SIMULATION OF A RAPID-EXIT INDUSTRIAL PARKING STRUCTURE

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When Eli Lilly and Company considered the use of multilevel parking structures as providers of high-density parking space, concern was expressed as to operating efficiency under peak-load, end-of-workday conditions. Simulation of various types of structures addresses itself specifically to this concern and, in addition, provides interesting and useful design information regarding the structure and the configuration of structure site. This paper will review the simulation study made at Eli Lilly and Company and the application of IBM's GPSS/360 simulator package.

BACKGROUND

The corporate headquarters facility of Eli Lilly and Company, located in an urban setting near downtown Indianapolis, is being developed on a continuing basis to keep pace with company growth and expansion. Current studies indicate that future automobile parking requirements will dictate some sort of high-density parking. The economic considerations of land acquisition and land use add impetus to requirements studies.

A solution to downtown parking problems has often been achieved by municipal parking garages. The use of these structures, however, has been based upon random entry and exit, with provisions for some projected peak load. But what of the industrial situation, in which entry and exit occur within short periods of time at the beginning and end of the workday? A decision to build a parking structure requires an acceptable answer to this question.

WHY SIMULATE?

Initial examination of the parking structure alternative provided gloomy results. The interrelationships of site constants, driving habits of employees, and structure designs appeared to weave an impenetrable net of activity. If a simulation model of the total operation could be developed, perhaps major questions could be answered with some degree of confidence. Specifically, three areas would have to be explored in detail.

General Feasibility

Can a parking structure in fact operate efficiently enough to continue present workdays without staggered shifts? It would be desirable to empty the structure within fifteen minutes.

Design Alternatives

What design features should be incorporated to provide optimum speed and safety? It may be necessary that alternative features be compared to determine the optimum (neither overdesigned nor underdesigned), and it is mandatory that features which would inhibit the flow be detected.

Location Selection

Of several available sites, which would provide the best location for a parking structure? Accessibility to employees' workplaces, compatibility of site and structure design, and the effect of current and projected "pre-structure" traffic patterns must be considered.

GPSS PARKING STRUCTURE SIMULATOR

At the outset of the modeling period certain basic assumptions were made which provided a "philosophy" of simulation. It was decided that the end of the day was the most restrictive and that the simulator would not initially be concerned with entrance problems. It was further decided that "worst-possible" situations would prevail in data collection and programming unless otherwise indicated by firm information. In addition, simulation results should be reported in a form usable for engineering purposes whenever possible.

The simulation, written in GPSS/360, includes the following subsections, each of which will be discussed in detail:

1. "Generation" of people and movement of them to the parking structure.

2. Vertical transportation of people within the structure.

3. Establishment of individual "car-person unit" exit routes.

4. Accomplishment of egress of "car-person" units.

5. Development of various control routines.

The program proceeds from one subsection to the next, starting the simulation at the end of the workday and continuing until the structure is empty (see Figure 1).

Generation of People

GPSS transactions are initially generated as people leaving their workplace and proceeding to their parking place. It was demonstrated early in the investigation that the simulator was quite sensitive to the arrival rate of people at the parking structure. Rather detailed data were collected at each of the seven major building exits at the Lilly facility to determine the actual time pattern of departure (see Figure 2). For a given simulation, a location was assumed, a "use profile" was developed (see Figure 3), and the required exit-rate curves were simulated as follows:

1. Data from each exit study were analyzed to determine average interarrival rates. The data in Figure 2 provided the following analysis:

Interval No.	Duration	Y	X
1	360 seconds	28	13
2	240 seconds	75	3
3	120 seconds	119	1
4	120 seconds	47	3
5	360 seconds	48	8

Where Y represents the average number of people leaving the exit from several days' data and X is the mean interarrival time within each interval, ($X = \frac{\text{Duration}}{Y}$).

