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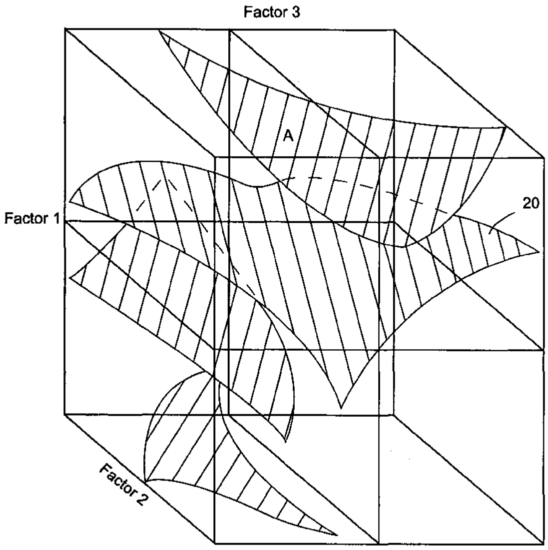
[Continued on next page]

(54) **Title:** VEHICLE SAFETY RESTRAINT DESIGN CONTROLLER



(57) **Abstract:** A safety restraint controller has a database (85) for storing a vehicle occupant restraint factor response model (90). The model (90) relates at least one predetermined restraint factor (88) with the vehicle occupant response (89), the restraint factors having a level that is indicative of setting values for controlling the safety restraint design. A database engine connected to the database (85) determines a level for the vehicle occupant response (89) based upon the model and upon a first level of the restraint factors. An optimizer is connected to the database engine for determining a second level of the restraint factors (88), whcih procudes the desired level of the vehicle occupant response based upon the desired level of the vehicle occupant response (89) from the databse engine; whereby the safety restraint design is controlled based upon the determined second level of the restraint factors that produces the desired level of the safety response.

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VEHICLE SAFETY RESTRAINT DESIGN CONTROLLER

The invention relates generally to a safety restraint controller and to a design methodology and design of experiments system for the design and development of a safety restraint system for an automobile.

New government requirements have significantly increased the number of test scenarios under which a safety restraint system must be evaluated and this has increased the need for improved design methodologies.

Specific injury criteria for a number of anthropomorphic dummies have been set. For any given injury criteria a statistical probability of a particular injury severity can be determined. Using these injury criteria to design a restraint system, it is possible to statistically determine for a given vehicle occupant and crash situation what the likelihood of injury will be and therefore evaluate the effectiveness of changes to a restraint system. Prior to the incorporation of the new requirements, airbag systems were designed using the hybrid III mid-sized male. Due to the often complicated nature of these systems and crash events, it is often not possible to design the system for protecting all possible vehicle occupants for all possible crash situations.

Significant advancements have been made in testing methodologies and computer modeling of restraint systems. Small modifications to the output of various restraint components often lead to significant changes in injury responses in vehicle occupants in varying crash conditions Using previously known methodologies significantly increases the amount of testing and computer simulations that must be run to verify the response of the system to changes in the vehicle structure.

Engineers have performed complex design of experiments to study the relationships between automotive safety restraint components and vehicle occupant responses resulting in intricate mathematical models requiring three-dimensional depictions of the inner relationships, as shown for example in Fig. 1. The various surfaces of Fig. 1 show exemplary relationships between three crash factors and one vehicle occupant response. The crash factors may be the output of an airbag inflator, such as the pressure or temperature, the stiffness of a knee bolster, or a seat belt's elasticity. The vehicle occupant's response may be an attribute of injury criteria such as chest deflection. Fig. 1 illustrates how changes in restraint factors affect the vehicle occupant's response. For example, surface 20 shows that parameters of the restraint factors produce a response value of "30". As shown in Figs. 2a-2b, contour plots can be used to depict relationships between restraint factors and the vehicle occupant responses in a two-dimensional view.

To use experimental results in a restraint system, the contour plots were studied to determine the optimal restraint component factors that would achieve a particular vehicle occupant response. To determine the restraint factors needed to achieve a desired level for two vehicle occupant responses, the contour plots for two vehicle occupant responses were placed atop of each other (see Fig. 2c); thereupon restraint factors were determined based upon the area, of both desired vehicle occupant response levels. The difficulty of analyzing the contour plots dramatically increases with the number of vehicle occupant restraint factors and responses involved. The new government regulations have significantly increased these vehicle occupant restraint factors by increasing the number of crash scenarios and vehicle occupants to be tested, making use of contour plots untenable.

The design of experiments approach was then used in the ever-changing vehicle environments. When the restraint factors and responses had to be changed from the tested initial laboratory configuration, the design of experiments determined a set of optimal restraint factors. The unwieldy manner of the contour plots to effectively address the ever-changing restraint factors and responses within a vehicle's restraint system development, hindered the ability of design of experiments to assist in modifying the restraint factors. Modifications to the restraint factors within the design and development of a restraint system to achieve the desired vehicle occupant responses was an art form. This art form was to be learned from years of experience in controlling the restraint equipment within a vehicle. For these reasons, the development of a restraint system lacks the effective use of the design of experiments approach for controlling a restraint system.

There is disclosed herein a computer implemented method for designing a safety restraint system so that a predetermined desired level of vehicle occupant responses is produced is disclosed.

Further disclosed is a computer-implemented method for controlling the design of an vehicle occupant restraint system so that a predetermined desired level of vehicle occupant responses is produced, the system having the steps of: storing an vehicle occupant restraint factor response model in a computer storage media.

Further disclosed is a safety restraint design controller for controlling the design of a safety restraint system so that a predetermined desired level of vehicle occupant's response is produced.

Further disclosed is a system design methodology, which is broken into four general stages: pre-design verification; design verification; pre-product validation; and product validation.

Further disclosed is a method of providing and selecting from a menu on the display in a restraint controller.

Brief Description of the Drawings

Fig. 1 is a three-dimensional graph depicting several restraint factor-responses as used in a conventional safety restraint design.

Figs. 2a-2c are contour plots of the restraint factor-response relationships as used in the conventional safety restraint art.

Fig. 3 is a flowchart representing the biomechanical system development.

Fig. 4 is a flowchart showing the computerized design of the experiments optimizer of the current invention.

Fig. 5 is a dual stage design methodology utilizing a biomechanical gray zone.

Fig. 6 is a dual stage design methodology depicting the biomechanical gray zone and sensor gray zone.

Fig. 7 depicts an output of one link on the outputs of the design of experiments graphical user interface.

Fig. 8 depicts a second output of one link on the outputs of the design of experiments graphical user interface.

Fig. 9 is a schematic depicting the memory and data structure of the current invention.

Detailed Description of the Invention

The following description of the preferred embodiment concerning the design and development of a safety restraint system is exemplary in nature and is not intended to limit the invention or its application or uses. The invention is clearly not limited to the attachment vehicle airbag and seat belt systems to these components and may be applied to various other structures that have an actuatable safety restraint device.

Fig. 3 is a flowchart representing the biomechanical system development which is divided into four distinct development stages: pre-design verification herein referred to as “pre-dv” 20, design verification herein referred to as “dv” 21, pre-product validation (pre-pv) 22, and product validation herein referred to as “pv” 23. Each distinct development stage contains four primary development analysis tools. These analysis tools include vehicle crashes 24, sled testing 25, numerical analysis 26, and sensor development 27.

