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A SIMULATION MODEL AND ANALYSIS: INTEGRATING AGV'S WITH NON-AUTOMATED MATERIAL HANDLING

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ABSTRACT

Companies that integrate old and new technologies need analysis methods with complex logic to evaluate the resulting system, making simulation a primary analysis tool. This paper presents the logic for a general purpose simulation model representing an automatic guided vehicle (AGV) system integrated with traditional material handling equipment. To accurately represent this type of system, logic includes vehicle loading/unloading and conventional equipment passing capability. The model's flexibility accommodates any combination of straight aisles and intersections through minor adjustments to the general model. The logic concepts are implemented using the SIMAN simulation language. An application is presented which demonstrates using the model to analyze the impact of interfacing AGV and traditional traffic upon aisle congestion and overall system performance.

INTRODUCTION

The advent of Computer-Integrated-Manufacturing, CIM, and its accompanying technological advances has greatly increased the introduction rate of automated manufacturing systems. Many of these systems are stand alone, or at least physically separated from other non-automated systems. The design and control of such systems is primarily concerned with the components and interactions within the system while a secondary concern is interfacing with the remaining portions of the total system.

When automated systems are incorporated with existing non-automated systems, the design and control become more difficult because interactions with the current system are of primary importance. Machining centers and components which are connected directly by hard material handling, e.g. conveyors, can often be treated as separate entities, where only the inputs and outputs interface with other system components. But, elements which must directly interface with the existing system present potential problems for the designer. One example is Automated Guided Vehicles, AGV's, which must use the same aisles as conventional material handling equipment.

Although there are procedures for designing paths for AGV systems, they typically do not directly consider conventional plant traffic. At first glance, it appears that introducing AGV's simply adds to current traffic. However, there are several important differences which can result in major congestion between the two types of traffic. The major difference is that an AGV is confined to a specific path, normally following a wire embedded in the floor of the aisle. Also, conventional material handling traffic moves at speeds two to four times faster than AGV's.

The degree of potential congestion within a system containing both types of traffic depends on many factors. If no vehicle stops occur within common traffic regions, congestion may be minimal since conventional traffic should have enough flexibility to avoid the slower AGV's. This avoidance may not be possible if both vehicle types are required to make frequent loading/unloading stops which temporarily block aisles. The degree of congestion is also affected to a lessor extent by vehicle traffic intensity.

Analysis of integrated systems requires complex logic, making it a suitable candidate for simulation. Ideally, a model should allow the designer to accurately determine the amount of potential vehicle interference and quickly isolate primary causes. It should then let the designer easily alter the system to evaluate other alternatives or configurations.

MODEL REQUIREMENTS

A simulation model for the analysis of congestion between AGV's and conventional plant traffic should be capable of modeling a wide variety of environments and providing output information relevant to the analysis requirements. Thus, the model should be designed generically, allowing modeling of total systems as well as portions of systems.

Due to the wide variety of systems, the model must be capable of representing multiple paths through the system for both types of traffic. Logic describing vehicle stopping for loading/unloading activities and logic necessary for conventional traffic to pass stopped or slow vehicles must be included. Likewise, it should accurately model the behavior of an AGV when it encounters a blockage. Output should let the user pinpoint the location and frequency of blockages for both types of vehicles. Finally, the model should be developed such that key parameters, e.g. vehicle speed and traffic intensity, can be easily modified.

It is the objective of this paper to present design logic for such a model, illustrate this design with a small example, and discuss the results of an application of the model. Although the actual simulation model was developed using the SIMAN model framework, this paper will concentrate on the design and logic of the model.

THE GENERAL MODEL

The Single Aisle

As a starting point for the model, a single straight aisle was considered. This permitted development and testing of fundamental program logic to accommodate the model requirements previously discussed.

The first major consideration was how to effectively represent the aisle to enable accurate description of vehicle movement. The design had to allow definition of various vehicle path parameters, such as travel direction, stopping indicators, entering points, and turning designators for subsequent intersection modeling. Also, vehicles physically occupy specific areas of the aisle while en route, which also had to be incorporated.

Since no two vehicles may occupy the same space, there are two logical modeling alternatives. The first is to model the traffic flow as a series of single servers, each with a queue size of zero, and allow blocking. Although this prevents two vehicles from occupying the same space, it does not facilitate easy incorporation of required vehicle passing logic. The second approach to is model the aisle as a series of consecutive resources that an entity must seize to continue moving. This second approach was chosen, allowing easier development of passing logic.

