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DISCRETE EVENT SIMULATION FOR QUICK SERVICE RESTAURANT TRAFFIC ANALYSIS

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ABSTRACT

This paper describes the development of a software tool that simulates and animates the traffic control in and around parking lots associated with Quick Service Restaurants (QSR). The Quick Service Restaurant Simulation (QSRS) module provides restaurant planners and designers with the ability to experiment with various parking lot and adjacent street traffic configurations in an effort to optimize proposed sites or to improve existing ones.

QSRS was designed to consider all of the important traffic parameters of a restaurant site in a flexible, user-friendly environment. Each site's parameters can be varied and modified to make quantitative comparisons of proposed solutions to determine optimal site design. The QSRS module provides high quality 3-D graphics with accurate spatial representation, allowing the user to visually observe the site in operation for verification of proposed configurations.

QSRS is currently being used at Taco Bell Corporation for three primary uses: 1) Post-construction fixes; 2) Development of standard layouts for site design standardization; and 3) Strategic permitting by visually communicating the proposed development to the community.

1 INTRODUCTION

Simulation is a scientific approach to mimic reality and to determine or predict the behavior and response of a system under varying conditions. Whether the system under consideration is a NASA flight simulator, a manufacturing production line, or a QSR, the theme remains the same: "How will the system respond when specific assumptions are varied?" Ultimately, simulation allows the analyst to assess the risks and characteristics of a system so that a decision maker can be provided with objective information on which to base a decision.

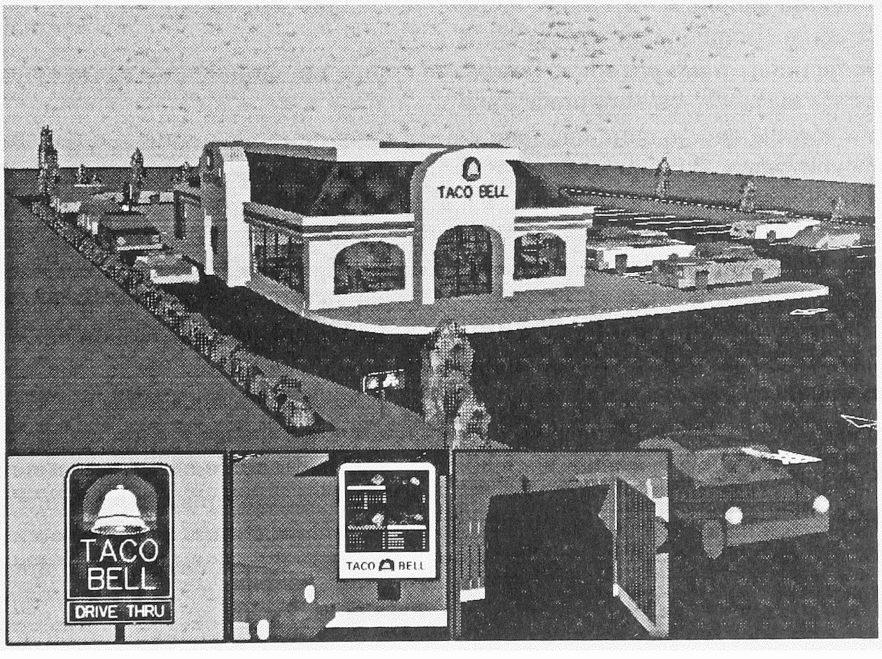

Figure 1: Simulation Model of Taco Bell Site

The real challenge in modeling QSR facilities is predicting human behavior, particularly driver preferences, which are often illogical. Simulation allows one to experiment with and to vary the assumptions on customer preferences to determine the customer's impact on the restaurant site. The QSRS module provides the ability to perform objective, quantitative comparisons between multiple arrangements of a site. If varying opinions exist about which layout is best, each alternative can be simulated and the performance characteristics for each scenario can be ranked for relative comparisons.

Simulation also provides a mechanism to replicate specific site conditions in accelerated time. Whereas observing certain conditions of an actual site can take several days, a validated model of a site can be run with back-to-back peak hours, independent of actual site analysis.

Perhaps simulation's most important capability is the ability to provide a dynamic graphical display of events as they occur in the simulation, providing an excellent vehicle for communication.

