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SIMULATION MODELLING AS A TOOL FOR PERFORMING AVAILABILITY AND SENSITIVITY ANALYSIS

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ABSTRACT

Simulation modelling is a general purpose tool that may be used to provide decision support in a number of application areas. It may be used to analyze, design or "optimize" manufacturing, materials handling, management, commercial and a wide variety of other systems.

This paper will report on the design of a prototype decision support tool, based on a simulation model of a vehicle fleet availability problem. The primary purpose of the model is to serve as a tool for the evaluation of the availability of equipment under different conditions and to perform sensitivity analysis.

OPSOMMING

Simulasiemodellering is 'n algemeendoelige tegniek wat gebruik kan word vir die verskaffing van besluitsteun in 'n aantal toepassingsgebiede. Dit mag gebruik word vir die analise, ontwerp of "optimisering" van vervaardiging-, materiaalhantering-, bestuur-, kommersiële en 'n wye verskeidenheid ander stelsels.

Hierdie referaat doen verslag oor die ontwikkeling van 'n prototipe besluitnemingshulpmiddel wat gebaseer is op 'n simulasiemodel van 'n voertuigvloot beskikbaarheidsprobleem. Die hoofdoelwit van die model is om te dien as 'n hulpmiddel by die evaluasie van die beskikbaarheid van toerusting onder verskillende omstandighede asook vir die uitvoer van sensitiwiteitsanalise.

1. INTRODUCTION

1.1 The need for simulation modelling [4,5]

A real system, such as a vehicle fleet, is complex and consists of a large number of "cause and effect" relationships and interactions among the different components of the system. The complexity of the system is further increased by the fact that the system usually contains significant random components. Designing, managing or operating such a system is a difficult task which could benefit from some kind of systems analysis and decision support tool. Such a tool should provide the capability to analyze the system as a whole, accounting for all the important relationships and dynamic interactions at all times. At the same time it should also be capable of incorporating the effect of inherent system randomness on system behaviour. It should be capable of evaluating the effect of a change in the values of controllable system parameters (for example usage rates and service delays) on measures of system effectiveness (for example vehicle availability). It should be possible to use the tool for the analysis of both new systems as well as proposed changes to existing systems. All the important components, interactions and characteristics of the system should be accounted for, but the complexity of the tool, from a user's point of view, should be limited in order to enhance the ease with which the tool may be applied. A computerized simulation model is one of the only approaches which will satisfy all or most of these requirements.

1.2 Definition of simulation modelling [2,4]

Simulation modelling is the establishment of a mathematically-logical representation of a system which may be exercised in an experimental fashion on a digital computer. A simulation model is therefore a computerized reproduction, replication or imitation, to a reasonably high degree of reality, of the behaviour of a real system.

Executing an experiment with a well designed and valid simulation model may be regarded as the "next best thing to observing the real system in operation". Therefore, a simulation model may be seen as a "laboratory" version of the real system.

1.3 Typical applications of simulation models [5]

Since a simulation model consists of a replication of the real system it may be used to answer a variety of questions regarding the behaviour of the system under different conditions. For example, a simulation model of a vehicle fleet may be used to evaluate the effect, on vehicle availability, of changing the vehicle service schedule. Similarly, it may be used to determine the approximate number of vehicles necessary to maintain a specified trip rate over a period of time, given that the minimum number of vehicles available should not fall below a certain level.

In general, simulation models may be used to evaluate and select amongst different system configuration alternatives as well as alternative, or proposed, operation and management strategies. The selection process should be based on some measure of system effectiveness or performance and in this respect a simulation model should be regarded as a system evaluation tool. Therefore, a simulation model may also be used to evaluate the sensitivity of system effectiveness for any of the controllable system parameters. In this way it may help to focus attention on the most important parts or aspects of the system.

1.4 Advantages and benefits of the simulation modelling approach [4]

Probably the most significant advantage of simulation modelling is the ability to predict the expected future behaviour of a system given a specified set of circumstances. The past behaviour of the system may be obtained from historical records, but the accurate extrapolation of this information into the future may only be obtained with relative ease by using a simulation model. Experimenting with a simulation model is without a doubt less expensive and less dangerous than experimenting with the real system. Furthermore, certain experiments with the real system may be impossible in practical terms and even if this is not the case, may provide misleading results caused by the uncontrollable variability present in the real system environment.