The pre-dv stage 20 begins with a vehicle crash. In the phase 1 calibration 28, a prototype vehicle or a vehicle of a similar body type is outfitted with a number of sensors and anthropomorphic dummies. The prototype vehicle is then crashed into a fixed barrier at a given velocity. Data is collected from the phase 1 calibration 28 and used to design the phase 0 initial sled setup 29. The phase 0 initial sled setup 29, which is comprised of approximately 12 sled tests, is used to develop the system design for belted and unbelted conditions in conjunction with multiple levels of crash severity. The sled testing 25 can be completed independently of sensor development 27 and/or used to assist sensor development 27. Data from the Phase 1 calibration 28 is used by a sensor development team to generate deployment times 35 for the various restraint devices, such as airbag inflators and seat belt pretensioners.

Once Phase 0 has been completed, Phase 1 generic system 30 sled testing can be conducted. Phase 1 generic system sled testing 30 comprises approximately 10 sled tests, which are done in a body in white, which more closely represents an actual vehicle environment and hardware. Data from the phase 1 generic system sled testing 30 is used to validate the simulation model 31 of the numerical analysis 26. Once the computer model has been validated, a design of experiments 32 is conducted to define the outputs of the various restraint components, as well as specifying hardware specifications such as the seat belt's elongation or the knee bolster's stiffness. This design of experiments 32 takes into account all of the various vehicle occupant types and in and out-of-position testing as required by government regulations and customer specifications and defines a polynomial equation, which defines the vehicle occupant response based on component parameters and crash/vehicle occupant information.

The design of experiments 32 uses the polynomial equation to define high/low outputs, belt system and thresholds for use with the biomechanical algorithm 33. The biomechanical algorithm 33 is used in conjunction with the generated deployment times/speeds 35 to confirm an ECU calibration 34. This information is then re-verified in the design of experiments 32 to define the initial high/low outputs and belt system.

The initial restraint parameters as defined by the DOE in process block 32 are used in the Phase 2 interim system development crash test 36 and Phase 2a and 2b. Preliminary velocities for high/low/no fire thresholds are set. Initial out-of-position testing is then conducted and used to validate/tune the DOE generated polynomial equations and biomechanical algorithm. At this point, the first designs arising from the DOE are incorporated into prototype vehicles and tested 36. Sled testing 37 in phase 2a and 2b is now conducted with pre-design validated components such as the steering wheel's steering column, the knee bolster structures, and seats. Results from the phase 2 interim system development vehicle crash 36 and the phase 2a and 2b sled testing are used to re-validate and adjust the simulation model in process block 38. The validation model is then rerun in a design of experiments in process block 39 to redefine the high/low outputs and belt system, as well as other restraint system factors for a given restraint system. Process block 40 then issues a new biomechanical algorithm, which is used by the sensor development team to confirm ECU calibration in process block 42. This information is then read into the design of experiments in process block 39 to redefine the high/low outputs and belt systems. Based upon the outputs from the design of experiments 39, the system design is finalized and produced. This includes all outputs such as inflator and pretensioner output and thresholds, as well as systems and hardware such as seats, brackets, seat belt elongation, and bolster stiffness.

Components meeting the specifications as directed by the design of experiments in process block 39 are produced and incorporated into sled testing Phases 3a and 3b 43 of the design validation phase 21. In process block 43, Phases 3a and 3b test the fire high/low/no deployment levels and phase 2 of the out-of-position testing are conducted. Results of this testing are then used to re-validate the simulation model in process block 44. The re-validated simulation process model 44 is incorporated by process block 45 into the design of experiments to once-again redefine the high/low outputs and belt systems of the vehicle via the biomechanical algorithm.

In process block 46, the DOE redefines and issues a new biomechanical algorithm. System components designs that require change are changed and incorporated into the pre-pv 22 stage. Components with a new design are re-tested in the phase 3 vehicle crash 47, as well as in the Phase 4 and 4b for the sled testing 48 of the pre-pv stage 22. Results from the pre-pv and phase 3 vehicle crashes, which contain production intent components, are re-introduced into the DOE in process block 49 to finalize and recheck the response of the system. The response of the DOE is incorporated into the biomechanical algorithm to finally determine and check the restraint system.

When the design of the vehicle's restraint system is finalized, the components are checked in the product validation Phase 23. Phase 4 verification and Phase 5 certification barrier testing is then conducted at block 51. This includes testing for FMVSS 208 requirements as well as NCAP testing. Phase 5 threshold response tests, Phase 6 inflator limit testing, and out-of-position sled tests are conducted on the vehicle sled 52.

Fig. 4 is a flowchart showing the computerized design of experiments optimizer of the current invention. Shown is the graphical user interface (GUI) 53, which is capable of receiving approximately 350 inputs directed towards those parameters necessary for the design of experiments. The GUI 53 receives vehicle input data, which includes the vehicle's geometry, crash pulses or numerous crash situations including frontal and angular, and vehicle interior data such as the bolster and seat stiffness. The GUI 53 further receives information on the restraint systems 55. This includes a range of values for items such as an airbag's inflator, including the pressure, pressure vs. time for, and time to fire the second squib. Further included are restraint factors such as seat belt webbing elongation and whether tensioners are being used. The GUI 53 further allows for the importation of various tested vehicle occupant data 56 including the size and position location of the vehicle occupant within the vehicle. Sizes include 5th, 50th, 95th in belted and unbelted conditions, six-year-old hybrid III, as well as a twelve-month anthropomorphic dummy.

Process block 57 receives data from the GUI 53 and runs a MADYMO model. The DOE generates in process block 57 a data deck of information or experimental data 58. Process block 59 performs a statistical analysis such as analysis of variance or linear regression on the data within the data deck. Upon completion of the statistical analysis, the data is ready to be post processed by the graphical output interface or GOI. It is possible by using the graphical output interface to remove variables from the equations without rerunning the entire optimization of the design of experiments. Once the determination is made as to which variables are important and will be used in the final system equations,

equations are brought together and lumped into a single equation or factor response model in process block 60. The system in process block 61 calculates the vehicle occupant response and restraint factors based on the polynomial equations generated in process block 60. It is possible and optional, to use an optimizer in process block 62 to optimize the restraint systems. Generally, the system is not, however, utilized to "optimize" the overall system. The system is "generalized" to meet the best overall vehicle occupant restraint for the highest number of vehicle occupants possible. Statistical accident data such as data collected by NHTSA can be used to determine appropriate risk factors to reduce overall accident injuries. Once the system factors are used to determine items such as the inflator outputs and thresholds, data is then utilized to develop a biomechanical algorithm. The biomechanical algorithm defines, based on the vehicle occupant injury numbers and the vehicle sensing system, the actuation of the specific restraint components.

The restraint system factors as developed by the biomechanical system development regime can be used to define a biomechanical algorithm. A biomechanical algorithm is an algorithm that defines the threshold speeds and response of vehicle components in the event of a vehicle crash. The biomechanical algorithm further defines the output parameters for the components of the restraint devices.

Figs. 5 and 6 are a dual stage design methodology utilizing a biomechanical gray zone. Fig. 6 is a dual stage design methodology depicting the biomechanical gray zone and sensor gray zone. WO 01/83276 gives details of how the dual stage design methodology uses the biomechanical gray zones and sensor gray zones.