The aisle was divided into a series of segments, each representing a station with an associated resource. The stations are of equal length, dependent upon material handling vehicle length. For example, it fork trucks are 10 feet long, each station must represent at least 10 feet. Thus, when a vehicle has seized that station's resource, it accurately describes the fact that the aisle segment is occupied and it does not allow any other vehicle to concurrently occupy that space. Further, there are stations on each side of the aisle representing the two possible travel directions.

A station numbering scheme was developed, keeping in mind the need to control travel direction. Even numbered stations indicate one aisle travel direction (e.g. south) and odd numbered stations indicate the other travel direction (e.g. north). Then, as vehicles enter the system and their path and direction are determined, travel is controlled by adding either +2 or -2 to the current station number to properly identify the next station.

Prior to advancing, the next required station resource availability is checked. If available, the entity is routed to that station, the resource seized, and the previous resource released. If the subsequent station is occupied by another vehicle and no passing is allowed, the entity is routed to that station's queue and remains in the queue until the resource becomes available, still retaining the previous station's resource.

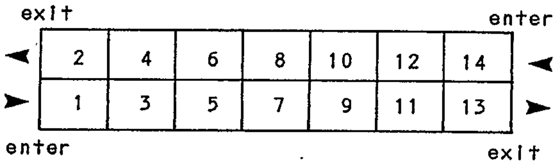

Figure 1: Single Straight Aisle

Figure 1 illustrates the station numbering scheme for a straight aisle. There are 7 stations on each side of the aisle, each representing 10 foot lengths. Odd numbers represent north-bound travel and vehicles entering at station 1 have a positive travel direction indicator, +2, to properly route them from station 1 to 3, to 5, etc., until exit station 13. Even numbers represent south-bound travel and vehicles entering at station 14 have a negative travel indicator, -2, to route them from 14 to 12, to 10, etc., until exiting at station 2.

This numbering proved to be integral for the vehicle passing logic. Although AGV's run on fixed paths without passing capabilities, conventional traffic may pass under proper conditions. There must be no oncoming traffic within a given safe passing distance, the passing destination must be unoccupied, and the vehicle cannot bypass a station where it needs to stop. In addition, the current position must not be situated too close to a system exit point or in a location where passing would be hazardous. To check that these conditions hold, a passing parameter is stipulated representing the number of stations ahead that a driver would consider for safe passing. Taking that number and multiplying by the travel direction indicator (+2 or -2) gives the passing zone boundary for checking.

For example, a fork truck at station 1 is blocked by a stopped vehicle at station 3. Assuming the passing parameter is three stations, the current station number plus the passing parameter times travel direction, 1+(3x(+2)), yields seven (7). Thus, the passing zone is all stations within the bounds of stations 2 and 7, excluding the occupied station 3. By sequentially checking resource availability at each station numbered between 2 and 7, which will include both sides of the aisle, it is determined if passing is allowed. If all resources are available within the passing zone bounds and the vehicle is not required to stop within the zone, it proceeds to passing destination station 7 with appropriate travel delay.

If safe passing cannot be immediately accomplished because one or more of the included stations is occupied, future passing attempts, when the item preventing the pass moves, may be possible. To accommodate future passing attempts, a clone of the blocked vehicle is placed in the queue for the unavailable station resource which is stopping the pass. Thus, that vehicle "resides" in two queues, one for the resource in its immediate path and the other for the pass blocking resource, waiting for the opportunity to move. The blocked vehicle waits for one of two conditions--either the vehicle blocking the path directly in front of it moves and the vehicle proceeds or the vehicle preventing the pass moves allowing another passing attempt. Upon later passing attempts, the same bounding and checking routine as previously described is used.

Once a vehicle may proceed, whether along a straight path or passing the blockage, any duplicate entities are destroyed. If a cloned vehicle exists, a designated attribute contains a specific value unique to the entity pair. The real vehicle and the duplicate entity are distinguished by the duplicate having a negative identifying number. This is necessary to facilitate proper moving logic because only the actual vehicle may proceed while the duplicate must be destroyed, relinquishing all claims on any resources or queue positions.