1.5 Disadvantages of the simulation modelling approach [1,2,4,5]

It should be realized that any simulation model will always contain some assumptions and simplifications and could never be considered as an absolutely correct replica of the real system. However, if the most important characteristics of the real system have been captured in sufficient detail the model will provide valid, acceptable and useful results.

Executing a simulation experiment may be time-consuming and is similar to performing a sampling experiment. The results obtained from such a simulation experiment are only estimates and subject to all the usual statistical complications inherent in all sampling activities. The availability of relatively powerful computing equipment and proper attention to the design of the simulation experiments, as well as the analysis of the results, should alleviate the consequences of these problems to an acceptable extent.

As is the case with all computer software, the output from a simulation model can be only as good as the input indicating a need for relatively accurate input data.

2. OVERVIEW OF A SIMULATION MODEL OF A TYPICAL VEHICLE FLEET

2.1 Scope and components of the model

The model includes most of the important activities taking place at a typical fleet despatch area and garage including trips, inspections and repair, defect occurrences, resource utilization and the performance of scheduled services. Therefore, the activities taking place in the despatch area and in the fleet garage are modelled to a high degree of detail. The effect of the environment, for example, the generation of trips and the performance of scheduled services at service facilities, is taken into account but not modelled in detail.

The movement of each vehicle through the system is modelled as a function of the state of each vehicle (for example availability and accumulated operating hours), the state of the system (for example resource availability) and system parameters (for example service delays and trips requested). Scheduled services, based on operating hours or calendar based scheduled services, performed outside the fleet environment, are monitored and modelled as delays during which the specific vehicle is not available for normal fleet duties.

2.2 Modelling strategy

The following guidelines were used in formulating a model development strategy :

i) For demonstration and communication purposes the model should support a dynamic screen animation facility. However, the animation facility should in no way be seen as a way of obtaining results or be used to reach any conclusions.

ii) The model should be a general purpose model of a vehicle fleet and its application should not be limited to any specific type of vehicle.

iii) The model should include all the important components and interactions relevant to the operation of a typical fleet under normal operating conditions.

iv) The model should be designed to serve as both a free standing decision-support tool and as a building block of a more comprehensive simulation model.

v) An attempt should be made to keep the detail at a minimum level compatible with reasonable validity for the specified decision making purposes as well as an acceptable level of ease of use from an inexperienced user's point of view.

vi) The model should be parameter driven as far as possible through the availability of a comprehensive user interface.

vii) The model and the user interface should provide all the necessary facilities for sensitivity analysis.

2.3 Overview of the software structure of the model

The structure of the simulation model, from a software point of view, consists primarily of the following modules :

i) The model logic module responsible for defining the model entities and components and controlling the flow of entities according to the specified relationships. This module was designed and coded by using a general purpose simulation language.

ii) The input data processing module responsible for handling input data provided by the user, performing any pre-processing that may be necessary and transferring the data to the model.

iii) The output data processing module responsible for handling all the results obtained from executing the model as well as any post-processing which may be necessary.

iv) The user interface module which is responsible for all interaction and communication with the user.

2.4 Universal applicability of the model

The model is driven by a set of input parameters, the values of which may be set or changed through a user interface. By changing the values of these parameters the characteristics of the model, and therefore the characteristics of the system being modelled, are changed accordingly. In this way experiments may be conducted whereby the effect of such changes in system parameter values on system effectiveness may be determined. For example, the effect of doubling the trip rate on the mean vehicle availability may be analyzed. Furthermore, changing certain input parameter values effectively changes the model structure. The user may, for example, specify the number of a specific type of scheduled services to be included in the model.

The applicability of the fleet model is therefore not restricted to a specific vehicle type or set of circumstances.

2.5 Validity of the model

A simulation model is an abstraction and simplification of the real system and will always be such. However, if all the important system components have been included in the model and if the interactions have been modelled at an appropriate level of detail the simulation model may still provide valid results for decision making purposes. However, it is still necessary to verify and to prove the validity of the model.

Model verification implies determining whether the model actually does what the model builder intended when the model was designed. Verification of the model was performed by checking and rechecking the model logic and programming code many times through the intensive use of the available tracing and debugging facilities.