Fig. 7 depicts the output of one link on the outputs of the design of experiments graphical output interface. One specific useful feature is the ability to click on a specific vehicle occupant such as the 95th percent driver and a frontal rigid barrier impact and determine the injury responses for that vehicle occupant. The responses shown for a given vehicle occupant represent the point when one or more vehicle occupant responses fall outside of an acceptable level. By placing the cursor onto a graph, the system provides the user with the variable, for example inflator tank pressure, that most significantly affects the out-of-bounds vehicle occupant response. The user can change the values of this variable by moving the variable slide. Upon doing so, the processor recalculates the vehicle occupant responses and thresholds for all vehicle occupants in all crash scenarios.

Fig. 8 represents a screen display of a biomechanical map of a particular vehicle during front 21 crash scenarios. On the left-hand axis 70 is represented a series of possible threshold speeds for the deployment of high and low airbag inflator outputs or pretensioners. Along the lower horizontal axis are the varying types of vehicle occupants in belted and unbelted stages that can be tested 72. For a given set of restraint factors, as well as real crash threshold information, sensor thresholds 74 are provided. For a given vehicle occupant, for example a 95th percentile male in an unbelted crash into a 0° barrier impact 76, two values are shown. The first is with respect to the passenger 77 and the second is with respect to the driver 78. The markers 77 and 78 represent locations where there is a "must fire" situation for a given vehicle. The sensor threshold is below the must fire threshold for an unbelted 95th percentile male driver or passenger situation, at about 24 Kph.

When investigating a 95th percentile male in an unbelted condition at a 30° rigid barrier impact, it can be seen that the sensor threshold 74 is higher for this crash than the must fire threshold values for driver 82 and the passenger 84. The system allows for a user to adapt the restraint factors to adjust the outputs for these given vehicle occupants and will be able to evaluate the effect of the changes on the vehicle occupant responses for all vehicle occupants and crash scenarios shown on the biomechanical map. The user can return to the screen, see Fig. 7, to evaluate the changes to the response of the system.

Instantaneous evaluation of all vehicle occupants in all crash situations is now possible without the need for costly and time-consuming testing. It is possible to determine which of the injury criteria will most significantly affect the overall passing or failure of the vehicle occupant's response with the system. It is possible to make a determination whether the injury criteria is "important" and also what possible remedies can be done to fix the problem. For instance, when it is determined that the head HIC value is slightly above the specification value, it may be possible to reduce the amount of pressure within the airbag to reduce the value of this injury criterion. Should the model for some reason not correlate on a particular injury value with the vehicle crashes 24 or the sled tests 25 (for example neck flexion), this value can be removed from the equation and the system evaluated. Those skilled in the art could glean from the data the possible choices of outputs to the restraint component designs.

Fig. 9 shows the organization of memory of the present invention. A first computer 84 performs the vehicle factor and response calculations based upon the factor response models. The response calculation values are used to control the settings of the restraint factor response model to achieve the desired vehicle occupant responses. The first computer 82 has a memory 84 that includes a data structure 85. The data structure 85 has a restraint factor data structure 86 and a vehicle occupant response data structure 87. The data structure 85 also includes restraint factor data 88 and vehicle occupant response data 89.

The restraint factor data structure 86 and vehicle occupant response data structure 87 have access to the factor response models 90 that are stored in a data base. The restraint factor data structure 86 includes restraint factors such as seat belt tension, airbag inflator pressure and temperature and size, as well as vehicle interior stiffness. The vehicle occupant response data structure 82 stores responses of a vehicle occupant for a different kind of situation such as HIC, chest G's, or Femur loads. Values for the restraint factor data structure 86 and vehicle occupant response data structure 82 are limited to actual real world values by the restraint factor constraint data structures 91 and vehicle occupant response constraint data structure 92.

Claims:

1. A safety restraint design controller comprising:

a database (88) for storing a vehicle occupant restraint factor response model (90), the model relating at least one predetermined restraint factor (88) with the vehicle occupant response (89), the restraint factors having a level that is indicative of setting values for controlling the safety restraint design;

a database engine connected to the database for determining a level for the vehicle occupant response (89) based upon the model and upon a first level of the restraint factors (88);

an optimizer connected to the database engine for determining a second level of the restraint factors (88), which produces the desired level of the vehicle occupant response based upon the desired level of the vehicle occupant response from the database engine;

whereby the safety restraint design is controlled based upon the determined second level of the restraint factors, which produces the desired level of the safety response.

2. The safety restraint design controller of claim 1 wherein the model relates a plurality of restraint factors (88) with a plurality of vehicle occupant responses (89).

3. The safety restraint design controller of claim 2 wherein the optimizer constrains the permissible level ranges for the restraint factors and for the vehicle occupant responses (89) in determining a second level of the vehicle occupant restraint factors.

4. The safety restraint design controller of claim 2 further including a computer-human interface (84) for constraining the permissible level ranges for the restraint factors and for the vehicle

occupant responses in determining a second level of the vehicle occupant responses.

5. The safety restraint design controller of claim 2 further containing a module for determining a second level of restraint factors.

6. The safety restraint design controller of claim 2 wherein the predetermined restraint factor is determined by conducting a vehicle barrier test.

7. The safety restraint design controller of claim 1 wherein the optimizer constrains the permissible level ranges (91) for the restraint factors and for the vehicle occupant responses (92) in determining a second level of the vehicle occupant restraint factors.

8. A computer implemented method for designing a safety restraint system comprising the steps of:

storing a vehicle occupant restraint factor response model (90) in a computer storage medium (84), the model relating at least one predetermined restraint factor (88) with the vehicle occupant response (89), the restraint factors having a level that is indicative of setting values for response output for components within the design of the restraint system;

determining a level for the vehicle occupant response (89) based upon the model and upon a first level of the restraint factors;

determining a second level of the restraint factors (88), which produces the desired level of the vehicle occupant response (89) based upon the determined level of the vehicle occupant response (89); and

modifying the restraint system based upon the determined second level of the restraint factors (88), which produces the desired level of the vehicle occupant response (82).

9. The computer implemented method for designing a safety restraint system of claim 8 wherein the model is based on a design of experiments involving the restraint factors (88) and the vehicle occupant response (89).

10. The computer implemented method for designing a safety restraint system of Claim 8 wherein the model includes relating a plurality of restraint factors (86) with a plurality of vehicle occupant responses (89).

11. The computer implemented method for designing a safety restraint system of Claim 8 further comprising the step of: constraining the permissible level of the plurality of the restraint factors (88) and for the plurality of vehicle occupant responses in determining a second level of the vehicle occupant responses (89).

12. The computer implemented method for designing a safety restraint system of Claim 8 wherein a computer-human interface (84) is used for constraining the permissible level ranges for the restraint factors and for the vehicle occupant responses in determining a second level of the vehicle occupant responses.

13. The computer implemented method for designing a safety restraint system of Claim 8 further including the step of determining a second level of the restraint factors.