Taco Bell Corporation has been using simulation as a part of an ongoing effort to improve traffic flow through existing restaurant sites, as a tool for developing design standards for future sites, and as a strategic permitting tool for better communication of proposed plans. Each of these uses potentially saves Taco Bell development time and costs.

Simulation was initially used to analyze specific sites providing valuable information used to develop a flexible module capable of modeling a wide range of sites while providing accurate on-site and off-site traffic analysis. The module contains the operation logic and decisions common to all QSR facilities, while providing flexible input features to simplify the model-building process and input of site specific layouts and assumptions such as traffic volumes and cycle times. The general features of the module include the following:

- Scale site layout
- 3-D scale vehicles and site graphic icons
- Adjacent streets with bi-directional traffic
- Multiple lanes of traffic
- Ingress locations
- Egress locations
- Parking lot stalls
- Restaurant dining locations
- Pedestrian traffic
- Drive-thru lanes and selection probabilities (driver side or passenger side)
- Ingress/egress probability tables (based on customer origin)
- Traffic signals at intersections
- Left turns (yield and protected signals)
- Vehicle types (customer or incidental traffic)
- Customer types by restaurant (dine-in, carry-out, or drive-thru)

2 MODEL DEVELOPMENT

The majority of the model development required by the user is in the construction of the physical layout for the site. There is a construction palette with sample site entities, that allows the user to copy and place common entities such as parking lot stalls. The model has all the general decisions embedded in the logic system and only requires the user to input the site-specific data for delay times and decision probabilities and to set flags, either through the use of data files or dialog windows provided through the standard *AutoMod* user interface. The following is a list identifying the major steps required to take the QSRS module and create a working model for a specific site:

(1) site layout drawing
(2) road path placement
(3) pedestrian path placement
(4) block placement
(5) data file editing

2.1 Inclusion of Site Layout Drawing

To create a new model of a specific site, the first step is to include a static layout from a CAD file using the IGES data exchange format to provide an accurate, spatial representation of the site. Using the *AutoMod* module "Igesin," a CAD layout is incorporated as a static reference system.

2.2 Road Path Placement

After the layout information has been included in the model, the actual layout of the road system is achieved using the standard *AutoMod* AGV system to control the vehicle movement and traffic patterns. The process is similar to a drawing in any CAD system using lines, arcs, and filleting options to generate the paths for vehicle movement. Using the static

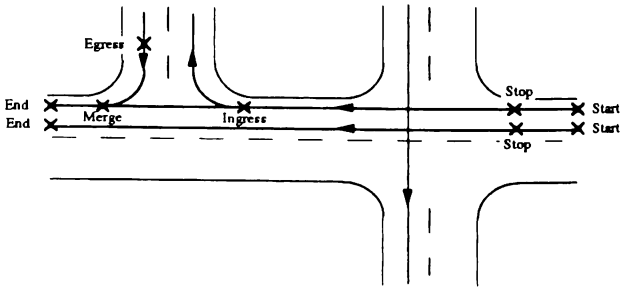

Figure 2: Key Street Locations

layout as a reference, key control points are named and located throughout the system as shown in Figure 2. The key adjacent street locations for a site include:

Start locations - Define where customers and traffic vehicles are introduced onto the adjacent streets.

Stop locations - Define the stop light limit line location for each lane of each street. Stop locations on the first lane of a street can have left turn attributes of "LEFT" for protected left turn signals, or "YIELD" for yielded left turns when traffic conditions permit. If the traffic signal has no light phases defined, it is considered a stop sign; otherwise, left turns are only allowed during the appropriate light phases.

End locations - Define the end of the street for each lane where the vehicle route is considered complete.

Ingress locations - Define the driveway entrance where the decision to enter the site is made. If the ingress is not blocked, the customer is placed on the restaurant stack count; otherwise, the customer continues along the street and represents lost business.

Egress locations - Define the driveway exit location where the egress delay occurs and the customer waits for a merge window to re-enter traffic on the first lane of the adjacent streets.

Merge locations - Define the point at which the customers are considered off-site and back on the street. This is also the point at which the customer cycle times are recorded and the customer is removed from the site exit stack.