Validation implies to determine whether the model, in terms of the output provided, is a valid representation of the real world system for the specified decision-making purpose. By using actual historical data from real vehicle fleets it was possible to prove the validity of the model with respect to mean vehicle availability and cumulative operating hours over a specified period of simulated time.

3. THE PURPOSE OF THE MODEL

The model was developed with several specific purposes in mind. However, the nature of simulation models is such that the possibility at least exists of using the model for other unforeseen purposes. This may, however, require additions or changes to the model structure. The following purposes have been included implicitly in the model development :

3.1 Sensitivity analysis

A simulation model is an ideal tool for performing sensitivity analysis. Sensitivity analysis is required to identify those sub-systems which have the most significant effect on system performance as measured, for example, by the mean vehicle availability. In this way it may be easier to focus attention on those sub-systems where additional effort, from a management and operation point of view, may provide worthwhile results.

3.2 Evaluation of the effect of change

The model is capable of evaluating the effect of changes in, for example, service schedules, resource levels and trip rates on measures of system performance such as vehicle availability, operating hours, minimum vehicles available and the utilization of resources.

3.3 Ad hoc decision making

It should be possible to use the model for purposes of ad hoc requests for decision support. It may, for example, be possible to use the model for evaluating the consequences of a specific short term proposed operation. This may, however, necessitate changes or adaptations to the model structure depending on the nature of the specific request.

3.4 Building block

The model was designed to serve as a building block, and may therefore be used as part of a comprehensive model. Such a comprehensive model may include several fleets and spare parts management. In this way an integrated model may be assembled with the fleet model as one of the building blocks.

4. THE STRUCTURE OF THE MODEL

The simulation model was developed using a general purpose simulation language. To make the model accessible to a wider potential user population a comprehensive user interface was developed. At present the model may be executed by using a typical microcomputer.

The available user interface is responsible for soliciting the values of all input parameters from the user, executing the required simulation experiments, post-processing the simulation results and presenting of all model outputs. The user interface should therefore be used to name, read, update and write all input and output data files, to plan and control the execution of the simulation experiment(s) and to obtain any output which may be available and required.

Through the user interface it is possible to execute a simulation experiment for a given, or user specified, set of input parameters and obtain a set of results. This mode is primarily intended for evaluating the effect of a specific proposed change in the operation or management of the system. For purposes of sensitivity analysis, a number of carefully chosen experiments could be executed and the results of these experiments subjected to further analysis. The user interface provides the necessary capabilities to plan, specify and execute the appropriate experiments, to execute the experiments, to perform the required analysis and obtain the available results.

4.1 Model input

For the sake of convenience the input parameters may be classified as follows :

i) System parameters (for example simulation run length and operating hours per day).

ii) Resource parameters (for example number of vehicles and number of despatch area crews available).

iii) Beginning of day delay time parameters (for example the minimum, expected and maximum values of the time needed to perform a preparation inspection on a vehicle).

iv) End of day delay time parameters (for example the minimum, expected and maximum values of the time needed to perform an end of day inspection on a vehicle).

v) Transport delay time parameters (for example the minimum, expected and maximum values of the time needed to transport a vehicle from the fleet despatch area to a service unit).

vi) Despatch area defect probability parameters (for example the probability for a defect to be noticed during an end of day inspection).

vii) Fleet service time parameters (for example the minimum, expected and maximum time needed to perform a defect repair or scheduled service at the fleet garage).

viii) Service unit time parameters (for example the frequency, as well as the minimum, expected and maximum time needed to perform a calendar based service at a specified service unit).

ix) Trip parameters (for example the mean trip rate and minimum, expected and maximum trip duration).

x) Scheduled trip start time parameters, specifying the distribution of typical trip start times.