2. The number of people to be generated in each interval for a given simulation was based upon the use profile. For example, if 10% of the capacity of a 600-car garage (60 people) were to come from the exit illustrated above, the number generated from each interval would be determined by:

$$N = Y \left(\frac{60}{\Sigma Y}\right)$$

3. People were assumed to exit in a manner described by the Poisson Distribution. A function was, therefore, set up as illustrated in the GPSS Manual, page 33, to be used as a mean interarrival time modifier in the GENERATE blocks.

4. GENERATE blocks were established based on the above information. A GENERATE block was required for each interval on each exit curve. GENERATE blocks to simulate the data in Figure 2 would be as follows:

```
GENERATE 13,FN1,,5,,11,F      Interval#1
GENERATE 3,FN1,360,14,,11,F   Interval#2
Etc.
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After generation, people are ADVANCED to simulate walking time from their workplace to the garage.

An additional step is accomplished by the time each person-transaction reaches the garage; the individual stall number is assigned. The stall number is a five-digit number which is used throughout the simulation. For example, stall number 31327 is on the third floor, in row thirteen, the twenty-seventh space. Stall numbers are assigned to parameter one of each transaction by a list function which has been randomly assembled.

Vertical Transportation of People

Once at the parking structure, people who are parked on upper floors utilize vertical transportation. This simulation provides the choice of stairs and an elevator. The branch is accomplished by a probabilistic transfer (the probability of using the elevator is higher when the person is going to a higher level). Should the queue waiting for the elevator be too long, the elevator decision is overridden and the stairs are used.

While the stairs simulation is quite straightforward, the elevator is rather complex. The elevator is loaded to capacity (unless queue length is less than one) and proceeds upward.

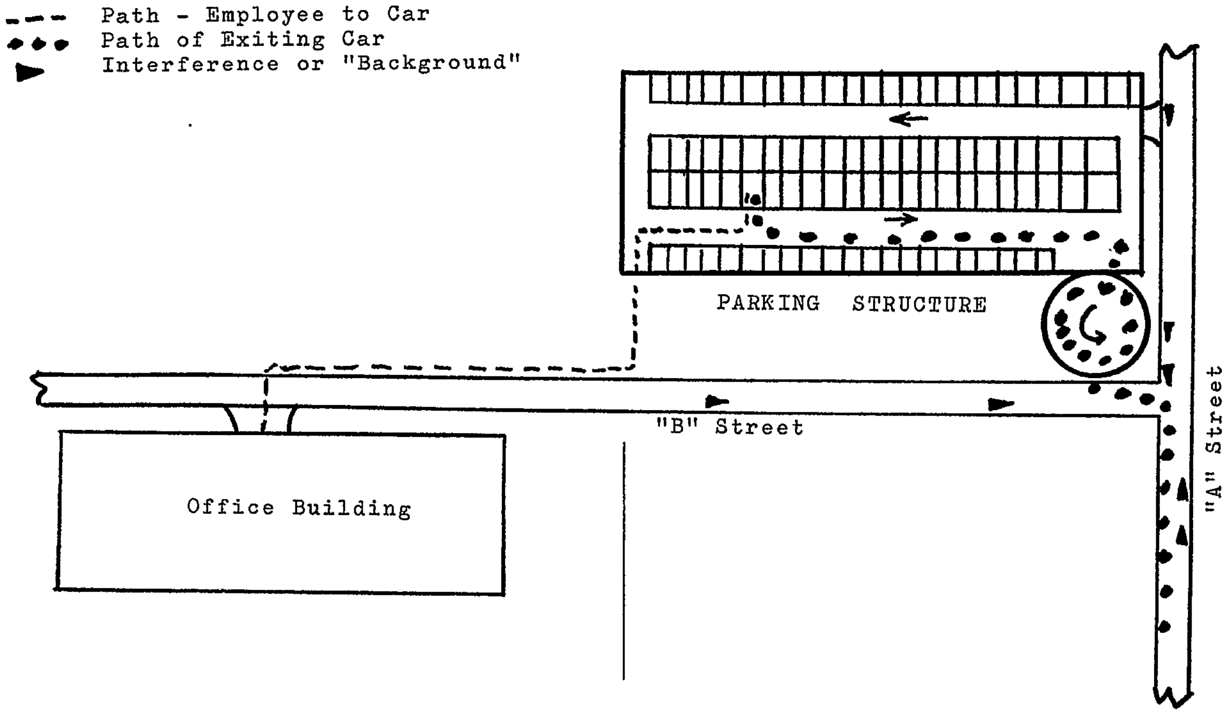


FIGURE 1
Schematic Diagram of Simulation

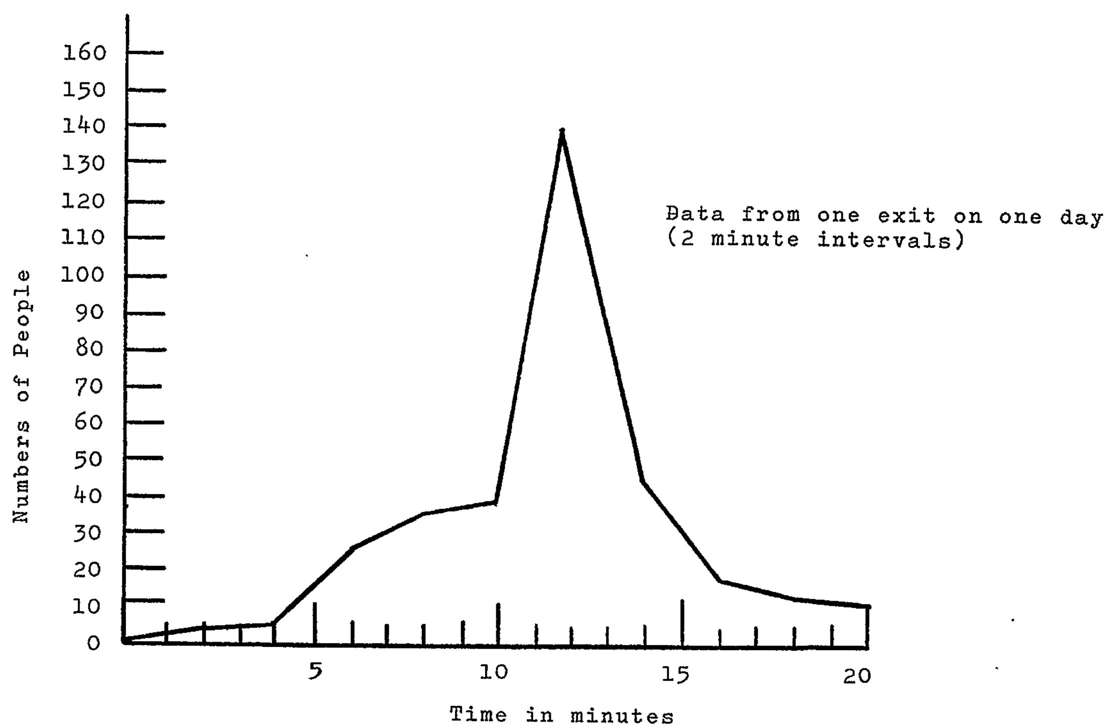


FIGURE 2
Building Exit Count

ANTICIPATED GARAGE USAGE PROFILE

Location Code	Building Exits							Total	Remarks
	B1	B2	B3	B4	B5	B6	B7		
G-1	15	20	5	-	20	25	15	100	Bridge B1 to G-1
G-2	10	10	20	5	35	-	20	100	
G-3	-	20	5	10	20	30	15	100	Tunnel B6 to G-3
G-4	5	20	10	10	10	15	30	100	New Sidewalk on "B" Street

Values Stated as a % of Garage Capacity

FIGURE 3
Use Profile

The length of time the elevator operates depends upon the current passenger mix. When the elevator is emptied, it is returned to the first floor by means of a control routine. Figure 4 is a simplified diagram illustrating the operation of the elevator simulation.

Establishment of Exit Routes

Each structure design is unique regarding method of exit. For each stall, a specific exit route must be prescribed.

Figure 5 represents the floor diagram of a particular garage design. Each row in the structure is simulated by a GPSS STORAGE of prescribed capacity. To exit the garage, therefore, a car must proceed from its stall row by row (or storage by storage) until it is out of the structure. Routes are established for each stall and appropriate storage numbers assigned to transaction