The parking stall segments are typically 18 feet in length and placed nine feet apart. The location of the parking stalls can be any desired numbering sequence. Keep in mind that groups of stalls or parking zones are defined later to determine parking lot search sequences for the various driveways or differing site conditions. The on-site decision points for each drive-thru lane of each restaurant include:

Choose locations - Used to select either the driver-side or passenger-side lane and place the customer on the selected drive-thru lane stack.

Board locations - Orderboard locations where the order delays are taken and where the food preparation delay is initiated.

Window locations - Where the food preparation delay is completed if needed, and the handoff delays are taken. Customers are removed from the drive-thru stack and restaurant stack, and are placed on the site exit stack if they are not going to park and dine on site.

2.3 Pedestrians Path Placement

Pedestrian path placement is optional and only required if there is at least one diner associated with a restaurant on the site being modeled. The pedestrian traffic is modeled using a separate standard *AutoMod* AGV system, in which key control points are named and located for pedestrian traffic. The stall locations in the pedestrian system use the same numbering sequence as those used in the road system. Crosswalks are established and blocks are used to prevent collisions between vehicles and pedestrians as shown in Figure 3.

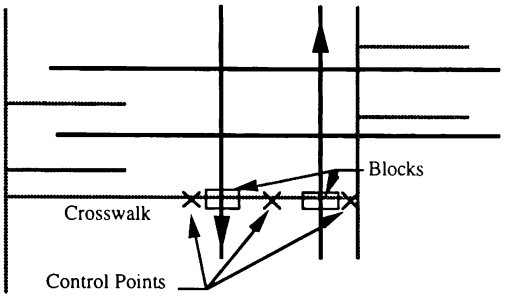

Figure 3: Parking Lot Crosswalk

2.4 Block Placement

Blocks are used to control vehicles at intersections and turn locations. Key entrance and exit blocks are required for site model operation. Other blocks are optional, depending on site requirements, to prevent vehicle collisions in the parking areas or street intersections, as illustrated in Figure 4.

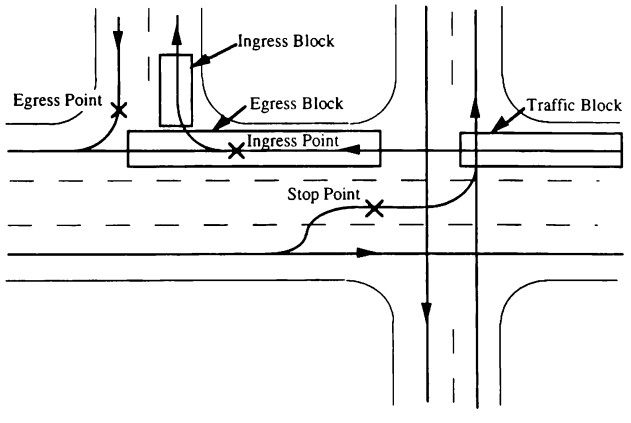

Figure 4: Traffic Control Blocks

The ingress block is used by the customer at the ingress point to decide if the driveway is open and free of traffic. The egress block is used by the customer at the egress point to determine if a merge window is available before exiting the site and merging onto the adjacent street.

The traffic blocks are used by vehicles making left turns to determine if there is any on-coming traffic before turning left.

2.5 Edit Data Files

The data and model parameters that define the operating characteristics of a site are included in specific data files accessible through the standard *AutoMod* interface. The traffic information is included in a file that defines the arrival rate and type of customer for each restaurant (drive-thru and/or dine-in). The incidental traffic section of the site file defines the arrival rate and size of traffic packs of incidental (non-customer) traffic for the streets. The pack size is determined first, then the pack creation is delayed until the number of sample delays is equal to the pack size using the incidental traffic distribution, as shown in Figure 5.

INCIDENTAL TRAFFIC

	<- Size (cars/pack) ->			<- Frequency (min/car) ->			
Street Name	Dist Type	Arg 1	Arg 2	Arg 3	Dist Type	Arg 1	Arg 2	Arg 3
STREET1	Nor	12	3	0	Exp	0.1	0	0
STREET2	Uni	5	2	0	Exp	0.15	0	0

Figure 5: Non-customer Interarrivals

The customer stream section of the site file defines the arrival rate of customer traffic for each restaurant (drive-thru and/or dine-in) on the adjacent streets as shown in Figure 6.