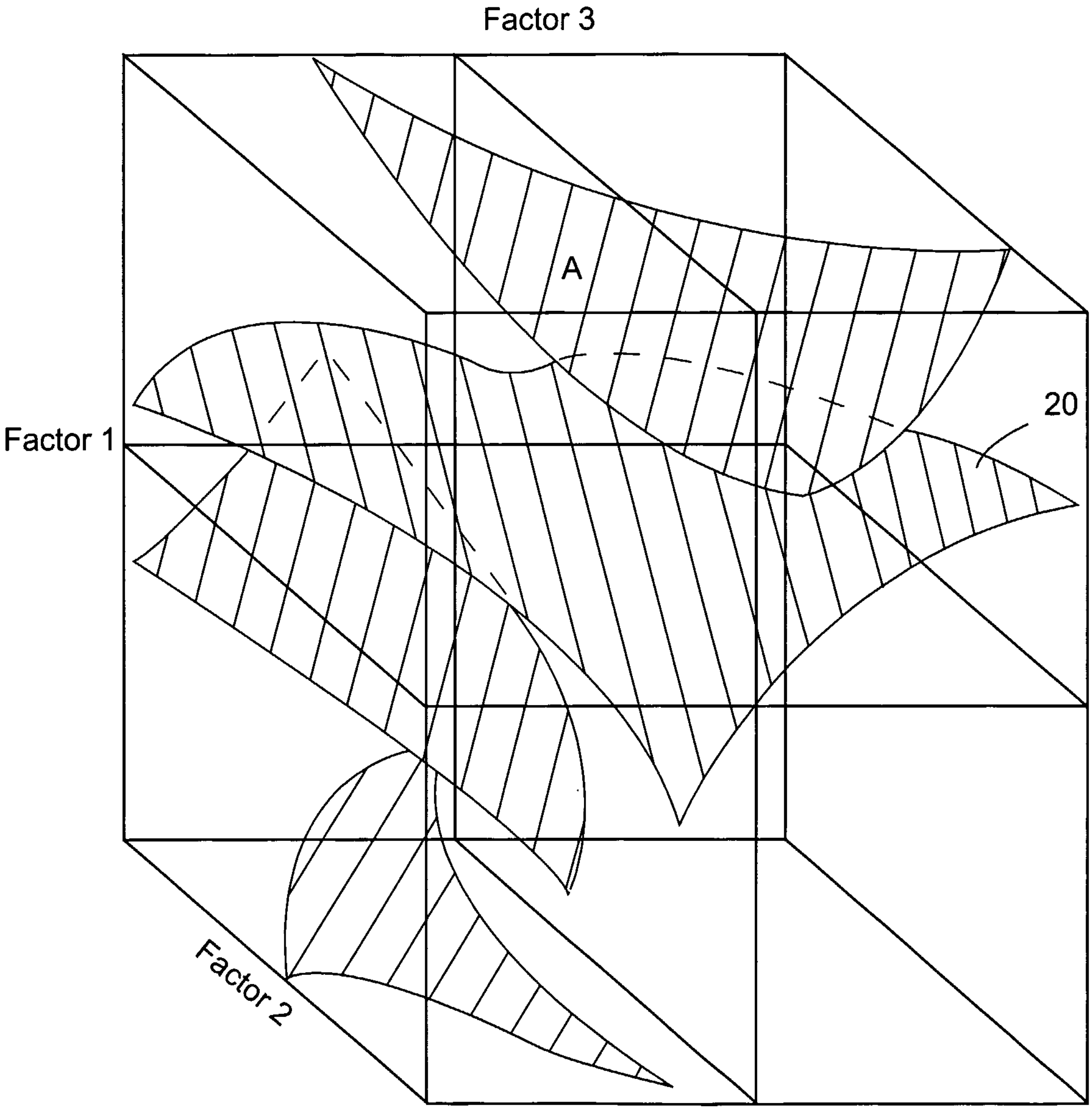


Fig. 1 Prior Art

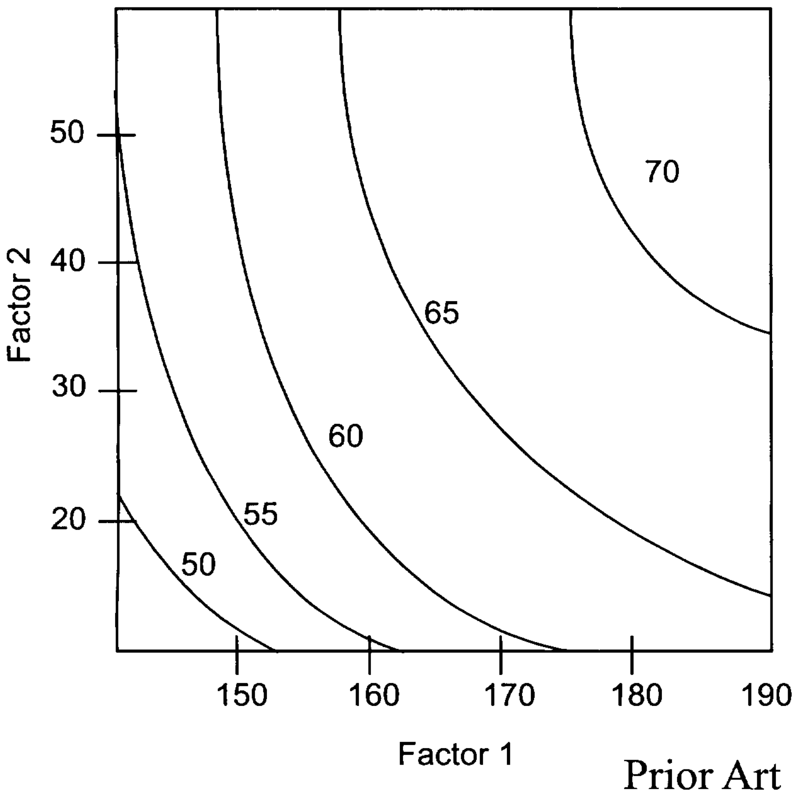


Fig. 2a

Prior Art

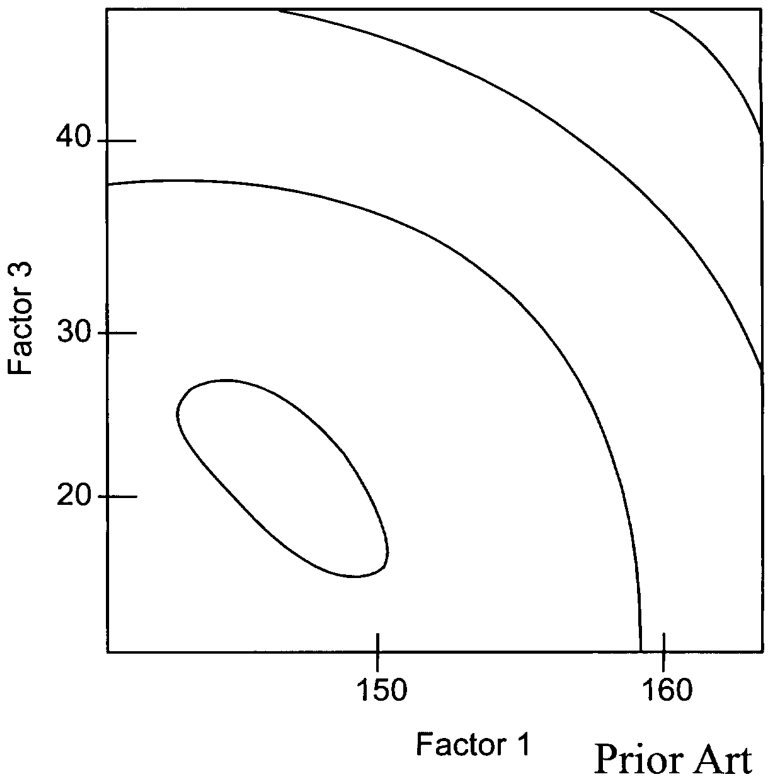
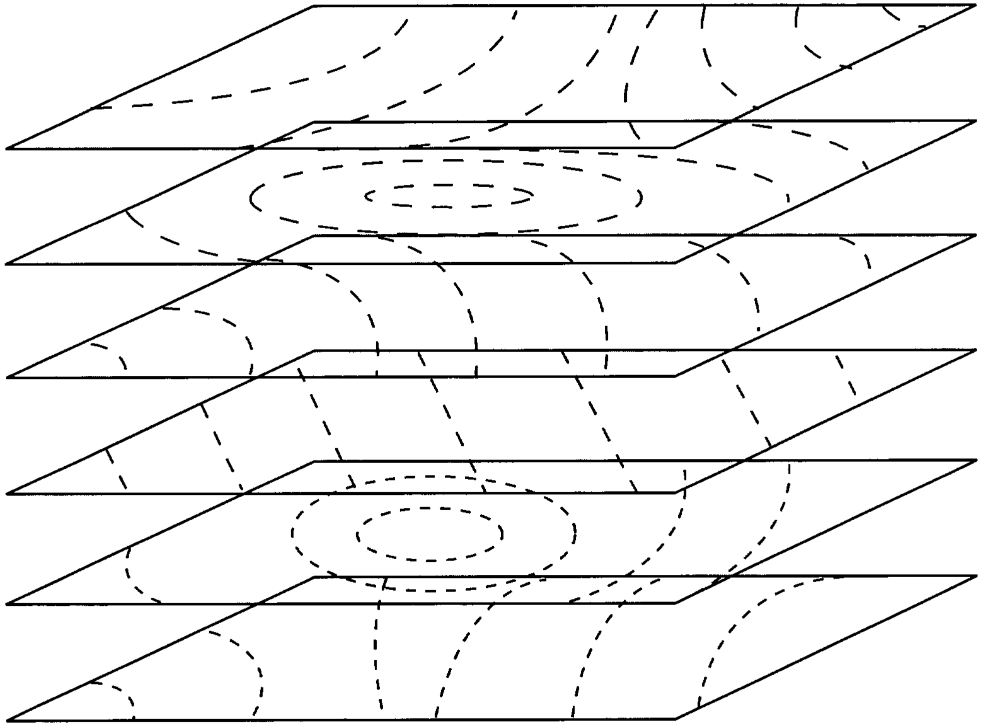


Fig. 2b

Prior Art



Prior Art

Fig. 2c

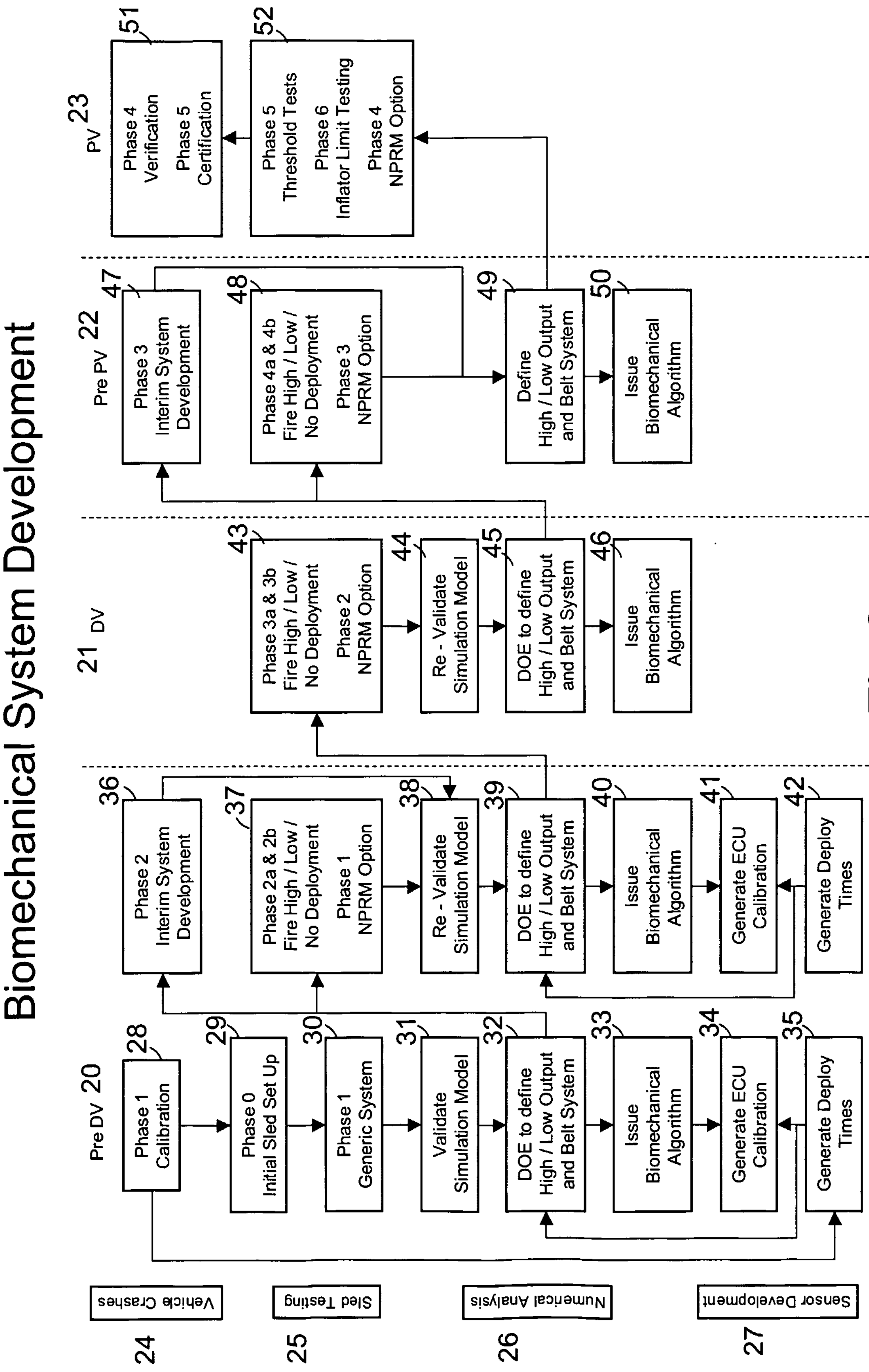

Biomechanical System Development
Pre DV 20
21 DV
Pre PV 22
PV 23
Phase 1 Calibration
28
Phase 0 Initial Sled Set Up
29
Phase 1 Generic System
30
Validate Simulation Model
31
DOE to define High / Low Output and Belt System
32
Issue Biomechanical Algorithm
33
Generate ECU Calibration
34
Generate Deploy Times
35
Phase 2 Interim System Development
36
Phase 2a & 2b Fire High / Low / No Deployment Phase 1 NPRM Option
37
Re - Validate Simulation Model
38
DOE to define High / Low Output and Belt System
39
Issue Biomechanical Algorithm
40
Generate ECU Calibration
41
Generate Deploy Times
42
Phase 3a & 3b Fire High / Low / No Deployment Phase 2 NPRM Option
43
Re - Validate Simulation Model
44
DOE to define High / Low Output and Belt System
45
Issue Biomechanical Algorithm
46
Phase 3 Interim System Development
47
Phase 4a & 4b Fire High / Low / No Deployment Phase 3 NPRM Option
48
Define High / Low Output and Belt System
49
Issue Biomechanical Algorithm
50
Phase 4 Verification Phase 5 Certification
51
Phase 5 Threshold Tests Phase 6 Inflator Limit Testing Phase 4 NPRM Option
52
Vehicle Crashes
24
Sled Testing
25
Numerical Analysis
26
Sensor Development
27

