehicle refuel rate (also to larger purchase size or greater refill frequency or both). The size of purchase is larger if the tank is bigger or the fuel-consumption rate is higher but is smaller if the refill point is higher. The purchase size increases with the level of shortages in the model.

The refill frequency is greater when the refill point of the fuel-consumption rate is higher. Greater frequency of refilling leads to more who refill daily and thus shorter times between arrivals, which cause longer wait time per visit and large purchase size. The increase in those who refill daily per station results in higher fuel sales rate and consequently lower station fuel inventory, which in turn increases the probability of fuel depletion and thus early station closure. The shortened station hours cause early arrival time, shorter times between arrivals, and longer search time. Shorter times between arrivals and more early arrivals cause longer wait times per visit.

On the other hand, larger purchase size and lower pumping rate result in longer pumping time and thus longer service time. The time spent per refill increases when search time, wait time, or service time increases. But smaller purchase size and higher refill frequency lead to longer time spent for per-gallon refill of gasoline.

The fuel inventory at the station increases with a higher fuel supply rate and decreases with a higher fuel sales rate. When the fuel inventory at a station is low, more fuel supplies are requested. However, the supply is reduced whenever there is an energy shortage. The fuel inventory in a vehicle's tank is raised with the vehicle's refuel rate and is reduced with the fuel-consumption rate.

The demand for travel increases with income but decreases with travel hardship such as the increase in travel time and travel cost. The increase in travel time has a greater impact on those with high incomes, whereas the impact of travel cost is greater for those with low incomes because they have limited budgets.

## THE MODEL

To illustrate the application of the model for medium-sized urbanized areas, the city of Richmond, Virginia, was selected as a case study. Area-specific data were obtained from Richmond; national data were used in the general part of the model.

### Household Attribute Assignments

In the model, households were stratified by income, vehicle ownership, and size. The joint probabilities of these three household attributes were used to stratify households into 60 strata (5 income levels, 3 vehicle ownership classes, and 4 household size groups).

### Assignment of Vehicle Attributes

Four attributes were assigned to the vehicles in the model: fuel-efficiency rate, tank capacity, plate number, and refilling point. The fuel-efficiency rate and tank capacity were directly related to the size of the vehicle. In the model vehicles were categorized into four classes: class 1, subcompact vehicles; class 2, compact vehicles; class 3, intermediate-sized vehicles; and class 4, full-size vehicles. The sizes of vehicles were assigned according to household income.

### Assignment of Household Annual Vehicle Miles of Travel

The assignment of household annual vehicle miles of travel (VMT) in the model was based on a recent study by Gorman (9) in which the data of the 1977 Nationwide Personal Transportation Study (NPTS) (10) were used to analyze household characteristics and the determinants of travel behavior. Annual VMT were assigned to households according to their income and vehicle ownership.

### Assignment of Daily VMT by Trip Purpose

After all households in the model had been assigned an annual VMT, the daily VMT by trip purpose was then assigned to vehicles owned by these households as follows:

1. Adjustment of annual household VMT by month: Because the model was developed for analyzing the problems of an energy crisis, the analysis period was short by nature. Because travel varies in different months of the year (9), annual VMT data cannot be used directly in the model for short-term analysis. Therefore, the data were adjusted by the months during which the energy shortages occurred.
2. Assignment of household annual work-trip VMT: Although the VMT varies on a monthly basis, the VMT for the work trip was assumed to be unvaried throughout the year. In the model the data from the 1977 NPTS were used to allocate the percentage of annual work-trip VMT. This percentage was assigned to each household according to its income level. The assigned household annual work-trip VMT was then divided by 52 to obtain household weekly work-trip VMT. On the other hand, household weekly non-work-trip VMT was obtained by subtracting household weekly work-trip VMT from household weekly VMT for all trip purposes. The assigned household weekly non-work-trip VMT was further categorized as shopping, social or recreational, personal business, and other trip purposes according to the data from the 1977 NPTS. The same data source was used to allocate the household weekly VMT by various trip purposes to different days of the week to obtain household daily VMT. Consequently the model assigned the daily VMT to the vehicles owned by the household.

### Assignment of Station Attributes

Before attributes were assigned to service stations in the model, the number of stations to be established for the 500 vehicle-owning households in the model was discussed. According to the 1981 National Petroleum News Fact Book (11), there were 3,436 service stations in Virginia in 1981. Because the total number of households in Virginia for that year was about 1,923,000 (12), the ratio of households to stations is 560:1. After an adjustment by carless households, only one service station was needed for 500 vehicle-owning households. Nevertheless, the model consisted of two service stations and reduced the number of pumps in each station by half to provide the consumers the opportunity to make selections between stations based on the differential in gasoline prices.