parameters. The car in stall #31527 (see Figure 5) desiring to exit from helix #2 would enter row #15 and proceed to row #38, row #14, row #39, row #16, and row #18 to enter helix level #32. Each of these numbers, representing consecutive storages to be entered, is assigned to a parameter.

Accomplishment of Egress

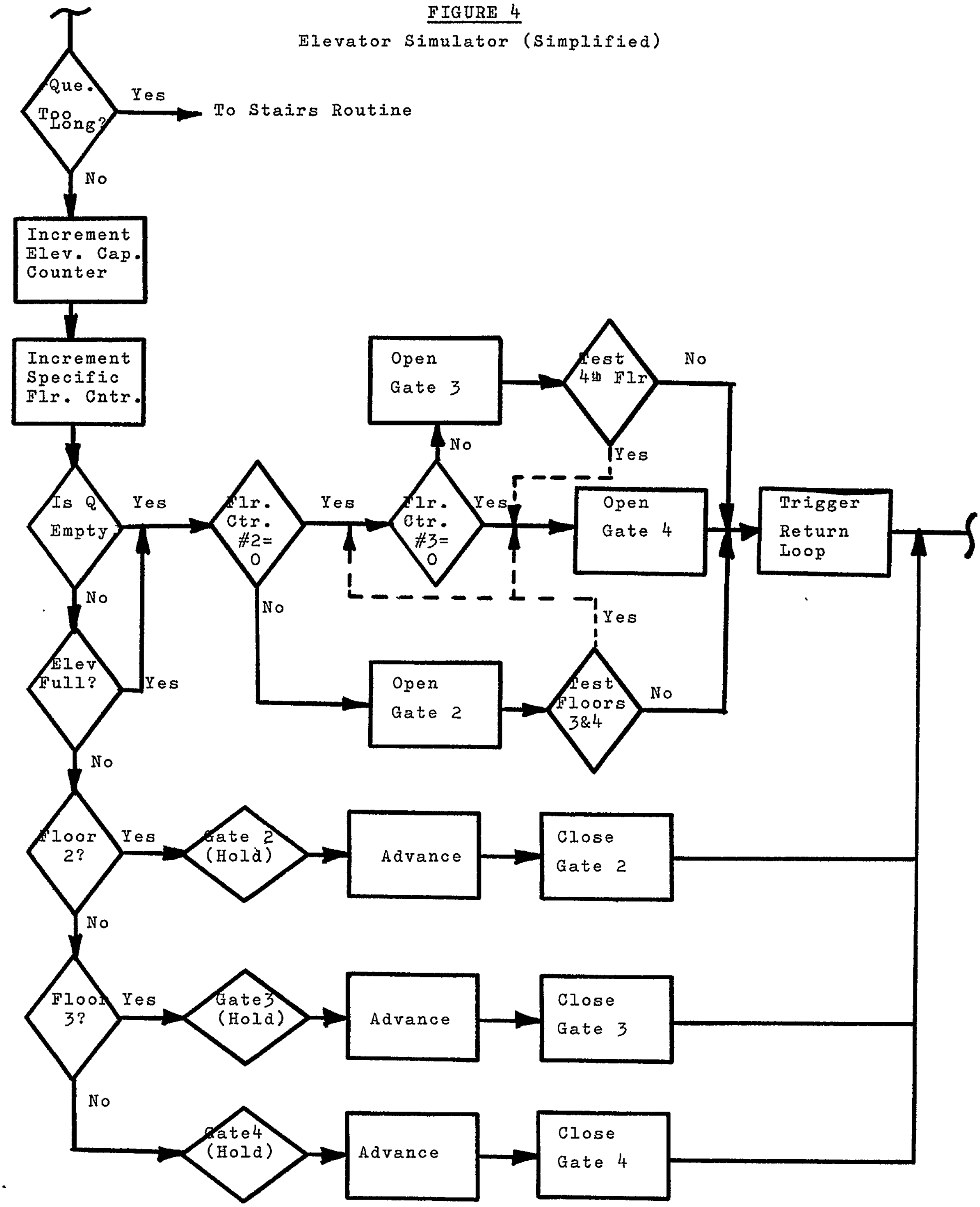
Progress of each transaction through the garage is based upon the capacity and/or current contents of each storage. Delays occur when storages do not allow entry of a given transaction. Indirect addressing is used throughout this portion of the program, since storage numbers to be used are stored as parameter values.

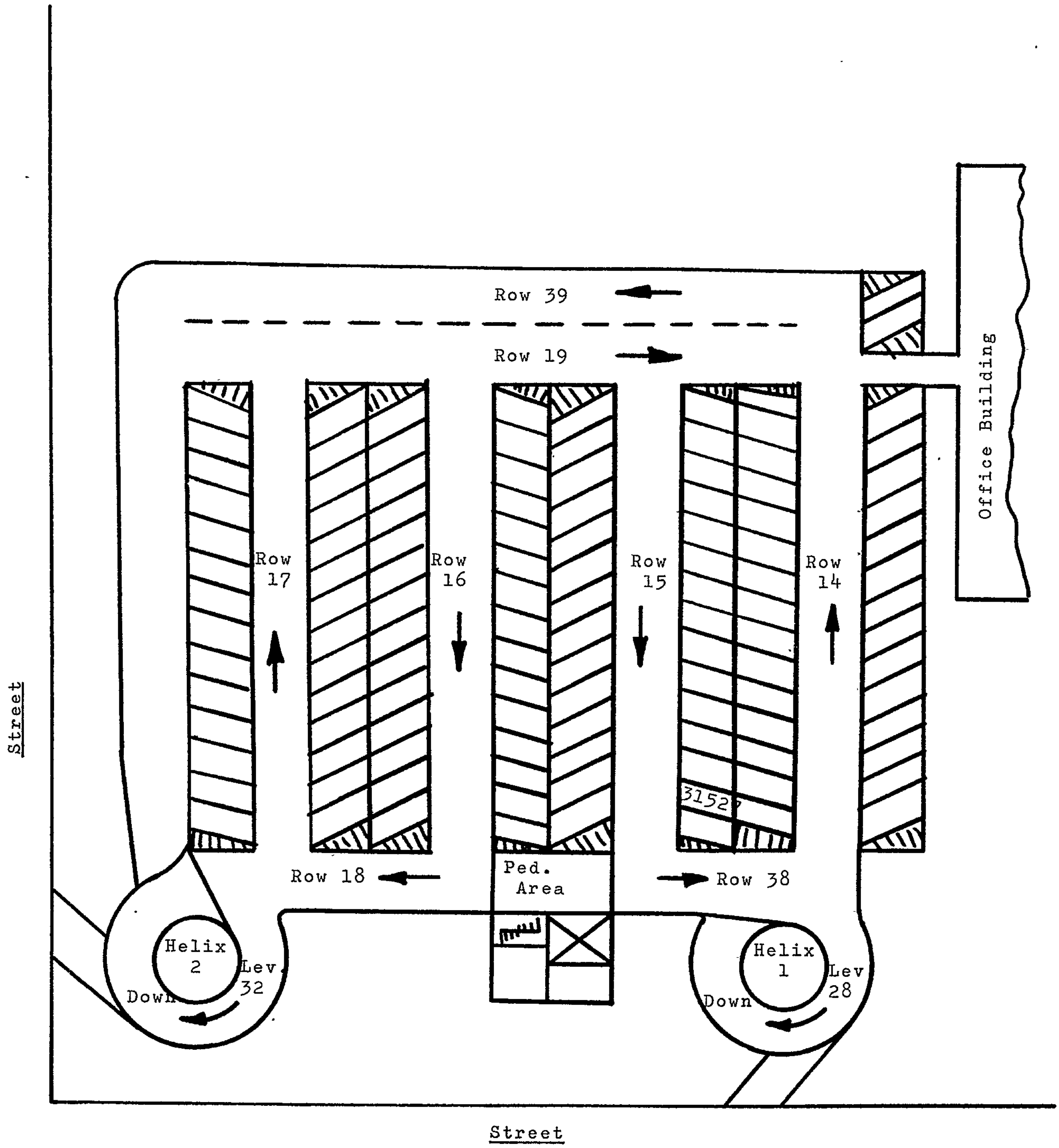
This portion of the program includes three basic sections:

Movement of the transaction from stall to helix. If the number of cars in the "stall-row" extends past the stall, the car must wait to back out. Once the blocking condition has cleared, the car "backs" into the storage and advances the normal time to travel the row length. The current contents of the next row (storage) is checked, and, if not restricted, the transaction enters it. The procedure is repeated until the transaction is

FIGURE 4

Elevator Simulator (Simplified)





Row numbers are GPSS STORAGE numbers.
Each row on each floor has a unique number

FIGURE 5

Parking Structure - 3rd Floor Plan

in the helix.

Movement down the helix. If the stall number was above the first floor, it is necessary for the transaction to proceed down the helical exit ramp. This is accomplished by decrementing the initial helix-level storage assignment and looping back through the helix routine.