Fig. 3

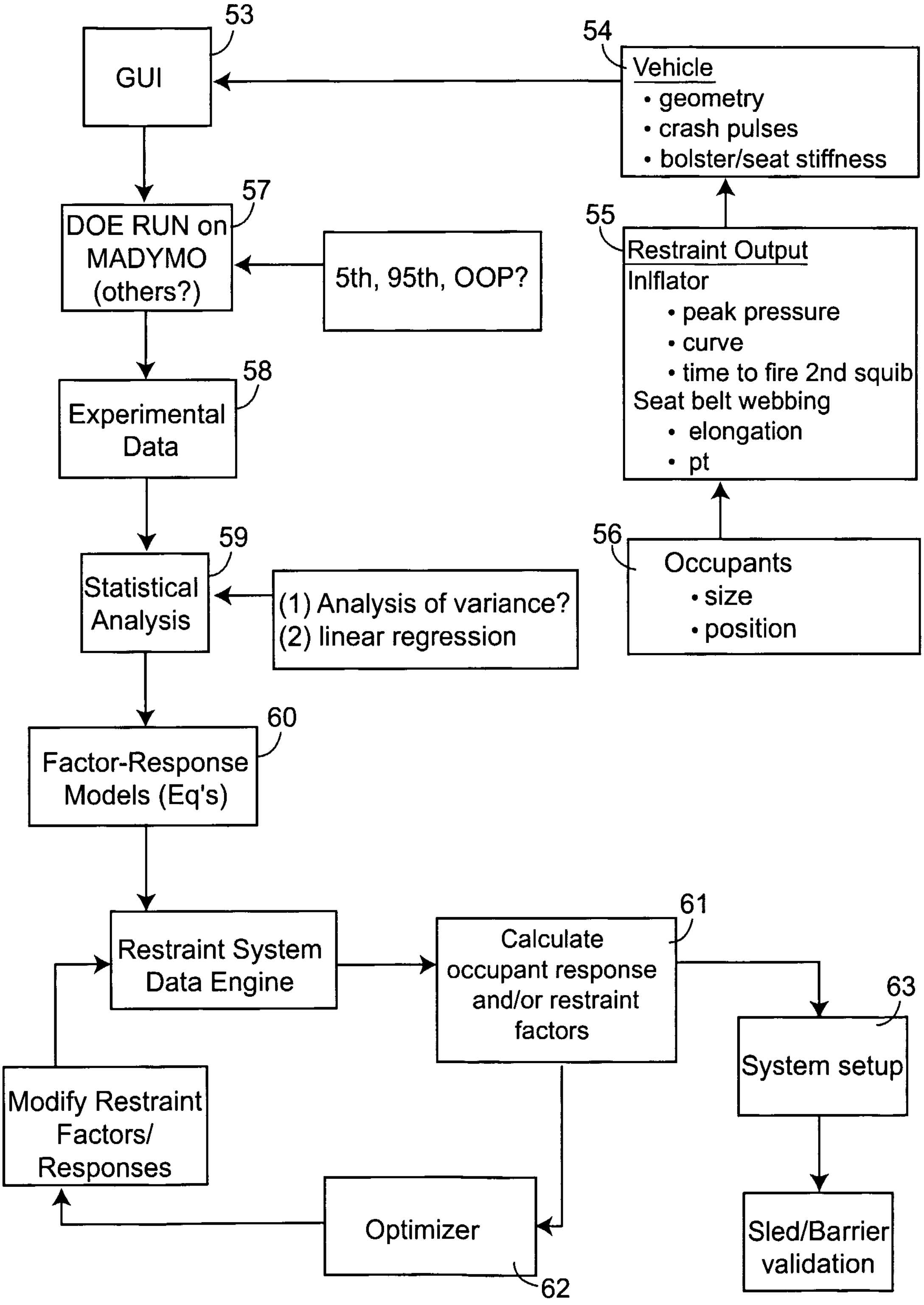

53
GUI
54
Vehicle
• geometry
• crash pulses
• bolster/seat stiffness
57
DOE RUN on MADYMO (others?)
5th, 95th, OOP?
55
Restraint Output
Inlflator
• peak pressure
• curve
• time to fire 2nd squib
Seat belt webbing
• elongation
• pt
58
Experimental Data
59
Statistical Analysis
(1) Analysis of variance?
(2) linear regression
56
Occupants
• size
• position
60
Factor-Response Models (Eq's)
Restraint System Data Engine
61
Calculate occupant response and/or restraint factors
63
System setup
Modify Restraint Factors/ Responses
Optimizer
62
Sled/Barrier validation