There were eight attributes assigned to the service stations in the model: station hours, an initial amount of fuel, tank capacity, replenishment schedule, replenishment amount, average price of fuel, pumping rates, and the nonpumping time for services other than refueling.

### Assignment of Refill Time

The travel component of the system was simulated on a daily basis. The fuel in the tank of each vehicle was correspondingly checked on a day-by-day basis to see whether the vehicle needed to be refilled (according to its current refilling point). When that point had been reached, the vehicle was ready to be sent to the service station for refueling. The time to visit the service station still had to be determined.

No existing data were available on the demand distribution of gasoline purchases at service stations. So a survey was conducted to determine the demand distributions at service stations in Richmond, Virginia. The results of the survey showed that

1. Most of the stations had similar demand distributions,
2. Usually the busiest times were on Monday from 7:00 a.m. to 9:00 a.m. and on Tuesday through Friday from 4:00 p.m. to 6:00 p.m., and
3. The busiest times on Saturday and Sunday were from 12 noon to 1:00 p.m.

However, the data obtained from this survey were only for normal situations. As mentioned before, early arrivals occurred during the past energy crises. An algorithm was thus developed in the model to assign arrival times to vehicles that are refilling under crisis conditions. It included two steps. The first step was to assign vehicles with a normal arrival time. The second was to shift the normal arrival time to an earlier time according to the degree of crisis.

### Refill Routine

The refill routine was simulated by the next-event approach. It consisted of several steps: searching for a station, joining a queue, being served, and updating the status of the system. The structure of the refill routine is illustrated in a simplified flowchart as shown in Figure 2, in which the SEARCH subroutine determines the time spent searching for a gasoline station and the decision to enter a station. The search time is a function of the station open hours. The decision to enter a station depends on the prices of gasoline and the queue lengths at the stations. The probability of entering a station is lower for a station with higher fuel prices or longer gasoline queues. The JOIN subroutine assigns the refilling vehicle to one of the channels of the station it entered. The TSER subroutine is then called to determine the service time needed to serve the newly arrived vehicle according to its purchase

**Figure 2. Simplified flowchart of the refilling routine.**

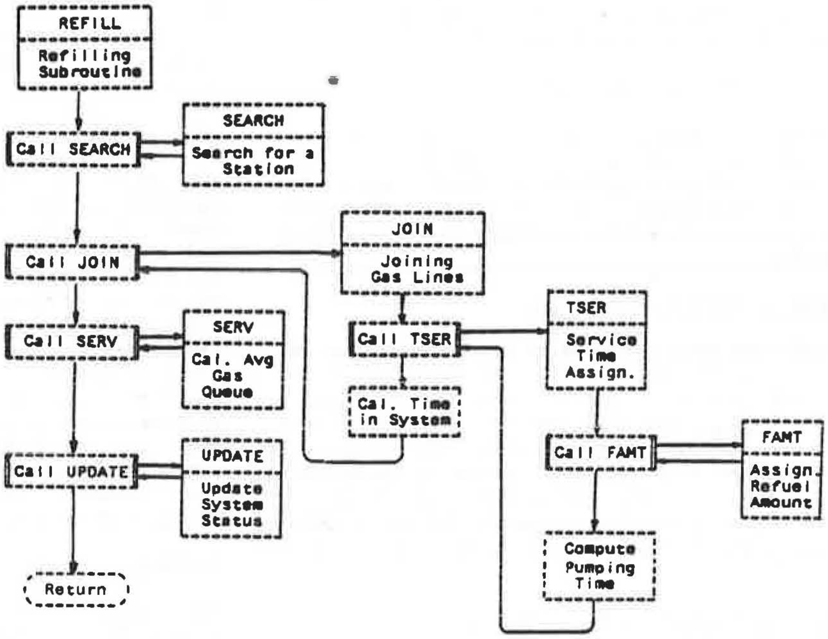
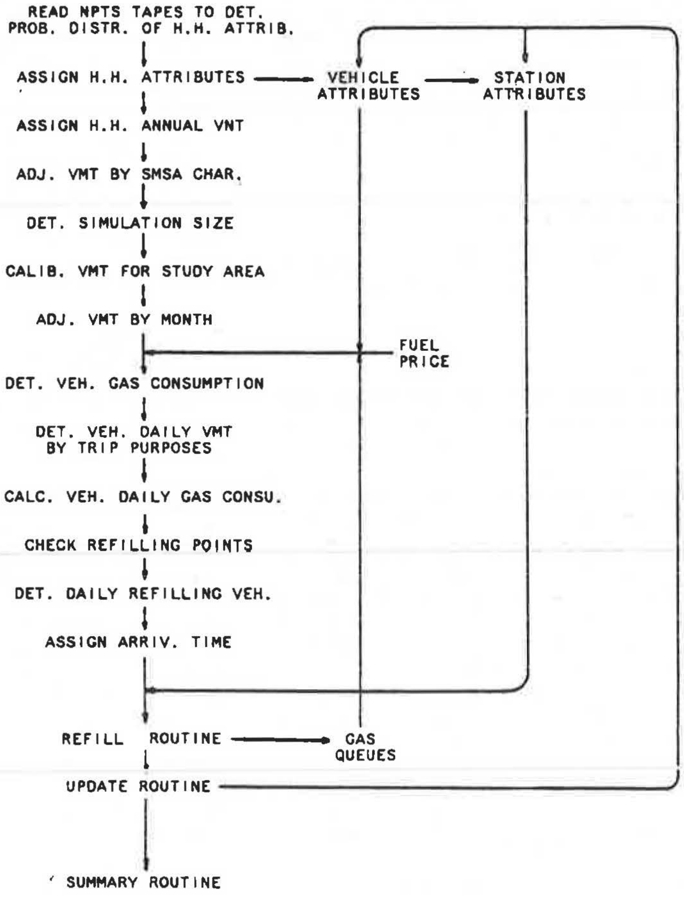


