SPECIAL REPORT

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PERS 288

COMPUTER PROGRAMME SPECIFICATIONS FOR THE STUDY OF DRIVER FATIGUE

NATIONAL INSTITUTE FOR PERSONNEL RESEARCH
COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

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Johannesburg, Republic of South Africa, June 1979.

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SUMMARY

This report deals with the computer programme requirements for the study of driver fatigue (Project Number 9015,4). An outline of the driving simulator, driving task and the controlling computer is given, and the storage requirements for analogue and digital data are calculated. The functions of the digital and analogue imputs and outputs are described, and the individual computer operations controlling these are stated in detail.

OPSOMMING

Hierdie verslag handel oor rekenaarprogrambenodigdhede vir 'n ondersoek na bestuursvermoeidheid (Projek nr 9015,4). 'n Oorsig van die nabootser, bestuurstaak en die beherende rekenaar word gegee, en die bewaringsbenodigdhede vir gelykvormige en digitale data word bereken. Die funksies van digitale en gelykvormige toe- en afvoere word beskryf, en die afsonderlike rekenaarprosesse wat dit beheer word breedvoerig vermeld.

CONTENTS

LIST OF TABLES AND FIGURES

1. AN OVERVIEW OF THE SIMULATOR AND THE DRIVING TASK

The driving simulator to be used to investigate the effects of fatigue on long distance drivers is basically the same as the Dynamic Visual Field Generator illustrated in Figure 1. This machine has been validated by Denton (1973, 1975) as a rectilinear velocity generator substituting for real vehicle motion. Vehicle velocity is controlled by a foot throttle and brake (with appropriate lags), while steering is accomplished by coupling the steering wheel to a servo-controlled steering mirror which also responds to a steering demand generated by the computer (not shown in the figure). Realistic vehicle noise and engine vibration have been added as these may be important in the generation of driver fatigue. For the sake of simplicity gears will not be used and an automatic transmission is thus assumed.

In addition to the moving road surface generated by the road surface projector, the subject is required to respond appropriately to road signs and symbolic risk signs which are projected on to a screen at the far end of the table by two slide projectors located above the cab. The visual effects of approaching and passing road signs have, for technical reasons, been simulated by varying the brightness of the image rather than by zooming. The subject is also required to respond to small lights situated under the road surface by pressing a switch located near the steering wheel. The lights flash randomly with an average rate determined by vehicle speed and by the computer.

As driver fatigue is probably as much a function of environmental complexity as it is a function of time spent at the wheel, provision has been made for the simulation of this factor. In the urban or high stimulus density areas road signs occur more frequently and are of the

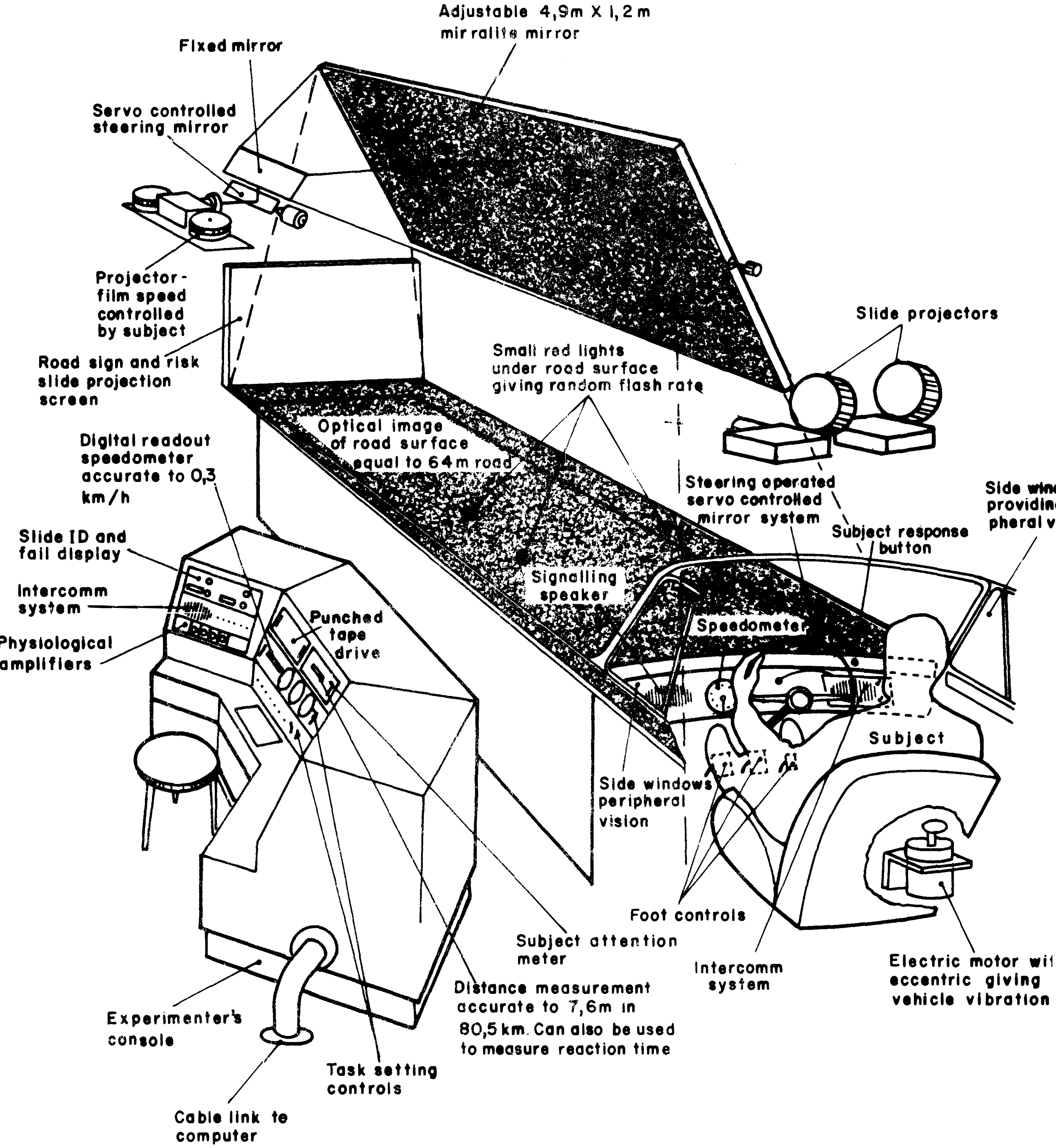

FIGURE 1 ADAPTED DYNAMIC VISUAL FIELD GENERATOR

type generally found within an urban environment. The random light flash rate is increased, and the probability of risk or emergency stimuli is also higher. In the rural or low stimulus density areas road signs occur at longer intervals and are appropriate to a rural environment. The random light flash rate and the probability of emergency stimuli occurring are reduced.

If a driver violation is detected by the computer (e.g. ignoring a stop sign or excessive speeding), feedback will be provided on a probabilistic basis to inform the driver of his error. Feedback could be in the form of a risk situation (indicated by slides) or a police siren, and the subject will accumulate penalty points according to the nature and magnitude of the violation. The subject will also be awarded points for good driving behaviour, and his nett score at the end of the journey will determine the remuneration he receives. This system of feedback is necessary to provide for the modulators of motivation which are normally encountered in the real driving situation.

Apart from objective driving performance, several physiological parameters will be monitored to provide indices of arousal level and psychophysiological fatigue. These include heart rate, skin conductance level, neck muscle tension and breathing rate.

Since drivers are normally required to be on the road for long periods, the duration of the experiment will be at lease eight hours. For this reason the physiological amplifiers will make use of special low drift operational amplifiers, and in the case of the measurement of skin conductance level, an AC system will be used to minimize electrode polarization effects. The servo amplifiers driving the road surface and steering systems also have low drift characteristics.

2. THE COMPUTER AND PERIPHERAL DEVICES

The following hardware is available for programme development and simulator control:-

(1) Interdata 7/16 minicomputer with 48 k Byte memory, display panel, autoload, power fail restart and clock module,
(2) Two flexible disk drive units each controlling a single diskette of 256 k Byte capacity,
(3) One Wangco Mod 7, 7 inch, 9 track, ANSI compatible , 800 Bpi, NZRI, tape deck (total storage capacity of one reel of tape: 5,76 M Byte),
(4) Sixteen channels digital input,
(5) Sixteen channels analogue input; 10 - bit resolution at 33 k Hz,
(6) Sixteen channels digital output,
(7) Universal Logical Interface for user designed peripherals,
(8) Two 8 - bit digital to analogue converters suitable for connection to the ULI board,
(9) One ASR 33 Teletype,
(10) One Regent 100 Video Display Unit.

The supporting software includes OS/16 MT2, TET 16, BAS16S, COPY, EDIT, CAL16D, BASIC level II, extended FORTRAN IV.

3. COMPUTER INPUT AND OUTPUT CONTROL - AN OVERVIEW

3.1 INTRODUCTION

The computer will be required to transfer both analogue and digital (discrete event) data from the simulator hardware on to magnetic tape and in addition is required to output analogue and digital information to the simulator. Transfer of data is thus the primary operation the computer must perform. Secondary operations involve the regulation of interactions between the subject and his environment (e.g. the operation of the police siren when a driver error is detected), the handling of hardware malfunctions, and the control of scheduled or unscheduled rest periods.