Movement into the surrounding street system. Upon reaching street level, each car will be affected by current conditions on the street. Two questions must be answered before proceeding:

1. Is traffic backed up to block the exit?

2. Is traffic "bearing down" so as to make exiting unsafe?

After satisfactory answers to these questions, the car-transaction enters the street system.

Two important features of the egress portion of the program are the use of user chains and the subsequent need to recognize "multiple-use" rows. Before entering any row, transactions are linked (FIFO) to a user chain which is numbered to correspond to the desired row (storage). When a transaction actually enters the row, the next waiting transaction is unlinked from the chain. The use of such chains significantly reduces computer run time when simulation delays occur, since only the current transaction is examined by the scan.

"Multiple-use" rows (i.e., rows from which transactions may proceed to different places) require special attention. When a transaction is unlinked from a user chain in such a row, it must be sent to the proper place in the program. A parameter assignment is made, therefore, which distinguishes various transactions on the same chain.

Control Routines

Each garage simulation has three basic types of control routines.

The system "camera" and run-time control. This short routine prints the contents of all storages (rows) at 120-second intervals and checks the total time of the simulation. The print of storage contents provides a snapshot of the position of all cars in the structure each two minutes. The total time check stops the program if the simulation runs beyond the predetermined clock time and provides normal output.

Elevator return loop. A transaction is generated, waits for a signal from the elevator simulator (a logic switch set), and then proceeds to return the elevator to the first floor and set all elevator counters (SAVEVALUES) to zero.

Background generators. These routines generate background traffic flow in the street system surrounding a given structure location. Exiting cars will be delayed should background interference exist at the exit ramp from the helix.

When viewed in segments, the GPSS simulator is adaptable to any structure design with variations to each segment as required.

Two major data studies were involved in the program development: (1) exit count studies from workplace buildings and (2) motion picture studies of current traffic conditions at each proposed site during the peak period of egress.

Four sites were considered at Eli Lilly and Company, and four different programs were simultaneously developed. This procedure provided an excellent source of comparative data throughout the study.

SUMMARY OF RESULTS

In the case of parking structures, simulation provided answers to the questions posed at the start of this paper. Certain designs at certain locations operated within the time limits required and within the restrictions imposed by external traffic flow. Engineering considerations were aided by comparative design information and the ability to test design concepts by simulation. The concern that such a structure might be built and prove highly unattractive for employee use was greatly eased. We are confident that the actual parking structure is more than adequately described by the GPSS model.