**Figure 3. Simplified model formation flowchart.**



size, whereas the purchase size is assigned by calling the subroutine FAMT. The time that the new arrival spent in queue is then calculated by calling the subroutine SERV, which sums up the time needed to serve all the customers in front of this new arrival. Average gasoline-queue and waiting time are also updated. When the vehicle has finished its refilling, the subroutine UPDATE is called, which changes the following status of the system:

1. The amount of fuel at the station is reduced by the amount of fuel pumped to the vehicle,
2. The amount of fuel in the vehicle's tank is increased by the amount of fuel purchased,
3. The number of customers in the channel is reduced by 1,
4. The number of customers in the station is reduced by 1,
5. The simulation clock is advanced by the amount of time spent servicing this vehicle, and
6. The simulation time attached to this vehicle is advanced to a value greater than 24, which is the end of a simulation day.

The formulation of the model is summarized in a simplified flowchart, shown in Figure 3. A more detailed description of the model may be found in Young's work (13).

## MODEL VALIDATION AND CALIBRATION

Because the model employs the Monte Carlo technique to assign attributes to its entities, it was run with a sufficiently large sample size and various random number seeds to reduce the nonrandom bias. The results showed that an adequate size to run the model was 500 households (about 1,000 vehicles). The outputs showed that the model was functioning in the manner intended. The fuel-efficiency rates were adjusted in the model to make the fuel consumption compatible with the Virginia data.

## SCATTERED-REFILL SCHEDULING

A scheme is proposed in this study to prevent excessive waiting by early arrivals at gasoline stations. Its basic concept is to diversify refilling activities so that waiting time can be minimized. This scheme is not a new idea. It is widely applied at universities during registration, when students are assigned registration times according to the initials of their last names to minimize waiting time.

Under this scheme a vehicle can refill at assigned times on the basis of the last digit of its license plate number. There are several times during which a vehicle can visit stations. For example, for stations that operate from 7:00 a.m. to 10:00 p.m. there are three 5-hr periods. For the first two periods, each hour is scheduled for vehicles with the designated last two digits. There is no restriction on digit requirements in the third period. Thus, this scheme gives refillers a certain flexibility to their refill schedules. Moreover, the tourist industry, which suffered seriously from the odd-even plan, will not be affected much by this scheme, because long-distance travelers have three chances a day to refuel their automobiles and complete their trip.

Because there is no easy way to prevent the panic that causes early arrivals at gasoline stations during an energy crisis, this scheme, although a little complicated in its administration, could be much more effective than other line-management measures such as the odd-even plan. The scheme can also be administered with minimum or maximum purchase requirements whenever tank-topping occurs.

## MODEL APPLICATION

### Simulating Panic Buying Behavior

The panic buying behavior during an energy crisis--tank-topping and arriving at the gasoline station early--is simulated by the model to examine the impact of such behavior on waiting time. Tank topping is formulated in the model by raising the refilling points of all vehicles in the model. The panic behavior of early arrivals is formulated in the model by making vehicle refilling times earlier. The results of these simulations are shown in Table 1, in which a 13 percent fuel supply shortfall and 40 percent gasoline price increase are given as the crisis conditions.