3.2 INTERFACING REQUIREMENTS - AN OVERVIEW

The following analogue inputs require conversion to digital form and transferral to magnetic tape (note that some are to be used in the pilot study only):

(1) Skin conductance level,
(2) electromyogram (muscle tension),
(3) heart rate,
(4) breathing rate,
(5) vehicle speed
(6) steering error
(7) steering wheel angle

The following analogue signals must be outputted to the simulator:

(1) steering demand to the steering servomotor,
(2) road gradient to the road surface projector.

The following digital information is to be monitored and/or stored on magnetic tape :

(1) distance pulses from road surface projector,
(2) light pulses from Random Light Generator (RLG),
(3) response switch in vehicle cab,
(4) slide identity number from two projectors,
(5) brake on/off switch in cab,
(6) projector reset switch,
(7) START and STOP switches on operator's console,
(8) outputs (two) from lamp fader.

The following digital information must be outputted by the computer :

(1) slide change command to two projectors,
(2) lamp fader controls (three lines),

(3) high density/low density indication to RLG (two lines),

(4) slide change malfunction indication to either of two displays on on the console,

(5) strobe pulses to two slide ID displays on console,

(6) pen recorder on/off command,

(7) police siren on/off command,

(8) rest/end-of-journey light on console.

3.3 INPUT/OUTPUT PRIORITIES AND CONTROL

All analogue input and output signals are to be monitored "continuously" at fixed sampling rates and thus receive highest priority. As sampling rates are low (highest sampling rate 20 Hz) all other input/output operations must take place within the inter-sample period. Transfer of analogue data into memory and magnetic tape is paused only if the computer detects a slide change malfunction (Section 5.5) or if a scheduled or unscheduled stop occurs (Section 5.7).

The steering demand output is "continuous" and is not influenced by a slide change malfunction. This is also the case for the road gradient output. However, as both these outputs are functions of vehicle velocity, this variable must still be monitored after a slide change malfunction has occurred.

All digital inputs and outputs are cued ultimately by distance pulses, and it thus follows that discrete events are neither initiated nor recorded when the vehicle is stationary. The only exception to this occures in the case of the road sign projector where in some instances the change of slide is activated by a timing pulse determined by the computer clock (see Section 5.3.2 for details).

The slide change command pulse routed to the risk slide projector is cued by distance pulses and by driver behaviour, and the latter variable also determines the operation of the police siren. Section 5.11 describes these operations in greater detail.

3.4 THE FUNCTIONS OF DIGITAL INPUTS

3.4.1 DISTANCE PULSES

Distance pulses are emitted by the road surface projector approximately every 15 metres and are used to cue operations that are required to occur at pre-determined points along the driver's route. The primary (i.e. most frequently occurring) operation initiated by distance pulses is the slide change command pulse to the road sign projector. Secondary operations include the slide change command pulse to the risk slide projector, the high/low density indicator command pulses to the RLG, the lamp fader controls, the pen recorder on/off command pulses, and the rest/end-of-journey command pulse to the light on the operator's console. Section 5.1 describes the use of distance pulses in greater detail.

3.4.2 RANDOM LIGHT PULSES

Arranged about the subject are 14 small red lights located just under the translucent road surface. These are randomly switched by the Random Light Generator (RLG). The lights are arranged into four fields ; one requiring predominantly foveal and parafoveal vision for detection of the lights, two requiring peripheral vision, and one requiring a scan of the rear-view mirror. Details of the computer operations are given in Section 5.2.

3.4.3 RESPONSE SWITCH ~~IN~~ VEHICLE

This switch is closed by the subject whenever he detects a random light. The computer measures the reaction time of this response relative to the occurrance of the light. If the subject does not respond within 1,3* seconds (provisionally) he is considered to have missed the light. If three successive lights are missed, the subject earns a penalty point and a risk slide may be presented. Computer operations are described in detail in Section 5.2.

3.4.4 SLIDE IDENTITY NUMBER FROM TWO PROJECTORS

Each slide is coded in binary notation by means of holes punched in the slide holder, and this code can be read when the slide is in the projector gate. As each successive slide is presented, its identity number is read by the computer which checks the ID against a number in memory. A slide change malfunction or lamp fail is detected by an incorrect or disallowed ID, and appropriate action is then taken by the computer. Section 5.5 discribes the relevant operations in detail.

3.4.5 BRAKE ON/OFF SWITCH

The vehicle brake-light mechanism is used to detect the application of brakes. Two input lines are used : a pulse on one line will indicate a "brake-on" response, and the other line indicates a "brake-off" response. A single location in memory will indicate the state of the brake lever at any moment in time, and this location is interrogated by the computer whenever it requires to know whether the brakes are on or off. Section 5.6 describes this in greater detail.

3.4.6 PROJECTOR RESET SWITCH

Whenever the slide change mechanism or projector lamp fails, data acquisition by the computer is paused until such time as the operator rectifies the fault. The operator then instructs the computer to resume data transfers by pushing the "projector reset"switch. This is described at length in Section 5.5.

3.4.7 START AND STOP SWITCHES ON OPERATOR'S CONSOLE

These two switches, which control the power supply to the road surface projector, will also be used to start or pause all data transfer operations so that magnetic tape can be saved in the event of a scheduled or unscheduled stop. Section 5.7 describes this in greater detail.

3.4.8 OUTPUTS FROM LAMP FADER

The lamp fader is used to "fade in" and extinguish the image of a road sign in order to simulate the approach and passing of such signs. Pulses on two lines from the fader indicate to the computer the instants when the sign image is at its maximum brightness, and when the vehicle "passes"the sign respectively. This information is used by the computer to detect driver violations. Section 5.3 gives details of the operation of the lamp fader.

3.5 THE FUNCTIONS OF DIGITAL OUTPUTS

3.5.1 SLIDE CHANGE COMMAND

In order to initiate a single change of slide on either projector, the computer must output a pulse to the respective projector. The operations involved are described in detail in Section 5.3.

3.5.2 OPERATION OF LAMP FADER

Three lines are used to control the fader ; one initiates its operation, and the other two hold the sign brightness constant or allow it to change, as a function of the subject's driving behaviour. A diagram illustrating the operation of the fader can be seen in Figure 3 in Section 5.3.

3.5.3 HIGH/LOW STIMULUS DENSITY INDICATION TO RLG

The flash rate of the RLG is modulated by vehicle speed and by the position of the vehicle along the route. Within an urban area the lights are activated at a higher average rate than in a rural environment. The positions of transition from one stimulus density area to another are encoded in memory in terms of specific distance pulse counts. Two output lines will be used : a pulse on one line signals a transition from high to low stimulus density, while a pulse on the other line signals a transition in the opposite direction. Section 5.8 deals with these operations in detail.

3.5.4 SLIDE CHANGE MALFUNCTION INDICATION

Whenever a malfunction of either projector is detected a pulse must be output on one of two lines routed to the operator's console. This causes a "projector fail" indicator to flash and also informs the operator which projector is involved. The operations resulting from a projector malfunction are described in detail in Section 5.5.

3.5.5 STROBE PULSES TO SLIDE ID DISPLAYS

Two displays located on the console are used to display the ID of the slides being presented on each of the projectors. The displays receive information directly from the slide ID readers, but are not updated until a strobe pulse is received from the computer - this occurring only when the computer is satisfied that the correct slide is being displayed. The slide ID information can be used by the operator to rectify slide change malfunctions, and also informs him when to change the magazine on the projector.

3.5.6 PEN RECORDER ON/OFF COMMAND

At pre-determined points in the journey three-minute long samples of the subjects' electrocardiogram will be recorded by a pen recorder. Two output lines will be used : a pulse on one line switches on the apparatus, while a pulse on the other switches the apparatus off.

3.5.7 POLICE SIREN "ON" COMMAND

The police siren is activated for a few seconds on a probability basis when a driver violation is detected. One output line is needed. The sequence of operations leading to the activation of the siren is explained at length in Section 5.11.

3.5.8 REST/END-OF-JOURNEY INDICATION ON CONSOLE

The effects of changes in the frequency and duration of rest periods on driver fatigue is an important aspect of this study. Because rest periods will be tied to vehicle position, the computer must inform the operator when a rest period is due to occur. This is accomplished by activating a flashing light on the operator's console. (The light is subsequently de-activated by the operator as described in Section 5.10).

3.6 ANALOGUE INPUTS - STORAGE REQUIREMENTS

A maximum of seven analogue inputs will be recorded in the pilot study - this may be reduced in the main experiment. Because the bandwidths of the various signals differ, different sampling rates will be necessary. While a sampling rate of only twice the maximum frequency of interest is theoretically required to recover the original signal after quantization, in practice a higher sampling rate should be used. In this study a sampling rate of five times the maximum frequency will be used, this value being slightly slower than the average sampling rate used in a number of studies.