Despatch area times

Prompt	Min.	Mode	Max.
Start of day inspection time :	0.750	« 1.250	2.000
Trip preparation time :	0.750	0.750	0.750
Between trip inspection time :	0.200	0.250	0.330
End of day inspection time :	0.167	0.250	0.500
Diagnose time :	0.083	0.133	0.167
Despatch area repair time :	0.333	0.605	1.500
Despatch time :	0.083	0.083	0.083
Transport time (Desp-Garage) :	0.167	0.333	0.500
Transport time (Desp-Serv.U) :	2.500	3.000	3.500

Press END or ESC to quit the input screen

Figure 1 A typical model input screen[1]

xi) Vehicle status parameters, specifying the starting state of each vehicle in terms of the remaining life to each specified scheduled service.

xii) Experimental design parameters, specifying the design matrix, perturbation factor and grouping of effects to be used for sensitivity analysis.

Figure 1 shows one of the typical model input screens, accessible through the user interface.

4.2 Model output

Since the model is to some extent an imitation of the real system a variety of outputs may be obtained depending on the user's decision support requirements. In the present model explicit provision has been made for obtaining the following outputs :

i) A summary of the values of the most important input parameters.

ii) The mean, maximum and minimum values of vehicle availability, monthly operating hours and resource utilizations calculated over the simulated time period.

iii) A graphical display of the simulated time history of, for example, vehicle availability.

1 All numbers and results are totally fictituous.

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Trips

Description	Average	Std.Dev	Minimum	Maximum	Plt
Trips Delayed	626.943	282.249	101.812	1192.588	N«

Description	Total	Mean/Day	Plt
Trips Executed	6683.000	8.911	N
Trips Requested	7768.401	10.358	N
Cumulative Operating Hrs	6676.550	8.902	N

ESC to exit, F1 to print, F2 to plot, F3 to save

Figure 2 A typical model output screen

iv) A graphical display of the sensitivity of vehicle availability and cumulative operating hours for the user specified input parameters or group of parameters.

Figure 2 shows one of the typical model output screens and figure 3 one of the available graphic output screens.