CUSTOMER STREAMS

			<-- InterArrivals (min) -->				
Rest Type	Street Name	Cust Type	Dist Type	Arg 1	Arg 2	Arg 3	Driveway Table
A	STREET1	DRIVE	Exp	0.10	0	0	TAB_1
A	STREET2	DRIVE	Exp	0.15	0	0	TAB_2
A	STREET1	DINE	Exp	0.10	0	0	TAB_1
A	STREET2	DINE	Exp	0.15	0	0	TAB_2

Figure 6: Customer Interarrival Streams

The site is limited to a maximum of two restaurants, and each restaurant can have a drive-thru and/or dine-in area. Delay times for each area are defined in sections of the restaurant file, as shown in Figure 7.

There is one parking lot defined and once a customer has selected a stall and parked, the customer will cross the parking lot and enter the dining area. The locations for parking stalls are contained in a data file "park.d," using the format shown in Figure 8. Parking zones used in search sequences can be defined at the bottom of the file. These search sequences can be associated with selected ingress locations or can be based on current conditions on site. For example, if the drive-thru

DRIVE-THRU DELAYS

Delay Type	Dist Type	Arg 1	Arg 2	Arg 3
PRE-ORDER	Log	5	2	0
ORDER	Log	30	5	0
PREPARATION	Log	78	25	0
PRE-HANDOFF	Log	4	2	0
HANDOFF	Log	26	4	0

Figure 7: Drive-Thru Delay Data

area is heavily congested, the search sequence may be different than when under other site conditions.

The probability tables in file "table.d" define the probability of selecting ingress and egress locations for site customers and are attached to customer streams defined in

PARKING LOT DEFINITION

Stall Location Prefix	Park Location Prefix	Stall Low	Stall High	Park Zone
stall	park	1	20	A
stall	park	21	40	A
stall	park	41	60	A

PARKING LOT SEARCH SEQUENCES

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SRCH:  DRVWY_1  A B C
SRCH:  DRVWY_2  C B A
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Figure 8: Parking Lot Description

the "site.d" file, as referenced in Figure 9. The summation of all the egress columns should add up to "1," and the summation of all the ingress rows should add up to "1."

DRIVEWAY PROBABILITY TABLES

TABLE: TAB_1

INGRESS	EGRESS1	EGRESS2	EGRESS3
1	.250	.000	.000
2	.000	.000	.500
3	.000	.000	.250

TABLE: TAB_2

INGRESS	EGRESS1	EGRESS2	EGRESS3
1	.250	.000	.250
2	.250	.000	.000

Figure 9: Driveway Probability File

3 MODEL ANALYSIS

In addition to the traffic module, a model-analysis template has been defined in *AutoStat,* which includes all the relevant model statistics or responses from the standard report. Site specific factors or responses can be added or easily removed. This provides a standard way of comparing and interpreting the results of the various sites analyzed.

The developed models are studied using traffic volumes from peak hour conditions to determine which layout has the best performance characteristics. Each layout can also be analyzed to determine its capacity by ramping up the traffic level at given intervals until the site performance drops off, indicating site saturation. The statistics are generated using between five to seven samples at each traffic level, changing the random number streams between runs. Some of the key site measurements include:

- Throughput count for the site and by customer type
- Customer cycle time by customer type
- Queue and stacking statistics
- Lost customers

4 APPLICATION

Recently, Taco Bell encountered a queuing problem on a dual site containing two restaurant concepts. The problem was that customers from restaurant "B" were backing up traffic on a shopping center access road, impeding customers entering restaurant "A." Figure 10 illustrates this problem, with the dark colored vehicles indicating restaurant "B" customers. The existing layout could not handle the peak hour traffic levels created at "B."

This site problem was generating some reluctance on the part of the state's department of transportation for building sites of a similar nature. Simulation solved the problem by evaluating the existing site as well as a proposed site that provides separate circular patterns for each restaurant, minimizing traffic conflicts, as shown in Figure 10. The major findings of the analysis determined that the new layout could:

- Increase throughput by 30 percent for restaurant "B"
- Eliminate problems with a dead-end parking lot
- Reduce customer cycle time
- Shorten drive-thru stacking, containing it within the restaurant property

The animation for each site was videotaped and the statistics were tallied on the performance of each layout, improving the existing site and actually enabling the permitting of future similar restaurant sites.