In the following calculations of the amount of information to be stored, it is assumed that the journey is of eight hours (28 800 seconds) duration exactly. The actual computer time (i.e. time during which the computer is sampling the data) is less than this due to stops en route. Another parameter of interest in the calculations is the number of distance pulses occurring over the entire journey. Pulses are received approximately every 15 m, and thus about ~~36 666 will be co~~unted for a

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journey of 550 km.

3.6.1 HUMAN PHYSIOLOGICAL SIGNALS

(1) INTERBEAT INTERVAL OR HEART RATE (HR)

The interbeat (R - R) interval of the heart will be recorded continuously. External hardware will convert the electrocardiogram signal into an analogue signal which has an amplitude proportional to the R - R interval. A sampling rate of 5 Hz will be used.

Each sample is stored as a two-byte (16 bit) number, the first byte containing the channel identification (ID) and the second byte the digital representation of the analogue signal. (Note that although the analogue-to-digital converters can give a resolution of one in 10 bits, only the eight most significant bits will be used in this study. This results in an error of measurement of less than 1 per cent)

The amount of storage required : 28 800 × 5 × 2 bytes = 0,288 M bytes.

(2) BREATHING RATE (BR)

Breathing rate is to be recorded as it has been shown to correlate with fatigue and because it modulates HR in some subjects. Breathing rate will be sampled continuously at a rate of 5 Hz.

Amount of storage required : 0, 288 M bytes.

(3) ELECTROMYOGRAM (EMG)

This variable, which gives a measure of muscle tension, relates to stress and response uncertainty. Since only tonic (slowly varying) levels are of importance, external hardware will amplify, rectify and filter the EMG signals to provide an input voltage approximately proportional to muscle tension, and with a maximum frequency of interest of 1 Hz.

Amount of storage required : 0,288 M bytes

(4) SKIN CONDUCTANCE LEVEL (SCL)

This variable, which gives a measure of physiological arousal, will be sampled continuously at 5 Hz over eight hours. In order to alleviate the problem of electrode drift an AC system will be used. However, the signal monitored by the computer is essentially DC.

Amount of storage required : 0,288 M bytes

3.6.2 VEHICLE ANALOGUE SIGNALS

(1) VEHICLE SPEED

Accurate velocity information is obtained from the tachometer of the Velodyne motor driving the road surface projector. The maximum frequency of interest is about 3 Hz, and thus a sampling rate of 15 Hz is required to enable accurate assessment of vehicle acceleration to be made.

Amount of storage required : $28\ 800 \times 15 \times 2 = 0{,}864$ M bytes.

(2) STEERING ERROR

As the tracking task in this simulator is compensatory, the steering error is equal to the angle of the steering mirror (relative to a horizontal line). This angle is approximately proportional to the output voltage of a potentiometer attached (via suitable gear reduction) to the mirror drive motor shaft. The maximum frequency of interest is 3 Hz, and the sampling rate is 15 Hz.

Amount of storage required : 0,864 M bytes.

(3) STEERING WHEEL ANGLE

This variable enables a measurement of the degree of "coarseness" of steering control to be made, and can also be used to estimate the relative amount of movement artefact within the EMG signal. The highest frequency of interest is 4 Hz (higher than in the steering error signal because of the lags in the steering wheel/steering mirror subsystem). The sampling rate is thus 20 Hz.

Amount of storage required : 28 800X20X2 = 1,152 M bytes.

The total volume required for all analogue signals is thus 4,032 M bytes.

4. DISCRETE DATA STORAGE REQUIREMENTS

4.1 TIME

In order to provide a time scale for printouts of analogue data, real time will be stored on magnetic tape. The resolution will be one second, and thus the maximum count is 28 800 seconds in eight hours. This can be represented by a 16 - bit number. Each number is identified by an eight - bit channel ID. The storage volume required is thus 28 800X3 = 86,4 k bytes.

4.2 DISTANCE PULSES

Distance pulses will be stored as data whenever discrete events are initiated by the pulse. The distance pulse count value and real time correct to one millisecond must be stored. The representation of a distance pulse count value of 36 666 requires a 32 - bit fullword, and another 32 - bit fullword is required for the real time value expressed in milliseconds. Thus each distance count recorded requires nine bytes of storage volume if an eight-bit channel ID is included.

The number of discrete operations which occur cannot be exactly specified as some depend on the occurrence of certain driver behaviours. The minimum number which can be recorded is the number of road signs (302). As the number of other operations (risk sequences, driver violations, etc) should not exceed this number, a total of 604 distance pulses to be recorded is probably a safe estimate.

Amount of storage required : 604X9 = 5,436 k bytes.

4.3 RANDOM LIGHT PULSES

Each light is coded as an eight-bit channel ID, and a 32 -bit real time value correct to one millisecond, i.e. five bytes per light. The average flash rate will be approximately one every four seconds, and thus the number recorded is approximately 7 200.

Amount of storage required : 7 200X5 = 36 k bytes.

4.4 DRIVER RESPONSE SWITCH

Each response to a random light is coded as an eight - bit channel ID and a 32 - bit real time value, correct to one millisencond.

Amount of storage required : 7 200X5 = 36 k bytes.

4.5 SLIDE IDENTITY NUMBER

Each slide is coded as an eight - bit channel ID, an eight - bit slide ID and a 32 - bit real time value correct to one millisecond. The number of slides to be presented is approximately 302 (road signs) plus 151 (number of risk slides - a generous overestimation) i.e. 453.

Amount of storage required: 453X6 = 2,718 k bytes.

4.6 BRAKE ON/OFF SWITCH OPERATION

Whenever the brake lever changes its state this fact is recorded as data. The number of brake on/off responses made over the entire journey cannot be exactly determined, but the number should not be less than twice the total number of recorded distance pulses estimated in Section 4.2, i.e. 1 208. Each response is coded as an eight - bit channel ID and a 32 - bit real time value correct to one millisecond (the real time value is positive if a "brake on" response is made, and negative if a "brake off" response occurs).

Amount of storage volume : 1 208X5 = 6,04 k byte.

4.7 ROAD SIGN "OFF" MARKER

It is necessary that both the onset and offset of a road sign be stored as data. The onset has already been accounted for in Section 4.2. The probable number of "off" markers is equal to the number of road signs plus the estimated number of risk slides, i.e. 604. Each off marker is coded as an eight -bit channel ID, and a 32 - bit real time value correct to one millisecond.

Amount of storage volume : 604X5 = 3,02 k bytes.

The total storage volume required for discrete (digital) data is thus 175,6 k bytes.

The total volume of all data is thus :
4,032 M bytes (analogue data) + 0,1756 M bytes (digital data) =
4,2076 M bytes.

One reel (600 ft) of magnetic tape can store 5,76 M bytes of information at 6 400 bpi. Thus the amount of tape available for inter-record gaps, file markers, etc. is 1,5524 M bytes (equivalent to 162 feet of tape).

5. DETAILED DESCRIPTION OF DISCRETE OPERATIONS

5.1 COUNTING OF DISTANCE PULSES

(1) At t=o (i.e. when the operator closes the START switch for the first time) the distance count value is set to zero. The computer now begins to control or monitor all inputs and outputs.

(2) As each successive distance pulse is received, the distance count value is incremented by one, and the real time (correct to one millisecond) when the pulse was received is registered.

(3) Each new distance count value is compared with a number (one of a list of many numbers) stored in memory. When a match occurs that distance count value, together with its real time value, is stored as data with a format as given in Section 4.2. The computer then branches to the subroutine indicated by the particular distance count value. It should be noted that as distance count pulses are often used to cue events which occur at fixed distances along the journey, and which must be related to real time to an accuracy of one millisecond, the counting and registering of distance pulses has a priority second only to the recording of analogue data.

(4) Whenever a match occurs between a distance count value and a number in memory, subsequent distance count values are compared with the next number in the memory list.

(5) Whenever a slide change malfunction occurs (Section 5.5) distance pulses must be ignored until such time as the projector reset switch is closed by the operator. It therefore follows that no distance pulse initiated operations can occur before the projector fault has been rectified.

(6) If the STOP switch is closed the computer must ignore all subsequent distance pulses until the START switch is closed. The operation of both these switches, together with real time,

must be recorded as data when they occur.

5.2 RECORDING OF RANDOM LIGHTS AND DRIVER RESPONSES

The format for the recording of pulses from the RLG is described in Section 4.3 and will not be repeated here. The recording of random light pulses has a lower priority than the recording of distance pulses.

Although the random lights and the subject's responses to them do not initiate feedback directly, the computer is required to evaluate the quality of the subject's attention to his environment by keeping a record of the number of missed lights. If the computer detects n successively missed lights it branches to a risk subroutine (described in Section 5.11). The exact value of n will have to be determined empirically; as a start n=3* can be assumed. (The reader is referred to Section 6 for a discussion of variable parameters. Parameters which may need adjustment during the course of development are indicated in this report by an asterisk (*)).

A suggested method for the determination of missed lights is as follows :

(1) The occurrance of a given random light pulse is registered by the computer and its light field and real time value are stored as data.

(2) The occurrence of the subject's response is registered by the computer and real time is noted and stored as data. The subject's reaction time (RT) is computed. If 150 ms* $<$ RT $\leq$ 1,3s* a number with value one is added to the bottom of a list of three* numbers stored in memory (the top or "oldest" number in the list being discarded). If RT $>$ 1.3s* or RT $\leq$ 150 ms* a number with value zero is added to the bottom of the list (note that a very short reaction time is probably a delayed response to the previous random light).