Fig. 4

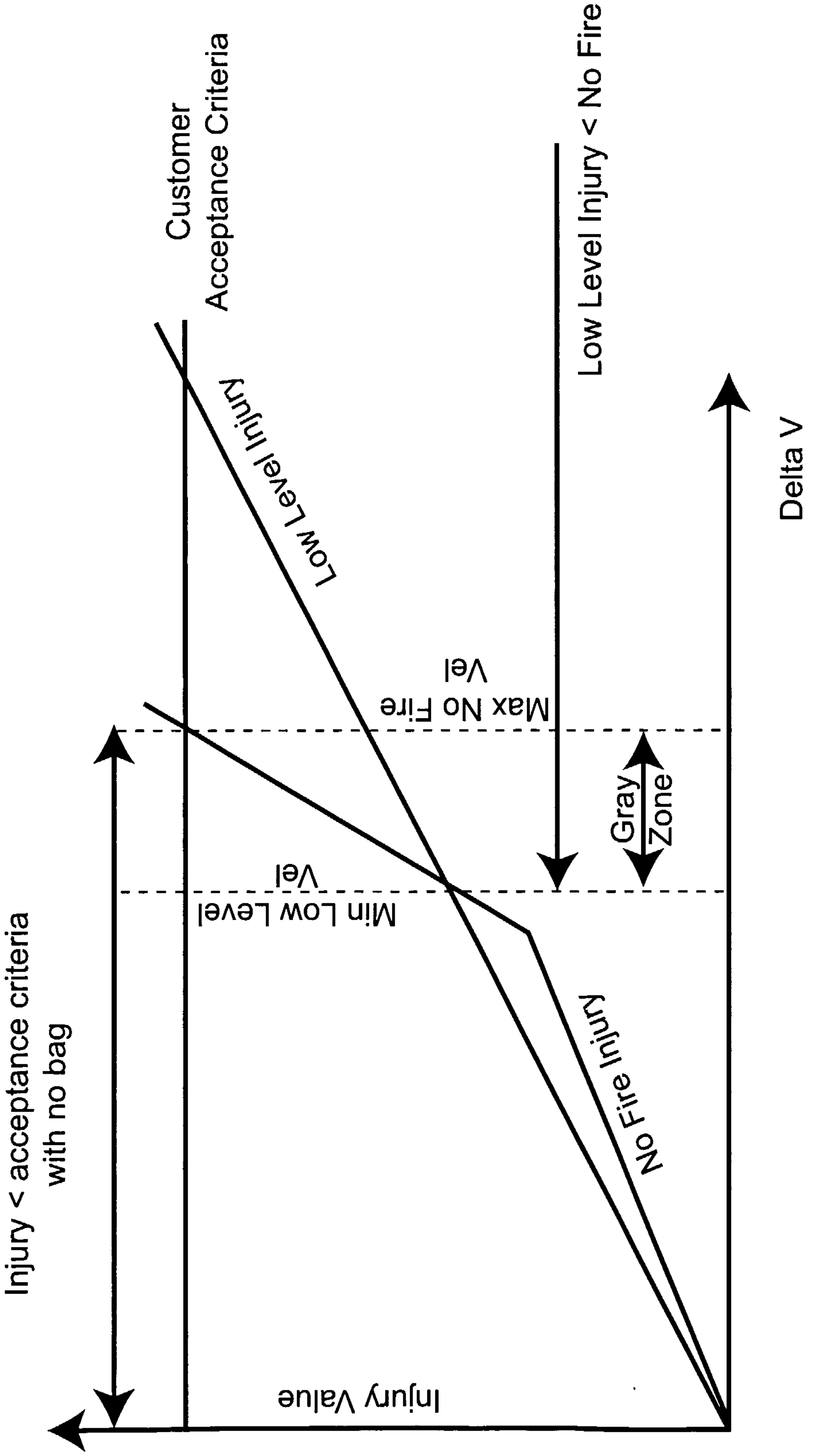

Customer
Acceptance Criteria
Low Level Injury < No Fire
Low Level Injury
Delta V
Max No Fire
Vel
Gray
Zone
Min Low Level
Vel
No Fire Injury
Injury < acceptance criteria
with no bag
Injury Value

Fig. 5

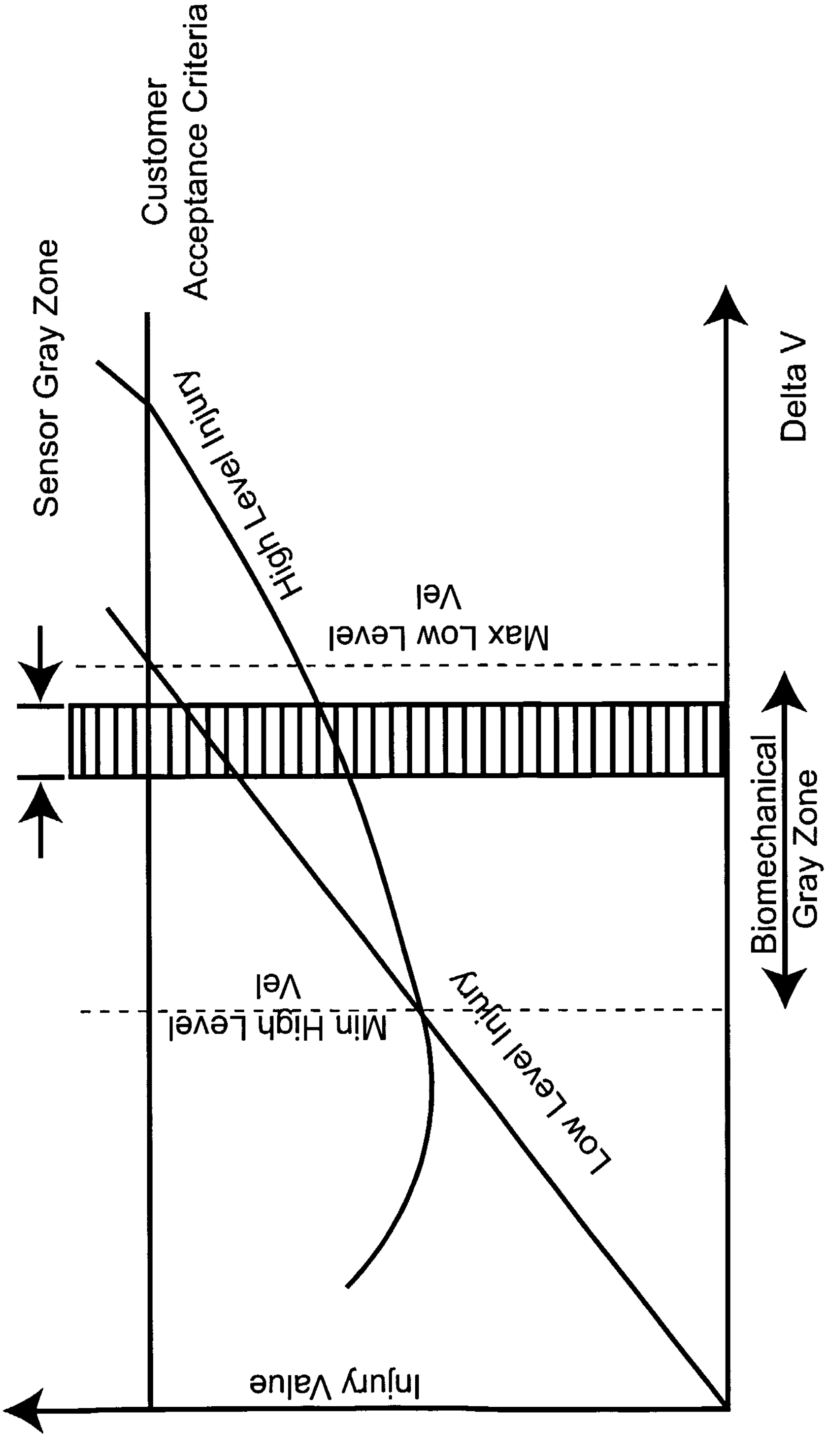
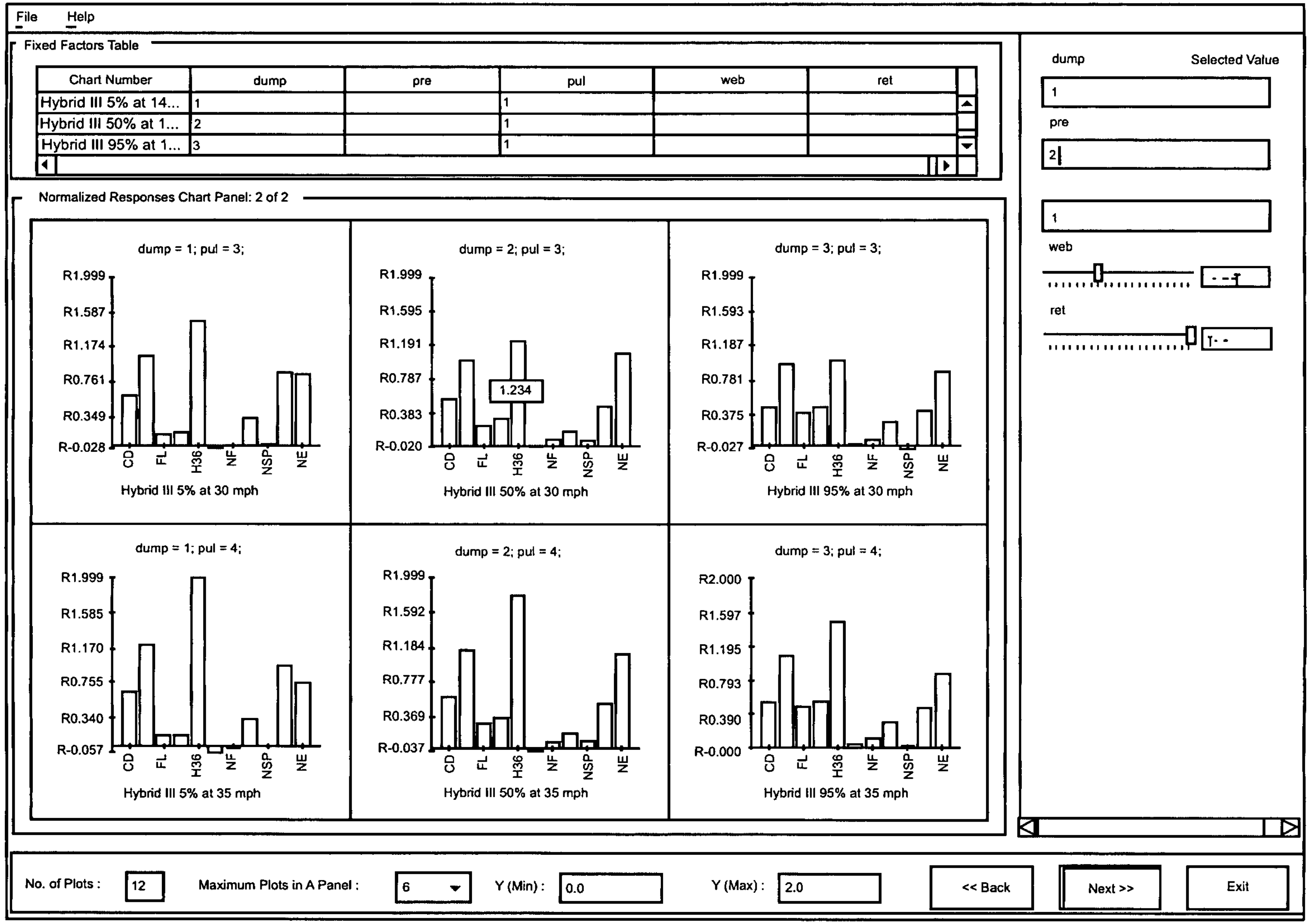