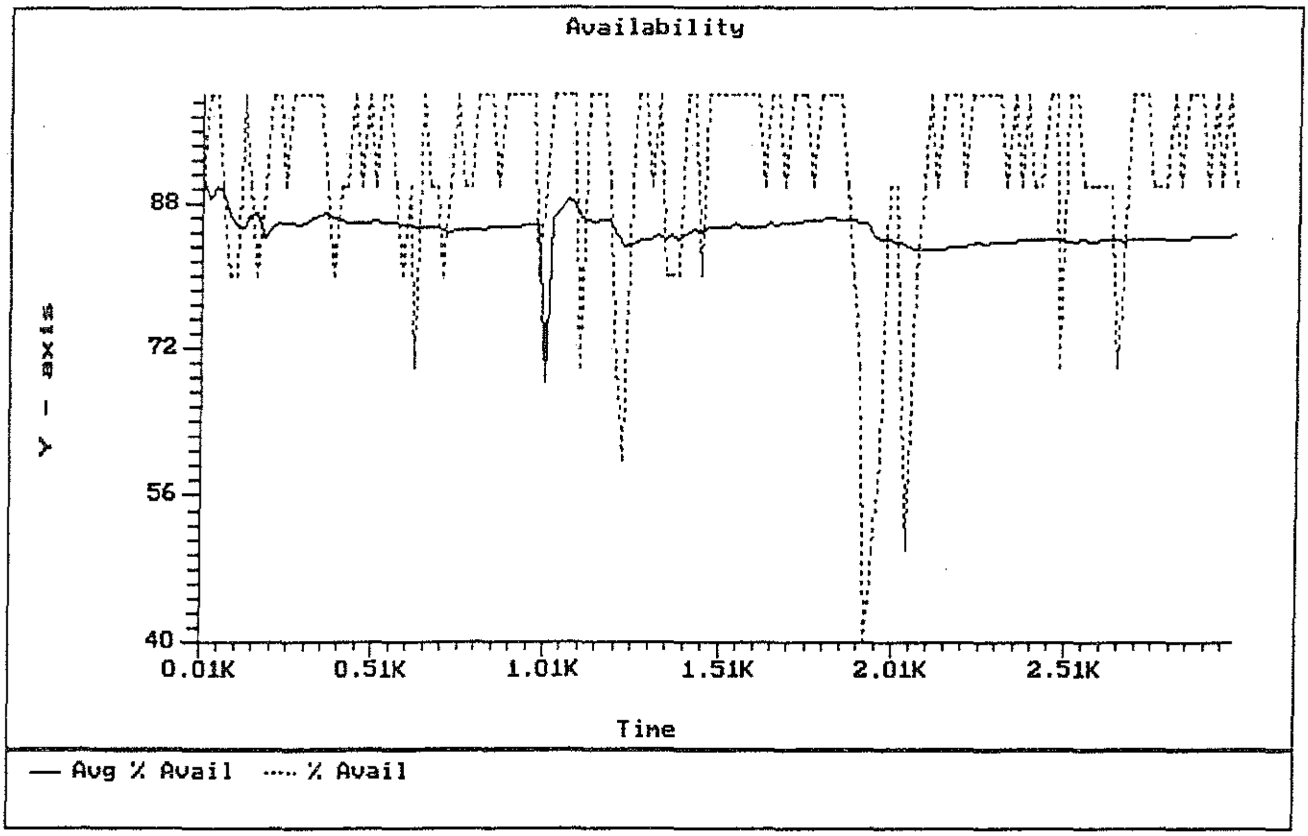

Figure 3 A typical graphic output screen

4.3 Animation facility

For demonstration and communication purposes a dynamic screen animation facility was developed. The animation is based on the same, but slightly simplified model and a typical animation screen is shown in figure 4. Execution of the animation requires somewhat specialized computer hardware and software.