(3) If no response has been recorded by the time the next light pulse is recrived, no data will have been recorded. If this occurs, a number with value zero must still be added to the list.

(4) Whenever all the numbers in the list are zero, the computer must branch to the relevant risk subroutine described in Section 5.11.

5.3 OPERATION OF THE ROAD SIGN PROJECTOR AND ASSOCIATED APPARATUS

When the distance count value is equal to specific values stored in memory, the computer must branch to the "road sign slide change" subroutine. The slide in the road sign projector is changed, and the code number of the new slide (stored in memory) is used to determine whether the driver is required to stop or not. The number of different conditions which may arise is shown in Figure 2.

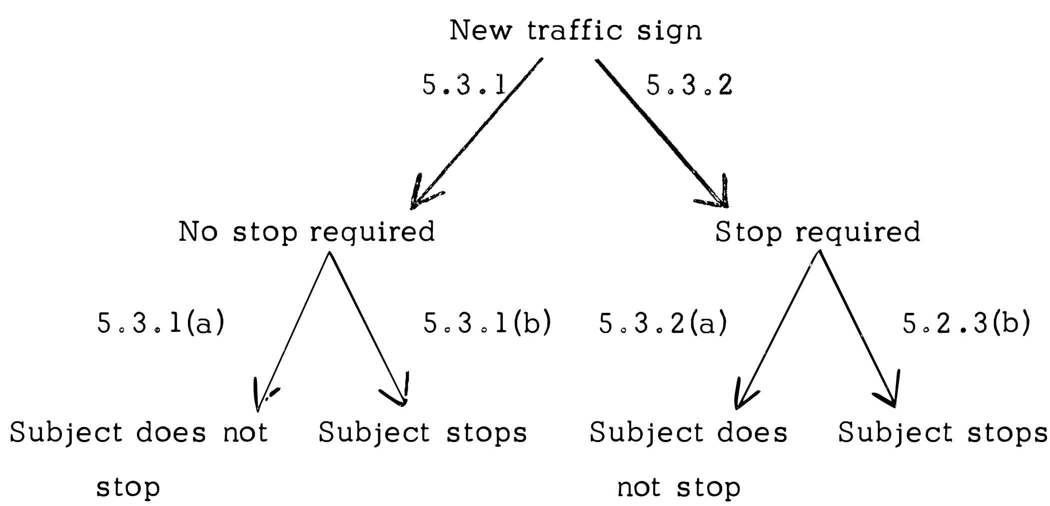

FIGURE 2 Different conditions arising out of the presentation of a new road sign.

Before the decision criteria for stopping are discussed, it is necessary that the operation of the projector lamp fader be described is some detail (refer to Figure 3). This apparatus enables the road signs to be faded in to maximum brightness as an approximation to the "zoom" effect experienced in the real-life situation.

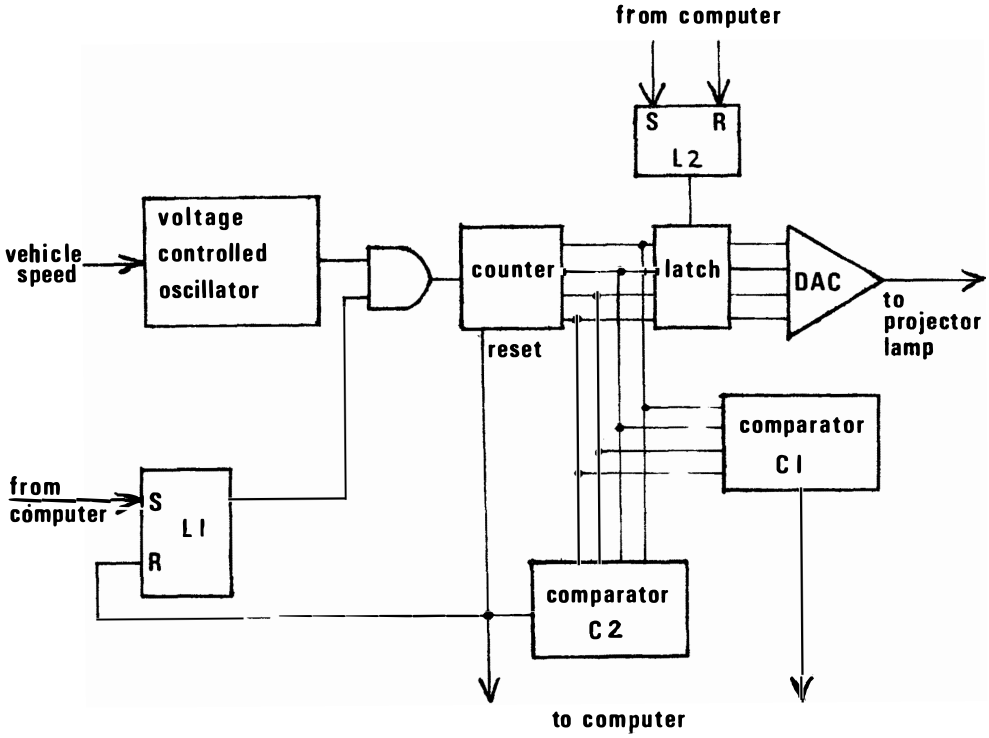

FIGURE 3 Schematic of projector lamp fader.

The lamp fader varies the brightness of the projector lamp such that the rate of change of perceived brightness is proportional to vehicle speed. When there is no slide to be projected the counter, which is reset to zero, receives no pulses from the voltage controlled oscillator (VCO). The output of the digital-to-analogue converter (DAC) is zero, and the projector lamp is off. When a new slide is to be projected the computer outputs a pulse to the set terminal of the RS latch L1, which then allows pulses through to the counter. The output of the counter, which is proportional to the integral of the vehicle speed with respect to time (i.e. distance travelled) is fed to the DAC which controls the brightness of the lamp.

In order to provide an indication of the "distance" of the vehicle from the road sign, two comparators C1 and C2 indicate brightness levels of near-maximum and maximum respectively.

5.3.1 NO STOP REQUIRED

5.3.1(a) SUBJECT DOES NOT STOP

(1) A slide change pulse is sent to the road sign projector which inserts the next slide into the projector gate.

(2) The computer notes the real time at which the output pulse is delivered.

(3) The computer outputs a pulse to the set terminal of L1.

(4) The operation of the fader is now automatic, and no further action by the computer (with respect to the fader) is necessary.

(5) When the lamp brightness is near maximum, C1 sends a pulse to the computer which then interrogates the slide ID reader in the projector. The slide ID is then compared with the required ID stored in memory (the format of the slide ID is discussed in Section 5.5). If there is a match, the computer stores as data the slide ID together with real time obtained in (2) above. It then outputs a strobe pulse to the road sign ID display on the console (this updates the display). No further action is then required.

(6) If a mismatch occurs, or if a disallowed number is read, the computer must store as data a code referring to this type of malfunction, together with the real time value obtained in (2) above. The computer than branches to a "slide change malfunction" subroutine (Section 5.5).

When the brightness of the sign is at maximum, comparator C2 resets L1 and the counter, and the lamp is thus switched off. This is analogous to the vehicle passing the sign. The pulse output to the computer by C2 is not used in this case, but is used when the subject is required to stop (see below).

5.3.1(b) SUBJECT STOPS

In the unlikely event of this happening the same sequence of events will still occur, and no intervention by the computer is necessary as this does not constitute a violation of the rules of the road by the subject.

5.3.2 STOP REQUIRED

The decision as to whether the driver has or has not stopped according to the instructions of a road sign is complicated by the fact that there are in the present apparatus no distance cues (such as a stop line) on the road which enable the driver to decide exactly where he must stop. The only cue available is the brightness of the sign. As the human being is a relatively poor performer in tasks requiring the judgement of absolute magnitude, it is quite possible for the subject to make an honest attempt to stop and yet "overshoot" the sign. The subject could then be unjustifiably penalized by the computer. To prevent this from happening, comparator C1 in Figure 3 is used to inform the computer of near maximum sign brightness. The computer may then stop the projector lamp from being switched off according to the following decision rules :

(1) When the computer receives a pulse from C1 it looks at the value of the most recent sample of vehicle speed (V_i) and at the state of the brake pedal (see Section 5.6). The decision as to whether the vehicle has stopped depends on these parameters and on two velocity thresholds V_{t1}* and V_{t2}* ($V_{t1} < V_{t2}$) which are pre-programmed.

(2) If $V_i \leq V_{t1}$, irrespective of the state of the brake pedal, the vehicle has stopped.

If $V_{t1} < V_i \leq V_{t2}$ and the brakes are being applied, the vehicle has "stopped".

If $V_i > V_{t2}$, irrespective of the state of the brake pedal, the vehicle has not stopped.

5.3.2(a) SUBJECT DOES NOT STOP

(1) If the subject fails to stop at a mandatory stop the computer stores as data a code referring to this type of violation, together with the real time at which the pulse from C1 was received. The computer then branches to the risk subroutine described in Section 5.11.