From the results shown in Table 1 it can be seen that the impact of early arrivals on average waiting time is more significant than that of the tank-topping behavior. In addition, for both types of panic behavior, the impact on average waiting time becomes more significant as the degree of severity becomes greater.

### Scenarios and Tests

In this study, gasoline-line management measures are evaluated under four different scenarios. Each scenario is a combination of the following crisis situations: the level of the energy supply shortfall, the percentage of increase in fuel prices, and the degree of panic behavior (tank topping and arriving early).

In the first scenario it is assumed that a 13 percent fuel supply shortfall and a 40 percent gasoline price increase exist and that both types of panic buying behavior occur as well. This scenario describes the height of the 1979 energy crisis in New York State as observed by Hartgen and Neveu (14). In the second scenario a shortfall similar to that of the 1979 energy crisis is defined but a 100 percent increase in fuel prices is hypothesized, which leads to minor panic buying behavior. In the third scenario a 30 percent fuel supply shortage and a 100 percent gasoline price increase are postulated and there is medium-level panic buying behavior. In the fourth scenario a 30 percent supply disruption and serious panic buying situations are considered; the price of fuel is assumed to have risen 40 percent.

The following gasoline-line management measures are assessed according to their effectiveness in reducing waiting time: odd-even plan, maximum and

**Table 1. Simulating panic buying conditions.**

| Panic Level by Behavior | | |
|---|---|---|
| Tank Topping | Arriving Early | AWTPR[a] (min) |
| None | None | 7.94 |
| Minor | None | 9.24 |
| Medium | None | 12.13 |
| Serious | None | 17.35 |
| None | Minor | 9.19 |
| None | Medium | 15.11 |
| None | Serious | 28.25 |

Note: Crisis conditions are 13 percent supply shortage and 40 percent price increase.

[a] Average wait time per refill (assuming that the average purchase size is 8 gal) of the last 28 simulation days (considering the first 7 days as the warm-up period).

minimum purchase requirement, and scattered-refill scheme. The do-nothing alternative will serve as the basis for evaluating these measures. In addition a combination of the maximum-minimum plan and the scattered-refill scheme is also tested. These scenarios and measures are shown in Table 2. The results of these measures are shown in Table 3.

In addition to the average wait time per refill (AWTPR), the indicator HARD is also employed in the evaluation process to reflect the hardship that automobile users encountered under a certain scenario and a certain management measure. The value of HARD is determined by (a) the percentage of vehicles being rejected at service stations (when a vehicle needs to be refueled but cannot enter the service station because of an unmatched plate number, size of purchase, or the early closure of the service station, it is defined as rejected by the station) and (b) the percentage of the potential reduction of fuel demand caused by increased fuel prices and waiting times. This indicator reflects not only the degree of inconvenience imposed on automobile users by the measures but also the hardship level of the scenario itself. However, the value of this indicator should be referred to only on a comparative basis.

The effect of fuel price increases on waiting time is also evaluated in the model. The short-run price elasticities estimated by Archibald and Gillingham (15) and Charles River Associates (16) are employed in the model to reduce fuel consumption as gasoline prices increase. The results show that increases in fuel price have little impact on waiting time.

## DISCUSSION AND ANALYSIS

The results of the model show that the scattered-refill scheme has proved effective in reducing the long waiting time caused by serious panic behavior. Nevertheless, its effectiveness in reducing waiting time is not much greater than that of the odd-even and maximum-minimum purchase requirement under less serious panic situations. Moreover, its hardship on automobile users is always less than that of the other plans, especially under serious panic situations. Tests other than the four scenarios just described have shown that if tank topping is contagious among refillers, the resulting long waiting time would not be effectively reduced by the scattered-refill scheme alone.

The effectiveness of the maximum-minimum purchase requirement ranks next to that of the scattered-refill scheme in minimizing gasoline queues. However, tests other than the four scenarios have shown that if the panic behavior of early arrivals is serious, the effectiveness of this plan is significantly weakened.

The odd-even plan is as effective as the maximum and minimum purchase requirements in reducing waiting times under serious tank-topping situations. Although the odd-even plan is the easiest one to administer, it imposes the most inconvenience on consumers, especially those who are heavy automobile users and long-distance automobile travelers.

All the tests show that the do-nothing alternative has the longest average waiting time under all scenarios. However, the values of HARD indicate that some other alternatives impose more inconvenience cost to automobile users than the do-nothing ones, especially the odd-even plan.

Thus, in order to effectively and adequately minimize the waiting times at service stations caused by both types of panic behavior, a combination of the maximum-minimum purchase requirement and the scattered-refill scheme is needed. It is recommended that the former be employed first for its easier administration. If the panic behavior, especially the early arrivals, continues, the scattered-refill scheme should be adopted.