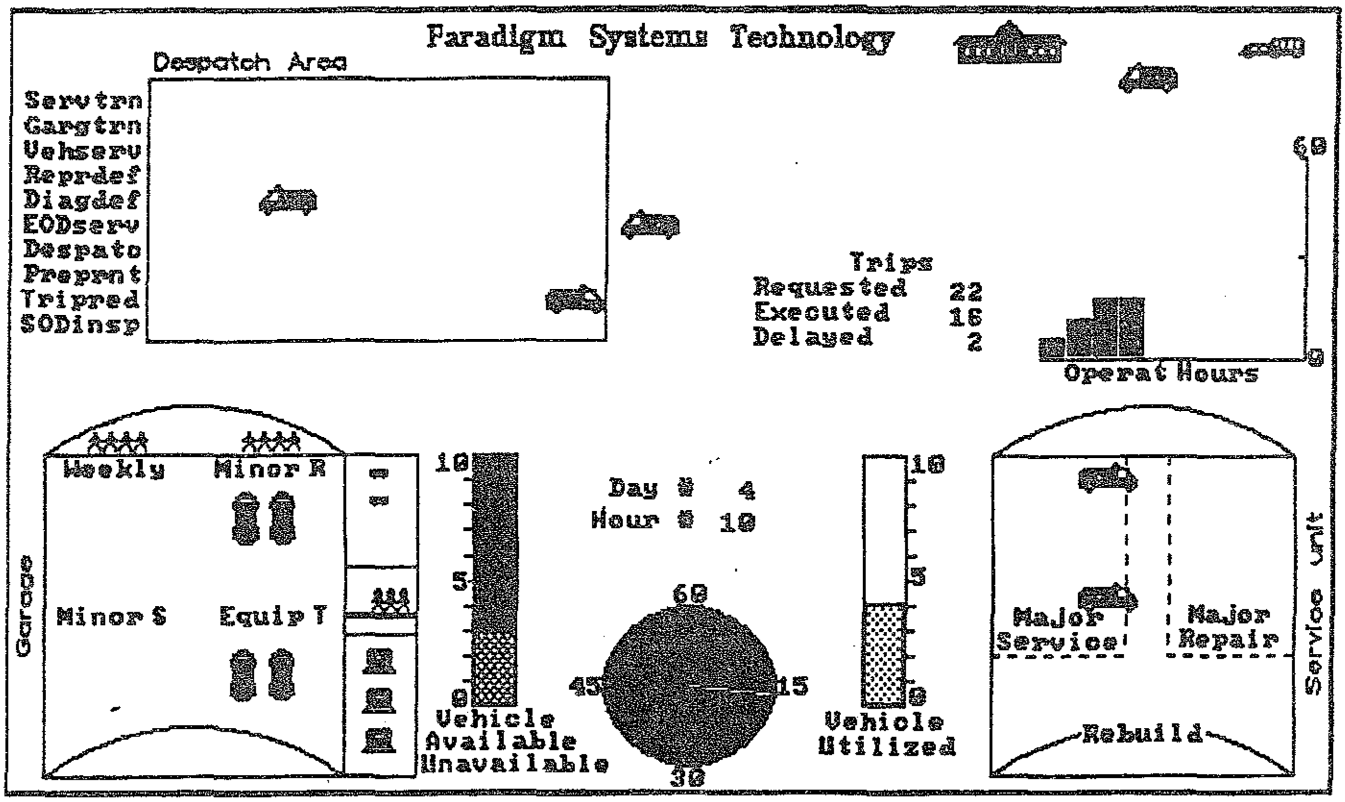

Figure 4 Animation screen

5. EXAMPLES OF TYPICAL APPLICATIONS OF THE MODEL

5.1 Sensitivity analysis

Values, applicable to a typical fleet, for the following input parameters were obtained or estimated :

i) System parameters

Simulation run length

Operating hours per day

Service hours per day

ii) Resource parameters

Number of vehicles allocated to the fleet

Number of despatch area crews available

Number of garage technical crews available

Number of operating crews available

Number of transporters available

iii) Despatch area delay time parameters

Beginning of day inspection time (minimum, mode and maximum)

Preparation time (minimum, mode and maximum)

End of day inspection time (minimum, mode and maximum)

Between trip inspection time (minimum, mode and maximum)

Despatch area defect diagnose time (minimum, mode and maximum)

Despatch area defect repair time (minimum, mode and maximum)

Despatch time (minimum, mode and maximum)

Transport time between garage and despatch area, as well as between despatch area and service units (minimum, mode and maximum)

iv) Despatch area defect probabilities

Defect probability during a beginning of day inspection

Defect probability during a trip preparation

Defect probability during an end of day inspection

Defect probability during a between trip inspection

Probability for various categories of vehicle damage.

v) Fleet garage and service unit time parameters

The applicable service schedule in terms of type (calendar or operating hours), the frequency of each type of service and the service times (minimum, mode and maximum).

vi) Trip parameters

Trip rate (mean)

Trip duration (minimum, mode and maximum)

Typical trip beginning times

vii) Vehicle status parameters

The remaining life of each vehicle with respect to each service at the beginning of the simulation run

viii) Experimental design parameters

The number of experiments

The perturbation factor

The grouping of input parameters

For purposes of sensitivity analysis, the prescribed experimental design (32 experiments) was executed with a perturbation factor of 50 percent. The input parameters were grouped into six groups or factors as follows:

i) All time delays pertaining to despatch area activities (x_1),

ii) all parameters pertaining to defect probabilities (x_2),

iii) all time delays pertaining to calendar services (x_3),

iv) all time delays pertaining to operating hour services (x_4),

v) all parameters pertaining to trip execution (x_5), and

vi) the repair times (x_6).

The results of the sensitivity analysis with respect to availability is summarized in figure 5.

From figure 5 it is, inter alia, clear that the vehicle availability is very sensitive to the delays attributable to calendar services and defect probabilities. Vehicle availability is not very sensitive to the delays experienced on the despatch area. However, if the length of service delays is primarily controlled by the availability of spare parts this particular result might be misleading since the availability or non-availability of spare parts is not included in the present model.