(2) The fader will continue to operate until the projector lamp is switched off (i.e. C2 outputs a pulse).

(3) When the computer receives the pulse from C2 it must output a slide change command pulse to the road sign projector. (This is to ensure that the next road sign is in the gate, i.e. a green traffic light or a "go" sign which must not be seen by the subject).

(4) The real time at which the slide is changed is noted and is stored together with the slide ID as data.

(5) The computer must not re-activate the lamp fader.

5.3.2(b) SUBJECT STOPS

(1) As soon as the computer decides that the subject has "stopped" it must output a pulse to the set terminal of the RS latch L2. This holds the input to the DAC constant irrespective of the operation of C2, i.e. the projector lamp is held on.

(2) When the computer sets L2 it must also start a timer.

(3) When t=25* seconds the computer must output a slide change command pulse to the road sign projector. A green robot or "go" sign is now projected. This event, together with real time correct to one millisecond and the slide ID must be stored as data.

(4) When t=30* seconds the computer must output a pulse to the reset terminal of L2. This switches off the projector lamp.

(5) The computer must not re-activate the lamp fader.

CASE WHEN THE DRIVER STOPS BEFORE COMPARATOR C1 OUTPUTS A PULSE, I.E. BEFORE MAXIMUM SIGN BRIGHTNESS.

This should normally occur very infrequently, depending on the setting of the reference count value of C1. Should this occur, subsequent operation of C1 is irrelevent and should be ignored by the computer.

(1) The computer must always monitor V_i (vehicle speed) when the vehicle is required to stop at a road sign. From the instant when $V_i = 0$ the computer must start a timer.

(2) When t=25* seconds the computer must output a slide change command pulse to the road sign projector (for the green robot or "go" sign). This event, together with real time correct to one millisecond, and the slide ID must be stored as data.

(3) The operation of the lamp fader is automatic, and no further computer intervention is required.

5.4 CHANGE OF SLIDE ON RISK SYMBOL SLIDE PROJECTOR

The risk stimuli have been designed to simulate the effect of increasing the conditional probability of an emergency situation occurring as a function of successive events. The subject is required to make an emergency stop should a slide showing a particular emergency stimulus be projected. The probability of the emergency stimulus is proportional to the number of preceding risk stimuli. It is to be expected that the alert driver will be more sensitive to the conditional probabilities than the fatigued driver, and this should be indicated by a difference in driving performance and/or physiological responses.

Risk sequences may consist of from one to five slides, with the emergency stimulus occurring anywhere within the sequence (or not at all). Because there is no lamp fader associated with the risk slide projector, the last slide in each sequence will be a dummy stimulus, i.e. an opaque slide, and is thus not seen by the subject. Slides are identified by an eight - bit slide ID as described in Section 5.5. Each slide is coded according to its position in the magazine (i.e. 1 to 100). All emergency and dummy stimuli will be indicated in the computer's memory.

The risk sequence may be initiated by :

(i) pre-programmed distance counts, or

(ii) driver violations (see Section 5.11.1).

It is possible that a risk sequence may be called while one is already in operation. If this is the case, the second call must be ignored.

(1) When the distance count is equal to specific pre-programmed values, or when the "risk probability generator" output is a one (see Section 5.11) the risk subroutine is called. The real time at which the call is issued is registered and stored as data.

(2) As soon as the next distance pulse is received, the computer must output a slide change command pulse to the risk slide projector.

(3) The projector will then insert a new slide into the gate. When the slide ID is available to be read, the slide ID reader will output a pulse to the computer. The computer then interrogates the slide ID reader, and the slide ID is checked against the correct pre-programmed value.

(4) If the slide ID matches the required ID, the next slide is presented. If there is a mismatch the computer must branch to the "slide change malfunction" subroutine described in detail in Section 5.5. Whenever there is a match between the slide ID and the required ID, the computer must also output a strobe pulse to the risk stimulus ID display on the console (this updates the display).

(5) When the slide ID check is positive, a new slide is presented every second* distance pulse for speeds below 90 km/h, and

every third* distance pulse for speeds equal to or greater than 90 km/h (the difference being due to speed limitations of the slide change mechanism).

(6) The slide ID is read and checked for each slide in the sequence. Whenever the computer receives the slide ID it must note the real time and store this together with the slide ID as data.

(7) Whenever an emergency slide is presented (this occurring for pre-programmed slide ID numbers) the computer must look at the current state of the brake pedal (see Section 5.6). The computer must also start a timer. If the subject is applying his brakes when the emergency stimulus appears, the computer does not have to evaluate the quality of the subject's response in terms of brake reaction time. If the subject has not applied his brakes within 950* milliseconds the computer must sample a "police siren probability generator" having the required probability as given in Section 5.11. If the brakes are applied (regardless of reaction time), real time correct to one millisecond must be registered and stored as data with a format as described in Section 4.6.

(8) Ten* seconds after the onset of the emergency stimulus, the computer must output a slide change command pulse to the risk slide projector.

(9) Whenever the computer reads the ID of the dummy stimulus, it must exit from the risk subroutine.

5.5 SLIDE ID CHECK AND THE "SLIDE CHANGE MALFUNCTION" SUBROUTINE

To provide a check of the correct functioning of the two slide projectors, all slides are coded by means of holes punched through the slide holder. Whenever a new slide is inserted into the projector gate this code number is read and is passed on to the computer. The code is an eight-bit binary number with a format shown in Figure 4.

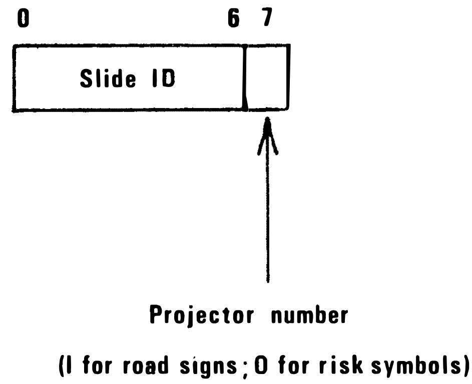

FIGURE 4 Format of the slide identity number

The slide IDs of all slides to be projected over the entire journey are stored in memory. Separate lists will be provided for both projectors, and within each list the IDs are in the correct order. Associated with each ID is a number which indicates whether the subject is required to stop or not; this information being used by the computer to evaluate the correctness of the subject's response.

In the road sign slide projector the ID of each slide gives its position in the magazine. This gives 100 IDs numbered from one to 100. In the road sign projector only , there are three disallowed slide IDs, viz. all zero's, all one's, and slide number 100 (i.e. 1100100[1]) (in the risk slide projector only the first two IDs mentioned are disallowed). Slide number 100 is a dummy stimulus (not seen by the subject) and is used to inform the operator of the need to change slide magazines.

Since it is not necessary to change magazines on the risk slide projector, slide number 100 is allowed. This is because the risk sequences are recycled after one revolution of the magazine.

Whenever a slide ID does not match the pre-programmed ID , or disallowed IDs are read, the following operations must occur :

(i) As soon as the error is detected the computer must ignore all subsequent distance pulses. The current distance count number is decremented by one. Real time correct to one millisecond is noted, and is stored as data together with a code meaning "slide change malfunction; projector x". (Note : If the slide ID is 100, the code stored as data must refer to an "end-of-magazine" condition).

(2) The computer must pause all data transfer operations except the outputs road gradient and steering demand. As these require vehicle speed information, vehicle speed will still be monitored, but successive samples must not be accumulated in memory.

(3) The computer must output a pulse to the set terminal of a RS latch which controls the operation of a "projector fail" indicator on the console. The computer does not output a pulse to strobe the slide number display on the console. Thus the operator can read the number of the last correctly displayed slide.

(4) The operator then corrects the fault manually, making sure that the last correctly displayed slide is in the projector gate. The operator then presses the "projector reset" switch.

(5) When this switch is closed, the computer notes the real time and stores this together with a code meaning "projector reset" as data. The "projector fail" indicator is reset by external hardware.

(6) All data transfers are now resumed. The next slide will be presented as soon as the next distance pulse is received.

NOTE : When slide number 100 is read on the road sign projector, the same sequence of events occurs. The operator must make sure that slide 100 is in the projector gate when a new magazine is installed. When the "projector reset" switch is closed, the next slide (i.e. slide no. 1) will be presented as soon as the next distance pulse is received. This is a dummy stimulus and is not seen by the subject.

5.6 BRAKE ON/OFF RESPONSES

Every time the position of the brake pedal changes a pulse is sent on one of two lines to the computer (for a "brakes on" response, the pulse will be on one line, while a "brakes off" response is indicated by a pulse on the other line). The position of the brake pedal at any moment in time is indicated by a number in memory : the "brake position index". This number is initialized to zero at the beginning of the experiment when the brakes are in the off position. Whenever a "brakes on" response is recorded, a one is added to the brake position index, whilst a "brakes off" response results in a one being subtracted from the brake position index.

Whenever a brake on or brake off response is recorded, this must be stored as data with a format as described in Section 4.6.