Although AGV's cannot pass, some checking must also occur when they are blocked. If an AGV is blocked longer than a designated time, an alarm goes off in a control room, indicating that an abnormal stoppage has occurred. In actual operation, the AGV continues to periodically try to move until the blockage is removed and the AGV then continues normally. Based on queue times of blocked AGV's, appropriate statistics are collected concerning where and how long delays occur.

An overriding concern while developing the model was to keep it generic, allowing the greatest flexibility in representing any given system and altering parameters to investigate impacts of various managerial policies. This is accomplished through extensive use of global variables and tabular information set in an experimental frame external to the model file. Centralizing parameter information in this way facilitates easy changing of system conditions as well as eliminates the need to recompile the entire model file for each alteration.

Much of the vehicle travel control information is organized into tables. First, as vehicles enter the system, they are assigned to a path based upon discrete probability functions. Each table look-up value is based on that path number as the independent variable. Table information includes: stopping stations (according to path and vehicle type), associated probability of stopping, and entering station number for path. Figure 2 shows these tables for the single aisle example.

Another table is not based on path but is based on station number and contains station identifier codes indicating allowable actions for an arriving entity to that station. For this straight aisle example, the following codes are used: 0--vehicle may try to pass if at this station, 1--passing not allowed if at this station, 2--this is an exit station and the entity should be sent to collect statistics before exiting the system. The table for this example is in Figure 3.

An entity arriving to the system proceeds as the following example illustrates. The discrete probability function for that vehicle type (AGV or other) is accessed to ascertain a travel path designated by a number, say path 1 entering at station 1. Table values corresponding to the independent variable path number, 1, are accessed--with a given probability, stopping station number may be retrieved and saved as an attribute, and entering station number to be used directly. From the entering station number, the travel direction number is determined (+2 for odd number station and -2 for even number station) and saved as an attribute.

path	entering station	AGV stopping station	prob.	fork stopping station	prob.
1	1	3	0.5	9	0.2
2	14	10	0.7	4	0.1

Figure 2: Vehicle Movement Control Tables

station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
code	0	2	0	1	0	1	0	0	1	0	1	0	2	0

Figure 3: Station Identifier Codes

Let a fork truck enter the system at station one, seizing resource number one, then delayed by the required travel time. After the delay, the travel direction number, +2 is added to the current station to determine where to next route the entity. Assume the resource at station 3 is unavailable because something is unloading in the aisle. Because the entity is a fork truck and checking the table value for actions at station 1 shows a 0 code (safe to pass), it attempts to pass as previously described. Since there is no planned stop within the passing zone (1-7), it looks ahead six sequential station numbers so as to check both sides of the aisle for available resources. The resource for station 4 is taken, thus blocking a pass. A clone of the fork truck is placed in queue 4 for station resource 4 with appropriate negative attribute identifier while the actual entity is placed in queue 3 for station resource 3 with matching positive attribute identifier. If the vehicle had needed to stop within the passing zone, the pass would be disallowed and the entity placed in only the queue for the next station it wishes to occupy.

This vehicle waits in two queues until either the unloading vehicle at station 3 moves and the fork truck may continue or the vehicle at station 4 blocking the pass moves and the fork truck may try to pass again. Assume the station 4 vehicle moves to station 2, allowing a second pass attempt. The same station resource checking process bounded by station numbers 1 and 7 commences only to find that passing is still blocked by the vehicle at station 2. After the clone is removed from queue 4 and destroyed, the fork truck is again placed in two queues, this time for stations 2 and 3, waiting for the same movement conditions. Next, suppose the vehicle at station 2 exits the system allowing another passing attempt. This time the check indicates a legal pass. The fork truck is removed from both queues, 2 and 3 with the clone entity from queue 2 destroyed, seizes the passing destination resource, 7, and is routed to station 7 with appropriate travel time delay.

When it tries to go to station 9, a check which occurs before each attempted movement to see if it needs to stop at the next station indicates that it must stop. The delay time is adjusted upward to reflect the length of a stop. Then, station 9 resource is seized and the entity is delayed. After the stop, the fork truck proceeds to station 11. When +2 is added to that station to give 13, a check of the table containing station codes returns 2 (Figure 3), meaning an exit station. Consequently, the proper statistics will be recorded and the fork truck exits the system.