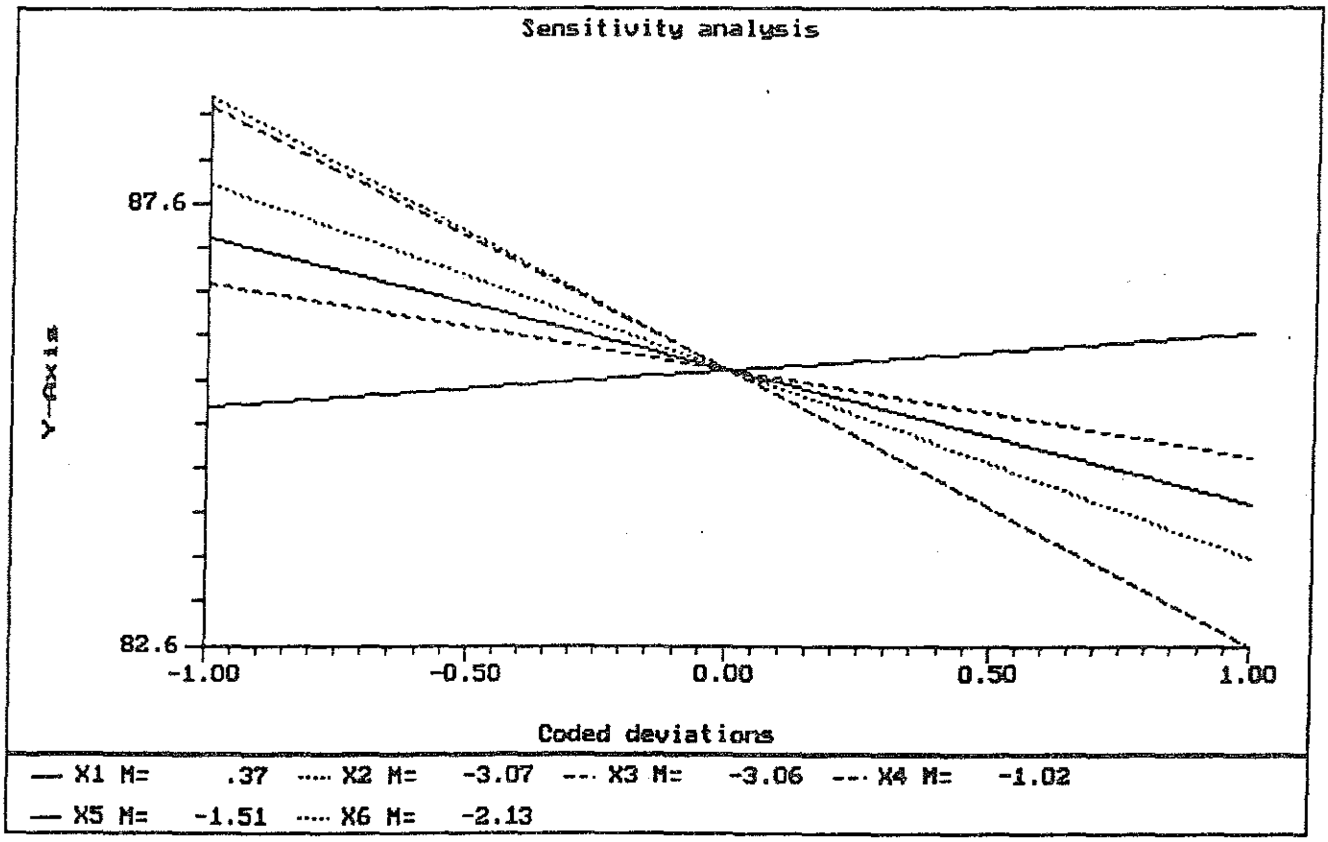

Figure 5 Availability sensitivity analyses

5.2 Estimating the effect of changes in operating policies

One can consider the same typical fleet with the same values for the input parameters. The effect of a proposed change in the service schedule needs to be evaluated. The proposed change may consist of removing some of the services, based on operating hours, from the service schedule altogether. The results obtained from performing the necessary two simulation experiments indicated that the mean availability increased by one percentage point if the service schedule is changed as proposed. This increase may not necessarily be significant.

Similarly, an estimate is needed of the mean availability attainable if all services are performed in the budgeted or ideal times. The results of performing an appropriate experiment with the model indicate that a significantly higher availability may be attainable under these circumstances.

6. CONCLUSIONS

Since a vehicle fleet is only one of the sub-systems of such an organization, the simulation approach may and should be expanded to include other important sub-systems. As already mentioned, the fleet model may be seen as a building block and therefore a part of a larger and more comprehensive simulation model or set of simulation models.

Simulation models invariably require realistic input data which may require significant effort to obtain. A large percentage of the required historical data may be available as part of existing or future management systems. Integrating the simulation model(s) with the management system, in such a way as to enable the direct transfer of the appropriate data to the simulation model, may be beneficial to the usefulness of the model. During future development the viability of this approach will be investigated.

At present a variety of computer hardware and software tools are available for the development of comprehensive simulation models of complex systems. Furthermore, it should be possible to develop valid and useful models, using these tools and following a sound modelling philosophy, without placing unreasonable demands on resources such as the available man-hours.

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