5.7 START AND STOP SWITCHES ON THE OPERATOR'S CONSOLE

These switches control the power supply to the road surface projector lamp and motor, and are also used to pause all input and output operations in the event of scheduled or unscheduled breaks in the journey.

(1) At the beginning of each experimental run, the computer and other hardware will be "on", but no road surface pattern will be observed until the START switch is closed by the operator. No transfer of data from and to the simulator will take place until this switch is closed.

(2) When the START switch is closed this fact must be recorded as data consisting of an eight-bit "channel ID" and a 32 - bit real time value correct to one millisecond. This also initiates all data transfers, and various parameters are set to their initial values (see Section 6).

(3) When the STOP switch is pushed this fact must be recorded as data with a format as in (2). All data transfers (including the recording of vehicle speed) are paused until the START switch is closed again.

5.8 HIGH/LOW DENSITY INDICATION TO RLG

The rate at which the random lights are switched is a function of :

(i) vehicle speed, and

(ii) location (urban/rural).

It is also necessary that the lights be switched at a low rate while the vehicle is stationary. This can be accomplished by means of the circuit outlined in Figure 5.

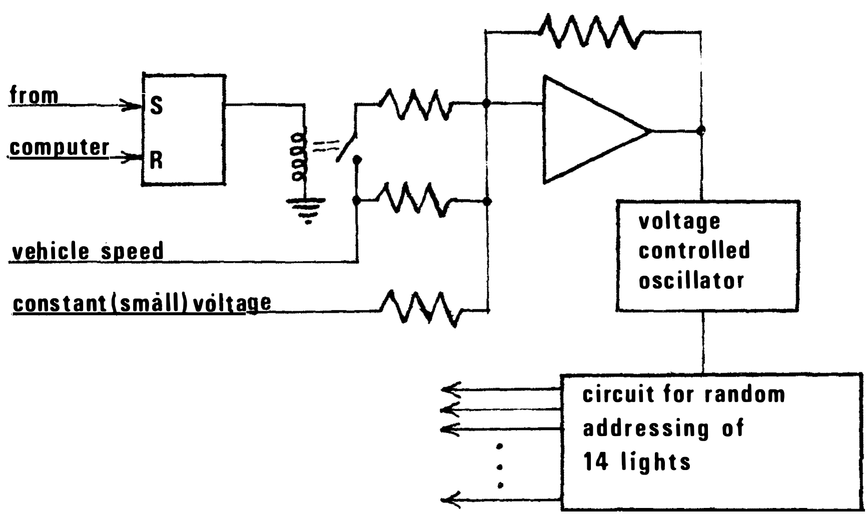

FIGURE 5 Schematic of Random Light Generator

(1) When the distance count reaches certain pre-programmed values*, the computer must output a pulse on one of two lines (set or reset) to condition the RS latch as in Figure 5.

(2) Whenever the computer outputs a pulse, real time (correct to one millisecond) must be noted and stored as data. The format will be an eight - bit channel ID (one for each output line) and a 32 - bit real time value.

5.9 EKG PEN RECORDER ON/OFF COMMANDS

(1) When the distance count is equal to certain pre-programmed values* the computer must output a pulse on one of two lines which control an RS latch.

(2) Whenever a pulse is outputted, real time must be registered and stored as data with a format as described in Section 5.8.

5.10 REST/END-OF-JOURNEY LIGHT ON OPERATOR'S CONSOLE

On some journeys rest periods will occur at places designated by specific distance counts. When the distance count is equal to these pre-programmed values,* the computer must output a pulse to the set terminal of an RS latch controlling a light on the console. This event must be recorded as described in Sections 5.8 and 5.9.

The computer will not be required to reset the light as this will be done manually by the operator. This event is not recorded by the computer as the STOP and START switches will have been activated by the operator, thus effectively recording the onset and offset of the rest period.

5.11 THE "RISK" AND "POLICE SIREN" SUBROUTINES

Every action taken by the driver on the road results in some form of feedback. Of particular importance is feedback relating to :

(i) the possibility of physical injury, and

(ii) law enforcement.

The driver tries to maximize the benefits of being transported rapidly to his destination while minimizing the risks associated with (i) and (ii). Thus his behaviour is partly a function of his perception of the relative magnitudes of the risks and rewards involved. Since these perceptions are liable to be influenced by fatigue, the experimental subject must be exposed to the same system of feedback that he encounters on the road so that his behaviour in relation to this system can be analysed for signs of fatigue.

The feedback associated with physical risk and law enforcement is essentially probabilistic in character, with the probability varying as a function of the nature, frequency and location of the behaviour concerned. For any given driver error or violation, the probability of material damage or physical injury is higher than the probability of detection by traffic police. Risk probabilities are also higher in urban than in rural areas because of the increase in exposure resulting from higher traffic volumes.

In order to simplify the computations involved in the generation of feedback responses, three probability levels (high, H; Medium, M; low, L) will be used. A distinction will be made between the probabilities associated with urban (U) and rural (R) environments, and between physical risk (PR) and the risk of detection by police (DP). Table 1 shows the probabilities which have been selected. It should be noted that these values are provisional and could be changed during the course of development.

TABLE 1 PROBABILITIES* ASSOCIATED WITH PARTICULAR RISK SITUATION PROBABILITY GENERATORS

	PHYSICAL RISK		DETECTION BY POLICE	
	URBAN	RURAL	URBAN	RURAL
HIGH P	0,4	0,2	0,2	0,1
MEDIUM P	0,2	0,1	0,1	0,05
LOW P	0,1	0,05	0,05	0,025

NOTATION : a high probability of a violation being detected by police in in a rural environment will be denoted by $P^{H}_{DP(R)}$, etc.

Whenever a driver violation is detected (see Section 5.11.1), the computer must sample two "probability generators", one for physical risk and the other for detection by police. The output of each generator can be a 0 or a 1, where P ("1") is the desired probability. If the output is zero, no further action by the computer is required until the generator is sampled again. If the output is one, the computer must carry out the actions associated with the particular probability generator in question.

The indication of physical risk is by means of projected risk symbols and is described in detail in Section 5.4. Detection by police is indicated by the sound of a police siren which is triggered by a pulse from the computer on one line (the pulse will trigger a monostoble which turns the siren on for a fixed period of time).

5.11.1 DRIVER ACTIONS WHICH RESULT IN THE SAMPLING OF THE PROBABILITY GENERATORS

The following actions will cause the probability generators to be sampled. In all cases, except when the sample is pre-programmed to occur at specific distance count values, the sampling of the probability generator will result in the subtraction of points from the driver's total "behaviour index" if the output of the generator is one. The behaviour index is set to 100 at the beginning of the journey (i.e. when the START switch is closed for the first time). The number of points subtracted is given in Table 2.

TABLE 2 NUMBER OF POINTS* SUBTRACTED IF THE OUTPUT OF A PROBABILITY GENERATOR IS ONE

	PHYSICAL RISK		DETECTION BY POLICE	
	URBAN	RURAL	URBAN	RURAL
HIGH P	1	1	8	8
MEDIUM P	1	1	4	4
LOW P	1	1	2	2

NOTE: In the assignment of probability generators below, it is assumed that the computer will choose the generator appropriate to the vehicle's position along the route (i.e. urban or rural). This is easily done if reference can be made to a "location indicator" which has a value of one in a rural area and zero in an urban area. The value of the location indicator is updated whenever the vehicle passes an urban/rural boundary. It should be noted that "urban" areas are approximately 10 km longer with respect to detection by traffic police than are the urban areas referred to when speaking of physical risk.

(1) At specific, pre-programmed distance count values* the output of the physical risk probability generator (only) is set to one.

(2) Speeding may generate physical risk and police detection. Let the speed restriction at the location in question be V_R (pre-programmed and referenced to specific road signs via distance count values), and let the vehicle speed at the i^{th} sample be V_i. Then :

If $(V_R + 5\%)^* < V_i \leq (V_R + 15\%)^*$ $\quad P_{PR} = P_{PR}^L \quad P_{DP} = P_{DP}^L$

If $(V_R + 15\%)^* < V_i \leq (V_r + 25\%)^*$ $\quad P_{PR} = P_{PR}^M \quad P_{DP} = P_{DP}^M$

If $V_i > (V_R + 25\%)^*$ $\quad P_{PR} = P_{PR}^H \quad P_{DP} = P_{DP}^M$

(3) Not stopping at a stop sign or red robot (see Section 5.3)

$P_{PR} = P_{PR}^H \quad P_{DP} = P_{DP}^M$

(4) Non-detection of n successive random lights (see Section 5.2)

$P_{PR} = P_{PR}^L$ only, i.e. the police siren probability generator is not sampled.