The Multiple Aisle

Utilizing the basic logic for the single aisle system, the modeling capabilities were expanded for considering more complicated systems. Multiple aisle models are developed by first considering only straight aisles and then overlaying them to form intersections. Figure 4 shows an example of three straight aisle sections combined to form a model with two intersections. The previous station number scheme is retained and all station numbers are unique.

More tables are added to the experimental frame to facilitate paths requiring turning. Figure 5 shows the partial expanded tables for the new example. Again, these tables have path numbers as the independent variables and the length of the tables is dependent on the total number of system paths. One table contains the station numbers for the intersection at which vehicles on that path turn (e.g. path 3, entering at 1 and exiting at 34 has a turning value of 11). The other table gives the station to which the vehicle is routed after pivoting in the intersection (e.g. path 3 turns to station 36).

Each intersection, in addition to the station indices of the aisles passing through, is labeled as a resource in itself, effectively creating multiple identifiers for intersection stations. Four intersection indices correspond to the four directions passing through the intersection (e.g. 11, 12, 37, and 38, see Figure 4) and one number identifies the single intersection resource (e.g. 44). These super indices for intersections must be numbered greater than any previously numbered station.

Codes are added to the table identifying allowable vehicle actions at given stations. Three (3) indicates an intersection resource, while anything greater than three is the intersection resource number (super index) corresponding to stations in an intersection (e.g. 11, 12, 37, and 38 have the number 44 in the table). Figure 6 shows a portion of this expanded table. Also note in Figure 6 stations close to intersections (5, 7, 9, etc.) are coded as 1 (no passing allowed) due to hazards associated with passing in that area.

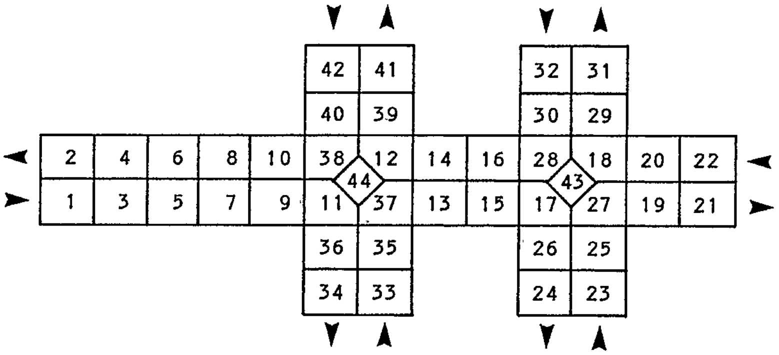

Figure 4: System With Intersections

path	entering station	AGV stopping station	AGV stopping prob.	fork stopping station	fork stopping prob.	intersection pivot	turning destination
1(1-21)	1	3	0.5	9	0.2	0	0
2(22-2)	22	10	0.7	4	0.1	0	0
3(1-34)	1	5	0.1	36	0.4	11	36
4(22-31)	22	0	0.0	20	0.1	18	29
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
9(32-2)	32	16	0.2	0	0.0	28	16

Figure 5: Expanded Vehicle Movement Control Tables

station	1	2	3	4	5	6	7	8	9	10	11	12	.....	36	37	38	39	.....	44
code	0	2	0	1	1	1	1	0	1	0	44	44	.....	1	44	44	1	.....	3

Figure 6: Expanded Station Indetifier Codes

Continuing with the previous example, suppose the fork truck has made its stop at 9 and identifies its next destination as station 11. From the vehicle action table, the corresponding resource number, 44, is retrieved. This resource must be free in order for the the vehicle to proceed. Assuming it is, intersection resource number 44 is seized and the fork truck now enters the intersection. Although resource 11 is never actually seized, the station number 11 is retained as the current station location for all vehicle movement logic. Recognizing that intersections are possible turning points, the attribute containing the pivot station identifier, which was previously accessed from tables upon entering the system, is compared to the current regular station index, 11. Assuming it matches, then the attribute identifying to which station it turns is accessed and set to be the next destination station for travel. Based on station value, i.e. even or odd, the travel direction indicator is reinitialized. After a time delay equal to travel time through the intersection, the fork truck turns to station 36 with the new travel direction indicator, -2. It proceeds to station 34, identified by the table as an exit station, statistics are collected and the fork truck exits the system.