## OTHER POTENTIAL APPLICATIONS

As indicated in contingency theory for management science, in order to fit changing and uncertain situations, the goal of a management plan varies according to the needs. Because it is likely that the prices of fuel will still not be allowed to clear the market during a future energy supply shortage (17), gasoline queues might be employed again as the market clearance mechanism. However, excessive waiting time is a pure loss to individuals and society. The usual goal of minimizing waiting times at service stations could be changed to selecting adequate action that allows gasoline queues to grow to the point where the level of supply shortfalls should be reflected. How to properly reduce excessive waiting time and employ the remaining waiting time to clear the market can be a challenge to all energy contingency planners. The model, if supplied with sufficient data, would be a potential tool.

The current maximum-minimum purchase plans all have fixed purchase limits. Variation in tank capacity among different vehicles is not considered. Under this type of fixed-limit plan, vehicles with smaller tank capacity are treated inequitably. Because the tank capacity of each vehicle is specified in the model, purchase requirement plans with vari-

Table 2. Scenarios and measures.

| | | | Panic Level by Behavior | | |
|---|---|---|---|---|---|
| Scenario | Supply Shortage (%) | Fuel Price Increase (%) | Tank Topping | Arriving Early | Measure |
| 1 | -13 | +40 | Serious | Serious | All |
| 2 | -13 | +100 | Minor | Minor | All |
| 3 | -30 | +100 | Medium | Medium | All |
| 4 | -30 | +40 | Serious | Serious | All |

Table 3. Test results.

| | Scenario 1 | | Scenario 2 | | Scenario 3 | | Scenario 4 | |
|---|---|---|---|---|---|---|---|---|
| Measure | AWTPR | HARD[a] | AWTPR | HARD | AWTPR | HARD | AWTPR | HARD |
| Do nothing | 33.72 | 0.81 | 15.20 | 0.53 | 18.63 | 0.63 | 35.10 | 0.90 |
| Odd-even plan | 20.84 | 0.90 | 8.87 | 0.64 | 12.57 | 0.79 | 25.13 | 0.98 |
| Maximum-minimum plan[b] | 19.29 | 0.73 | 5.23 | 0.58 | 8.23 | 0.70 | 28.68 | 0.77 |
| Scattered-refill scheme | 6.85 | 0.14 | 4.12 | 0.23 | 6.09 | 0.26 | 7.34 | 0.16 |
| Both[c] | 4.29 | 0.59 | 3.92 | 0.50 | 4.55 | 0.59 | 3.84 | 0.60 |

[a] For definition of HARD, see text.
[b] Maximum limit, 10 gal; minimum limit, 8 gal.
[c] Both maximum-minimum plan and scattered-refill scheme.

able limits can be easily simulated by the model to determine the optimal purchase limits for vehicles of various size classes.

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# Analysis of Total Energy Use of Urban Transportation Energy Conservation Strategies

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**As part of a technology assessment project sponsored by the U.S. Department of Energy, an evaluation was made of total energy consumption by fuel type resulting from local travel (by urban households) for 1980, 1990, and 2000 in two scenarios and under three alternative policies. Energy consumed in vehicle operation, fuel production, vehicle production, and infrastructure construction was projected, and the relative impact of each policy was also evaluated. A substantial decline in total energy use in national urban passenger travel from 1980 to 2000 was projected for both scenarios and all three policies. However, the analysis also indicated that indirect energy use required to support the policies can offset some of their direct energy savings. Further, the scenario that resulted in the greatest total energy savings did not save the greatest amount of petroleum.**

In a project sponsored by the U.S. Department of Energy, Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) (1), several alternative strategies promoting energy conservation in urban transportation were assessed to determine their energy, environmental, and economic impacts. The alternative strategies were tested in three cities for 1980, 1990, and 2000. They represented policies and technology developments designed to conserve urban transportation energy while maintaining a productive economy. They were set within two socioeconomic scenarios that differed in terms of growth rate of gross national product (GNP), social organization, retail fuel price, total metropolitan population, average household income, environmental regulations, and types of fuel available for transportation. The expected energy impacts, both direct and total, of these alternative strategies are related here.

## PROJECT STRUCTURE

To evaluate the energy impacts of the alternative strategies properly, the strategies themselves, scenarios, vehicle characteristics, and fuel supply and prices assumed in this study need to be briefly described. The three conservation strategies analyzed were termed the in-place policy, group travel policy, and individual policy. As a baseline, the in-place policy was established as the extension to the year 2000 of all programs and plans in place in 1980 that affected urban transportation. For the three case-study cities used in this analysis, the in-place policy was defined in terms of existing