(5) Steering errors. In this case we must be cognizant of two types of error, viz., (i) a single error of large magnitude and short duration, and (ii) a smaller error which exists over a longer time period. Let the error tolerance for (i) and (ii) respectively be E_{SS}^* and E_{SL}^*. Let the steering error for the i^{th} sample be e_{si}, and let the i^{th} root-mean-square error measured over a time interval T be e_{si}^{rms} (see Appendix 3). Then :

If $|e_{si}| \geq E_{ss}$ $\quad P_{PR} = P_{PR}^H \quad P_{DP} = P_{DP}^L$

If e_{si}^2 (rms) $\geqslant E_{sL}$ $P_{PR} = P_{PR}^M$ $P_{DP} = P_{DP}^M$

(6) Reaction time to emergency slide (Section 5.4). If the brake reaction time is greater than 950* milliseconds, the police siren probability generator only must be sampled with $P_{DP} = P_{DP}^H$

(7) It is desirable that the probability of risk be related to the occurrence of certain environmental events such as the rate of switching of random lights. Let the time interval between successive random lights be $\Delta t_r = t_i - t_{i-1}$ where t_i is the real time associated with the i^{th} random light, and let ΔT^* be a pre-programmed threshold. Then :

If $\Delta t_r \leqslant \Delta T$ $P_{PR} = P_{PR}^L$ $P_{DP} = 0$ (i.e. police siren probability generator not sampled).

In the case of speed violations, root-mean-square steering error, and to a lesser extent non-detection of random lights, continuous violation will result in continuous sampling of the probability generators. This will result in eventual operation of the risk slide projector and police siren in a relatively short period of time. To prevent this from happening, operation of the risk slide projector and the police siren can be related to the occurrence of distance pulses in the following manner :

(1) When the violation is first detected, the probability generators are sampled normally as described above, and the appropriate action taken if the outputs of the generators are one.

(2) Distance pulses are counted from the time the first error is detected. After five* pulses (for urban areas) and 10* pulses (for rural areas) have been counted, the computer must again look at the most recent sample of vehicle speed, rms steering error, and light detections. If these are again outside the error tolerances the probability generators are sampled, otherwize no further action is taken until such time as another error is detected, whereupon steps (1) and (2) are repeated.

It should be noted that this restriction of probability generator sampling applies only to speed, rms steering error and random light violations.

5.12 ANALOGUE OUTPUTS

5.12.1 STEERING DEMAND

Ideally, the steering demand should consist of pre-programmed shifts in the slew angle of the road which would then be in phase with road signs indicating road bends. As this approach would require a large amount of computer memory, it has been decided instead that the computer should output a pseudo-random steering demand generated by a simple algorithm. This is done easily by summing a number of sine-wave terms with non-harmonic frequencies. The different effects of slowly-varying (i.e. road curves) and rapidly-varying components (due to wind gusts or road irregularities) can readily be simulated by means of this method.

The slew angle of the road is given by the expression

$$\Theta_i = \sum_{j=1}^{n} A_j \sin K_j x_i \qquad (1)$$

where x_i is a function of velocity and time. Because of the particular apparatus in use, the slew angle of the road is equal to the integral of the steering demand (output by the computer) with respect to time. Thus the steering demand output by the computer must be equal to the derivative of the desired steering function with respect to time, i.e.,

$$\text{steering demand output} \quad S = d\theta/dt$$
$$= d\theta/dx \quad dx/dt$$
$$= V \, d\theta/dx \qquad (2)$$

where V = vehicle speed.

Thus the steering demand output by the computer is of the form :

$$S_i = K_s V_i \sum_{j=1}^{n} A_j K_j \cos K_j x_i \qquad (3)$$

where :

S_i = i^{th} value of steering demand output

K_s^* = a scaling constant

V_i = i^{th} sample of vehicle speed

A_j^* = amplitude of the j^{th} term

K_j^* = spatial frequency of the j^{th} term

n = number of terms (6 in this case)

x_i = distance travelled at i^{th} sample of speed.

As distance pulses are received every 15 metres, these cannot be used as a measure of x_i since V is sampled at a high rate (15 Hz). Instead x_i can be calculated from successive values of V_i by means of numerical integration (see Appendix 1).

The values of S_i must be outputted to the digital-to-analogue converter at a frequency of 15 Hz.

The parameters A_j^* and K_j^* are functions of scaling and task difficulty and are likely to be changed during the course of development. The reader is referred to Appendix 2 for details of the calculation of these terms. Provisional values will be : $K_1 = {}^{2\pi}/L$; $K_2 = {}^{13 \times 2\pi}/5L$;

$K_3 = {}^{29 \times 2\pi}/5L$; $K_4 = {}^{167 \times 2\pi}/5L$; $K_5 = {}^{307 \times 2\pi}/5L$; $K_6 = {}^{557 \times 2\pi}/5L$;

where L = 2 500 metres

$A_1 = - A_2 = A_3 = 1$; $A_4 = - {}^{3}/5$; $A_5 = (3 \times 167) / (5 \times 307)$;

$A_6 = - (3 \times 167) / (5 \times 557)$

Note that it is assumed that $[x_i]$ = metres and $[V_i]$ = metres per second. In order to obtain this it is necessary that the output of the analogue-to-digital converter dealing with vehicle speed be multiplied by an appropriate scaling constant.

5.12.2 ROAD GRADIENT

Road gradient is treated in almost the same way as the steering demand, i.e.

$$a_i^{(g)} = K_g \sum_{j=1}^{n} A_j \sin K_j x_i$$

where :

$a_i^{(g)}$ = vehicle acceleration due to gravity at i^{th} sample of velocity

K_g^* = a scaling constant

A_j^* = amplitude of j^{th} term

K_j^* = frequency of j^{th} term

x_i = distance travelled at i^{th} sample of velocity. $[x_i]$ = metres

n = number of terms = 3

The frequencies to be used are :

$K_1 = {}^{2\pi}/L$; $K_2 = {}^{5\pi}/L$; $K_3 = {}^{11\pi}/L$ where L = 4 000 m

The amplitudes are proportional to the reciprocal of the frequency, i.e.
$A_1 = 1$; $A_2 = {}^{2}/5$; $A_3 = {}^{2}/11$

NOTE : the values of the above parameters are provisional and could be altered during the course of development.

Since the road gradient must appear at the input to the road surface projector servomotor as a ramp function with a slope proportional to a_i , the above function must be integrated with respect to time. This may be accomplished numerically by using the trapezoid rule, i.e.,

$$V_i^{(g)} = V_{i-1}^{(g)} + \frac{hc}{2} (a_{i-1}^{(g)} + a_i^{(g)})$$

where :

$V_i^{(g)}$ = i^{th} value of "road gradient demand"

h = $^{1}/$ (sampling frequency of speed) = $^{1}/15$ seconds

$$c = \begin{cases} 1 & \text{when } |V_i| \quad 0 \\ 0 & \text{when } V_i = 0 \end{cases}$$

The variable c is introduced to prevent a change in road gradient demand when the vehicle is not moving. Without this feature the subject would have to alter the brake pressure in order to keep the vehicle stationary.

A NOTE ON THE SCALING CONSTANT Kg

The value of K_g should be such that the binary number output to the road gradient demand DAC never exceeds eight bits in length, (this also applies to the steering demand scaling constant K_s). The value of K_g also sets the maximum magnitude of $a_i^{(g)}$. For a road gradient of 7 per cent the acceleration of a frictionless body would be approximately 0,69 ms^{-2}. The maximum acceleration due to gravity of a heavy vehicle should be considerably less than this.

6. CHANGE OF PARAMETER VALUES

A number of computer operations are dependent on the value of one or more parameters. The optimum values of most of these is as yet unknown and can only be tested by means of experimentation. In order to ease the problem of re-programming it would be convenient if the computer programme could be structured to be independant of the values of these parameters, which could then be defined and re-defined by the operator whenever necessary.

Parameters whose values may need alteration, or which will be defined in a subsequent report, have been labelled in this report by means of an asterisk (*), and are listed in Table 3.

TABLE 3 REDEFINABLE PARAMETERS

Parameter	Reference	Provisional value
Brake RT (emergency stimulus)	3.4.5; 5.4; 5.11.1	950 ms
Pen recorder (EKG) on/off markers	3.5.6; 5.9	not yet defined
Rest/end-of-journey markers	3.5.8; 5.10	" " "
High/low stimulus density markers (RLG)	3.5.3; 5.8	" " "
High/low stimulus markers (police)	5.11.1	" " "
No. of missed random lights	5.2	n = 3
RT acceptance limits (random lights)	5.2; 3.4.3	150 ms $<$ RT $\leq$ 1,30s
Speed thresholds (stopping criteria)	5.3.2	not yet defined
Delay at robot or stop sign	5.3.2(b)	25 s
Reset of lamp fader delay	5.3.2(b)	30 s
Risk slide projection rate	5.4	$V_i < 90$km/h : 2 pulses
" " " "	5.4	$V_i > 90$km/h : 3 pulses
Dummy stimulus delay (risk slides)	5.4	10 s
Risk and police detection probability	5.11	see Table 1
Points debited for violations	5.11.1	see Table 2
Pre-programmed risk markers	5.11.1	not yet defined
Speed trapping thresholds and p values	5.11.1	V_R + 5%
Speed trapping thresholds and p values	5.11.1	V_R + 15%
Speed trapping thresholds and p values	5.11.1	V_R + 25%
Steering error tolerances	5.11.1	not yet defined
Random light interval threshold	5.11.1	" " "
p generator sampling rate	5.11.1	urban : 5 pulses

cont ....