The application for which this model was originally developed (described later in the paper) required modeling portions of a plant with paths containing a maximum of one turning point and one stopping station. However, if an entire system is to be represented, paths with multiple turns and stops may exist. Although this AGV/traditional material handling integration model is general purpose, converting from a system segment model to representing an entire system can easily be accomplished with some minor adjustments.

Multiple turns per path may be incorporated by expanding current tables to include a second turning parameter table or accessing turning information from a separate table listing more detailed path descriptions, similar to a part route designation. Multiple stops per path and per vehicle may be accommodated by expanding existing tables or increasing the attribute array to include more stopping station identifiers.

One possible model limitation that cannot easily be altered is the constant fork truck speed requirement. Though this constant speed is specified in the experimental frame and may change between simulation runs, all fork trucks, system-wide, travel at the same constant speed (i.e. all travel 8 mph or all travel 7 mph). This is necessary to allow proper entity flow and enable correct fork truck passing logic. Even with this limitation, the model is still a good basic analysis tool for identifying potential bottlenecks.

MODEL INPUTS AND OUTPUTS

By modeling system components as described above, maximum flexibility in system representation is achieved. Because the SIMAN modeling language is used, full advantage is taken of the separate SIMAN experimental frame. It is possible to define all system variables and/or parameters in the experimental frame, external from the model.

The TABLES element is used for all the table look-up information described: entering stations, pivot stations, turning destinations, stopping stations, stopping probabilities, turning destinations, and station action codes. Discrete cumulative probability functions define the probability of taking given paths for each vehicle while uniform distributions define stopping time delays. Vehicle interarrival times are entered as parameters.

Global variables are used extensively to define system control parameters. These include: vehicle travel times (time needed to traverse a station length), time AGV may be blocked before alarm sounds, maximum number of vehicles created, and passing distance. The experimental frame gives quick access to these variables enabling great flexibility in adjusting the system and answering the "what if" questions.

Output statistics relative to analyzing congestion include: queue times when progress is blocked, system time per vehicle type, number of vehicles in the system per vehicle type, number of AGV alarms (indicating abnormally long stops), and number of times fork truck passing is blocked. These basic statistics are used to calculate other relevant measures, for example, percentage of time vehicles are blocked (based on queue and system times) and alarm rate (number of alarms per hour). In addition, the SIMAN output file capabilities was used to record exact station locations where bottlenecks occur. These files were then accessed by user written programs for detailed analysis of AGV and fork truck blockage.

Although most adjustments necessary to accurately define any particular system based on the generic model can be done in the experimental frame, a few minor alterations must be made in the model file to tailor it for a specific application. In the model file, the correct station range must be entered and a separate resource number must be designated for AGV off-aisle stopping.

The basic SIMAN model file for the generic model contains 131 block statements. Use of the SIMAN station capability allows this model file to remain the same size regardless of the situation being modeled.

ANALYSIS

To illustrate the generic model's potential, an application is presented. Although a model's size and scope varies according to the specific system represented, basic management concerns transcend many manufacturing environments. Further, important system modeling considerations, such as logic for fork truck passing and vehicle stops, are universal.

This model was developed for a large manufacturing plant that is basically a metal cutting and assembly facility. The existing plant is well established (over 25 years) and the company is now integrating new product line production into the facility. The new operations are highly automated with an AGV material handling system. The AGV system also extends into current production areas where it interfaces with traditional material handling equipment.

Management became quite concerned about what impact integrating traditional and AGV traffic will have upon plant operations. Their prime concern is the busy main plant aisle and whether needed material will get to designated line locations when needed, i.e. will traffic congestion prohibit efficient deliveries to the line. Also, if severe AGV blockage occurs, the number of planned AGV's may be insufficient to meet required demand.

To investigate these concerns, the generic model was used to represent two sections of the main plant aisle, chosen because of high volumes of existing traffic and potentially high AGV/traditional interaction. Portions of the system were modeled rather than the entire system because plant construction prohibited accurate collection of traffic pattern data in other locations. Also, potential vehicle interaction in other areas is expected to be slight. In the modeled areas, data was collected for current fork truck motion, including path frequency and stopping information. Some AGV data was known, such as stopping station locations, while path frequency was based on an analysis of the proposed AGV system layout and anticipated load.