5 SUMMARY

The current traffic module has been used to build and analyze over 45 sites and has been successfully used to graphically present designs and solutions to architects,

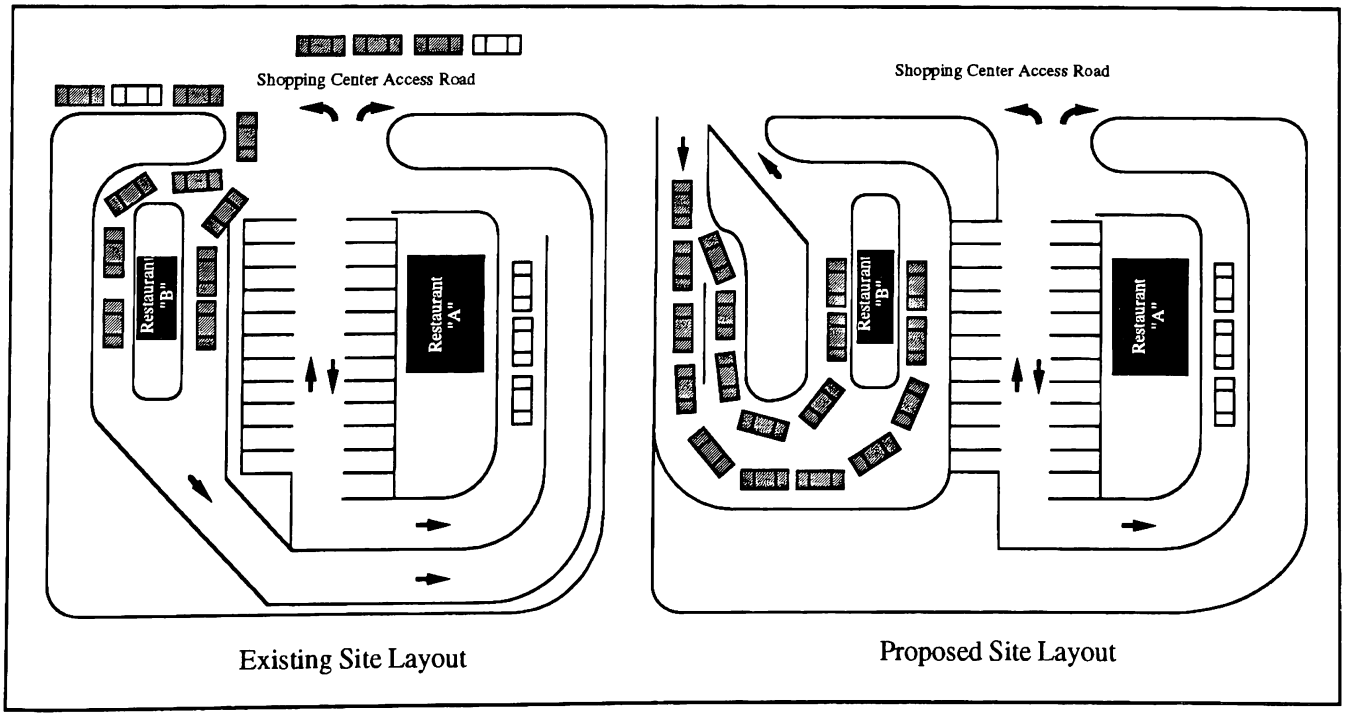

Figure 10: Analyzed Sites

engineers, and planning commissions. The site development team at Taco Bell is currently providing this new tool through a regional network, and plans to make this technology available to all organizations and agents of Taco Bell involved in site design, construction, and permitting processes.

AUTHOR BIOGRAPHY

STEVEN L. JAYNES is a Senior Simulation Analyst with AutoSimulations and has conducted numerous simulation studies over the past five years in a variety of applications. He was previously involved with applied research for manufacturing applications at the Institute for Robotics at Lehigh University, and software development for CAD/CAM applications at GE Calma. He holds B.S. and M.S. degrees from the Manufacturing Engineering Department of Brigham Young University, with an emphasis in Computer-Integrated Manufacturing.

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