Parameter	Reference	Provisional value
p generator sampling rate	5.11.1	rural : 10 pulses
Steering demand parameters (K_s, A_j, K_j)	5.12.1	K_s not yet defined
Road gradient parameters (K_g, A_j, K_j)	5.12.2	K_g not yet defined
Scaling constant (estimation of x_i)	Appendix 1	not yet defined
Number of terms for e_s (rms)	Appendix 3	n = 6

7. NUMBER OF "CHANNELS" REQUIRING AN IDENTITY CODE

A large number of events on different channels are required to be recorded by the computer. Each is coded by means of an eight - bit channel ID. The different channels are listed in Table 4.

TABLE 4 INPUT AND OUTPUT CHANNELS REQUIRING IDs

Channel	Reference
(1) Skin conductance level	3.6.1 (4)
(2) Electromyogram	" (3)
(3) Heart rate	" (1)
(4) Breathing rate	" (2)
(5) Vehicle speed	3.6.2 (1)
(6) Steering error	" (2)
(7) Steering-wheel angle	" (3)
(8) Steering demand output	5.12.1
(9) Road gradient output	5.12.2
(10) Distance pulses	3.4.1 ; 5.1
(11) Random lights, field 1	3.4.2 ; 5.2
(12) " " " 2	" "
(13) " " " 3	" "

cont ...

Channel		Reference
(14)	Random lights, field 4	3.4.2 ; 5.2
(15)	Subject response switch in cab	3.4.3 ; 5.2
(16)	Brake on	3.4.5 ; 5.6
(17)	Brake off	" "
(18)	Slide change output, projector 1	3.5.1 ; 5.3
(19)	" " " , " 2	" "
(20)	Slide ID, projector 1	3.4.4 ; 5.3 ; 5.5
(21)	" " , " 2	" " "
(22)	Slide ID indicator strobe, projector 1	3.5.5 ; 5.3
(23)	" " " " , " 2	" "
(24)	Slide change malfunction indicator 1	3.5.4 ; 5.5
(25)	" " " " 2	" "
(26)	Projector reset switch	3.4.6 ; "
(27)	START switch	3.4.7 ; 5.7
(28)	STOP switch	" "
(29)	Lamp fader comparator 1	3.4.8 ; 5.3
(30)	" " " 2	" "
(31)	Lamp fader, L1 set	3.5.2 ; 5.3
(32)	" " , L2 set	" "
(33)	" " , L2 reset	" "
(34)	High-to-low density transition, RLG	3.5.3 ; 5.8
(35)	Low-to-high " " , RLG	" "
(36)	Pen recorder on	3.5.6 ; 5.9
(37)	" " off	" "
(38)	Police siren on	3.5.7 ; 5.11
(39)	Rest/end-of-journey light	3.5.8 ; 5.10
(40)	Real time (one second intervals)	4.1

REFERENCE

Denton, G.G., (1974). Motion - a study of induced percepts of velocity. CSIR Special Report PERS 213, National Institute for Personnel Research, Johannesburg, South Africa.

APPENDIX 1 CALCULATION OF DISTANCE TRAVELLED FROM VEHICLE SPEED

As the steering and road gradient demands are functions of distance travelled it is necessary that the vehicle speed be integrated with respect to time. Distance pulses cannot be used as they are too widely spaced and would thus limit the higher frequencies of the output functions at low speeds.

The simplest method of numerical integration is the trapezoid rule, viz.,

$$\int_o^h f(x)\,dx \approx \frac{h}{2}(f(o) + f(h))$$

The algorithm for the calculation of distance travelled is thus :

$$x_i = x_{i-1} + \frac{K_d h}{2}(V_{i-1} + V_i) \quad \text{where } x_o = 0$$

where :

V_i = the i^{th} sample of vehicle speed

x_i = total distance travelled at the i^{th} sample of speed

h = $^1/$ (sampling frequency of speed) = $^1/15$ second

K_d = a scaling constant such that $[x_i]$ = metres

APPENDIX 2 AMPLITUDE AND FREQUENCY VALUES FOR THE STEERING DEMAND

The slew angle of the road is given by a function with terms of the form $A_j \sin K_j x_i$ where $K_j = 2\pi / L_j$. For a constant speed V, the term becomes $A_j \sin \frac{2\pi V}{L_j} t_i$

i.e. $W_j = \frac{2\pi V}{L_j}$ $\quad W_j$ = angular frequency of j^{th} term. (1)

A steering demand which is thesum of three such terms with frequencies which are not harmonically related is sufficiently "random" to preclude the subject from learning the pattern (provided the period is sufficiently long). The steering demand may thus be generated by a series of six terms; the first three (low frequency) terms representing road curves, and the last three (high frequency) terms simulating wind gusts or road irregularities.

To obtain the minimum value of L_j (i.e. maximum W_j) it is assumed that the tracking task will become difficult at a speed which is near to maximum for the vehicle used in the simulator. A typical angular frequency for a difficult tracking task is 10 radians / second (1,59 Hz). Assuming a top speed of 130 km/ hour (36,1 m/s), and using equation (1) above, it follows that L_6 = 22,69 m.

Let L_1 = 2 500 m, and let the steering demand function be periodic with a period of 5 x 2 500 m = 12,5 km

i.e. $\frac{W_1}{W_6} = \frac{5}{x} = \frac{L_6}{L_1} = \frac{22,69}{25\ 00}$

It follows that x = 551 approximately.

If we let the frequencies of all terms be in the ratio of prime numbers, and for convenience let the frequencies form an approximate geometric series (i.e. $W_2 \approx 2W_1$; $W_3 \approx 4W_1$; $W_4 \approx 1/4\, W_6$; $W_5 \approx 1/2\, W_6$) then the frequencies of the six terms will be in the ratio:

$$\underbrace{5 : 13 : 29}_{\text{low frequency components}} : \underbrace{167 : 307 : 557}_{\text{high frequency components}}$$

Thus, since $L_j = \frac{W_1 L_1}{W_j}$, $K_j = \frac{2\pi}{L_j}$ can be calculated for all j.

For convenience, the low frequency components are assumed to have equal amplitudes, while the high frequency components have amplitudes inversely proportional to their frequencies (this is to prevent the number of steering wheel reversals over a given period from being determined by the highest frequency term).

APPENDIX 3 CALCULATION OF ROOT-MEAN-SQUARE STEERING ERROR VALUES

The root-mean-square value of a continuous signal e (t) over a time interval $T = t_2 - t_1$ is defined as

$$e(rms) = \sqrt{\frac{1}{T}\int_{t_1}^{t_2} e^2 (t)\, dt} \qquad (1)$$

For a discontinuous (sampled) signal the integration must be performed numerically. Let e be sampled at a rate f, i.e. inter-sample period $h = {}^1/f$. Let there be n* samples over the time period $T = t_i - t_{i-(n-1)}$ i.e. $T = (n-1)h$

The integral over this period is given by the trapezoid rule as follows :

$$\int_{t_i-(n-1)h}^{t_i} e^2 (t)\, dt \approx \frac{h}{2} \left(e^2 (t_i - (n - 1) h) + 2e^2 (t_i - (n - 2) h) + \right.$$

$$\left. + 2e^2 (t_i - (n - 3)h) + \ldots + 2e^2 (t_i - 2h) + 2e^2 (t_i - h) + e^2 (t_i) \right) \qquad (2)$$

NOTATION : let $e^2(t_i) = e_i^2$

thus $e^2(t_i - (n-1)h) = e^2_{i-(n-1)}$, etc.

let $\int_{t_i-(n-1)h}^{t_i} e^2(t)\,dt = I_i$

Then $I_i \approx \frac{h}{2}\left(e^2_{i-(n-1)} + 2e^2_{i-(n-2)} + \dots + 2e^2_{i-1} + e^2_i\right)$

Substituting i - 1 for i :

$I_{i-1} \approx \frac{h}{2}\left(e^2_{(i-1)-(n-1)} + 2e^2_{(i-1)-(n-2)} + \dots + 2e^2_{(i-1)-1} + e^2_{i-1}\right)$

$= \frac{h}{2}\left(e^2_{i-n} + 2e^2_{i-(n-1)} + \dots + 2e^2_{i-2} + e^2_{i-1}\right)$

Thus $I_i = I_{i-1} + \frac{h}{2}\left(e^2_{i-1} + e^2_i - e^2_{i-n} - e^2_{i-(n-1)}\right)$ (3)

Now f = 15 Hz, and let n = 6*.

$h = {}^1/15$ seconds

Thus $T = (6-1)/15 = {}^1/3$ second

Let $I_1 = I_2 = I_3 = I_4 = I_5 = 0$

$I_6 = \frac{1}{30}\left(e_1^2 + 2e_2^2 + 2e_3^2 + 2e_4^2 + 2e_5^2 + e_6^2\right)$

Thus $I_7 = I_6 + \frac{1}{30}\left(e_6^2 + e_7^2 - e_1^2 - e_2^2\right)$, etc.

The i^{th} value of rms error is thus given by

$e_i\,(rms) = K_e^*\sqrt{\frac{1}{1/3}\,I_i} = K_e^*\sqrt{3I_i}$ (4)

K_e is a scaling factor, such that $[e_i\,(rms)]$ = degrees of arc.
if e_i is the output of the steering error ADC.