To briefly describe the model scope, a two intersection model constructed contains 108 stations (including intersections) with 33 possible travel paths and represents 500 feet of aisle. It was anticipated that AGV's will spend 20 to 25% of total travel time in this region. Any statistics mentioned for the application system refer to this two intersection model. Statistics are based on runs of 480 minutes (an 8 hour shift) with approximately 500 AGV's and 1000 fork trucks passing through the system during that time.

Prior to discussing the results of analysis, an interpretation of the term "blockage" is in order. An AGV blockage implies that an AGV is forced idle. However, fork truck blockage could actually be due to a driver slowing down and following a slow-moving AGV until passing is possible. Thus, statistics for the percentage of time that fork trucks are blocked should be viewed as lost time due to congestion rather than actual stops. Also, drivers may be able to take steps in practice which avoid some blockages, making these statistical values worst case.

An initial run showed AGV's blocked more than 20% of the time with forks blocked about 30% of the time these vehicles were in the system. More significantly was the length of AGV blockages--96 AGV alarms were recorded or 12 per hour. In this analysis, an alarm was triggered if an AGV was blocked for more than 30 consecutive seconds. Since time before an alarm is sounded is set by management to reflect what they consider an abnormally long stop, serious problems are indicated.

Auxiliary programs were then utilized with the SIMAN output files to analyze and isolate where major bottlenecks occurred. The majority of blockage was at fork truck stopping stations since forks currently unload or load on-aisle occupying the AGV wire path. Subsequent runs were made selectively removing stopping stations reflecting a possible managerial decision to have off-aisle fork truck stops, just as AGV stops are off-aisle.

Each time a particular fork truck stop was removed, a better understanding of key blockage points was gained. If removing a stop made no impact on congestion when compared to the original run, the stop was replaced and another removed. Through sequential eliminations, stops along the aisle area between the two intersections were determined to be prime problems. When these were eliminated, AGV blockage reduced to less than one/half percent with only one alarm and fork trucks were blocked only 11% of the time.

Another alternative to removing on-aisle vehicle stops is reconfiguring traffic patterns. Either AGV wire could be laid differently or forks might be rerouted. In this investigation, one portion of AGV track was expanded from one-way to two-way traffic, allowing some travel to be rerouted off the crowded main aisle. With original system conditions in tact (i.e. all fork truck stops on-aisle), there was favorable impact on AGV blockage, almost halving the number of alarms from the original run. However, fork blockage was not significantly impacted, suggesting more analysis should be conducted if management is considering AGV rerouting.

Some additional runs were conducted varying fork truck speed and varying fork truck traffic density. Although these factors did not greatly impact this particular system, they may be important factors to consider in other environments.

Actually, any system parameter initialized in the experimental frame may be altered to investigate potential impact. For example, the number of AGV's may be adjusted, which could be extremely useful in initial analysis of proposed systems to more effectively evaluate actual need. The length of time before an AGV alarm sounds may be changed to reflect different management policy. Altering the passing parameter, reflects how cautious the drivers may be (assuming looking ahead more stations shows more caution) and how that affects system performance. Traffic density may be increased to investigate increased production placing greater demand on material handling resources.

By intelligently using output statistics and altering system parameters, many variables may be investigated and evaluated, even before any capital is spent, to determine the most effective system and allow more frugal expenditure.

CONCLUDING REMARKS

As companies rapidly move to upgrade existing facilities, many examples of integrating old and new technologies exist. One example examined in this paper is integrating an automatic guided vehicle (AGV) system with traditional material handling systems. Since AGV's are confined to specific paths and travel at much slower rates than traditional material handling equipment, they do not merely add to current traffic. Rather, they complicate material handling strategies and associated logic. Analysis of an integrated system requires complex logic making simulation a primary analysis tool.

This paper presented the logic for a general purpose simulation model representing an AGV/traditional material handling integrated system. Any series of straight aisles and intersections may be constructed through slight changes in the general model. To facilitate easy access to system parameters for evaluating management "what if" questions, all major system parameters were assigned within an experimental frame separate from the model file, exploiting the characteristics of the SIMAN simulation language used for this model. Placing parameters in the experimental frame allows quick system changes accomplished without recompiling the entire model file.

An industrial application serves as an example of the model flexibility and illustrates statistical analysis techniques, specifically the parameter affect upon system performance. By utilizing a well-thought simulation model design, such as the one presented here, effective system evaluations can be made before, during, and after an integrated system is implemented.

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