Sensor Gray Zone
Customer
Acceptance Criteria
Delta V
High Level Injury
Max Low Level
Vel
Biomechanical
Gray Zone
Min High Level
Vel
Low Level Injury
Injury Value

Fig. 6



Fixed Factors Table

Chart Number	dump	pre	pul	web	ret
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Hybrid III 50% at 1...	2		1		
Hybrid III 95% at 1...	3		1		

Normalized Responses Chart Panel: 2 of 2

dump Selected Value: 1

pre: 2

1

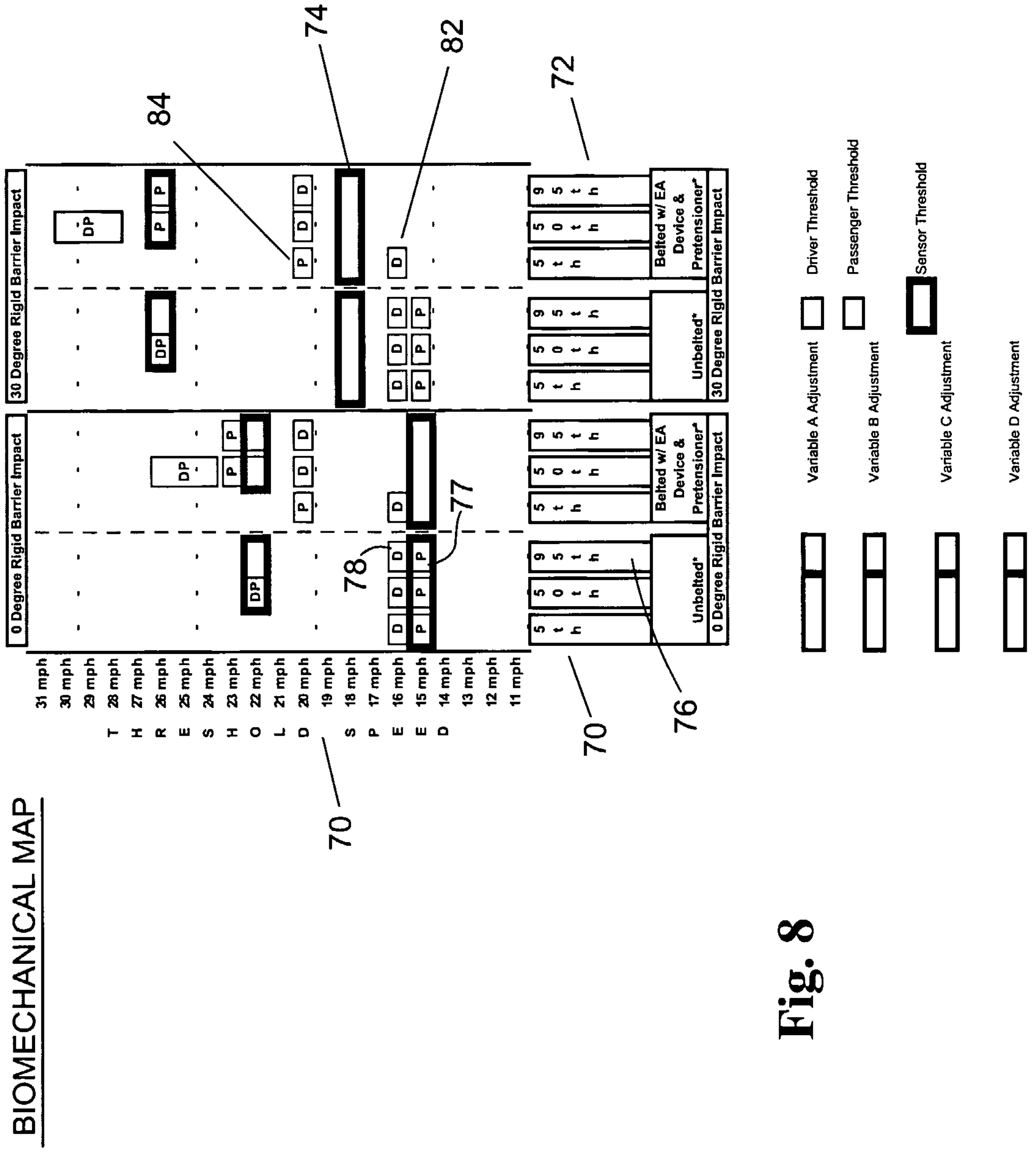
No. of Plots : 12

Maximum Plots in A Panel : 6

Y (Min) : 0.0

Y (Max) : 2.0

Fig. 7


BIOMECHANICAL MAP
0 Degree Rigid Barrier Impact
30 Degree Rigid Barrier Impact
31 mph
30 mph
29 mph
28 mph
27 mph
26 mph
25 mph
24 mph
23 mph
22 mph
21 mph
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12 mph
11 mph
THRESHOLD
SPEED
D
P
DP
5th
50th
95th
Unbelted*
Belted w/ EA Device & Pretensioner*
Driver Threshold
Passenger Threshold
Sensor Threshold
Variable A Adjustment
Variable B Adjustment
Variable C Adjustment
Variable D Adjustment
70
72
74
76
77
78
82
84

Fig. 8

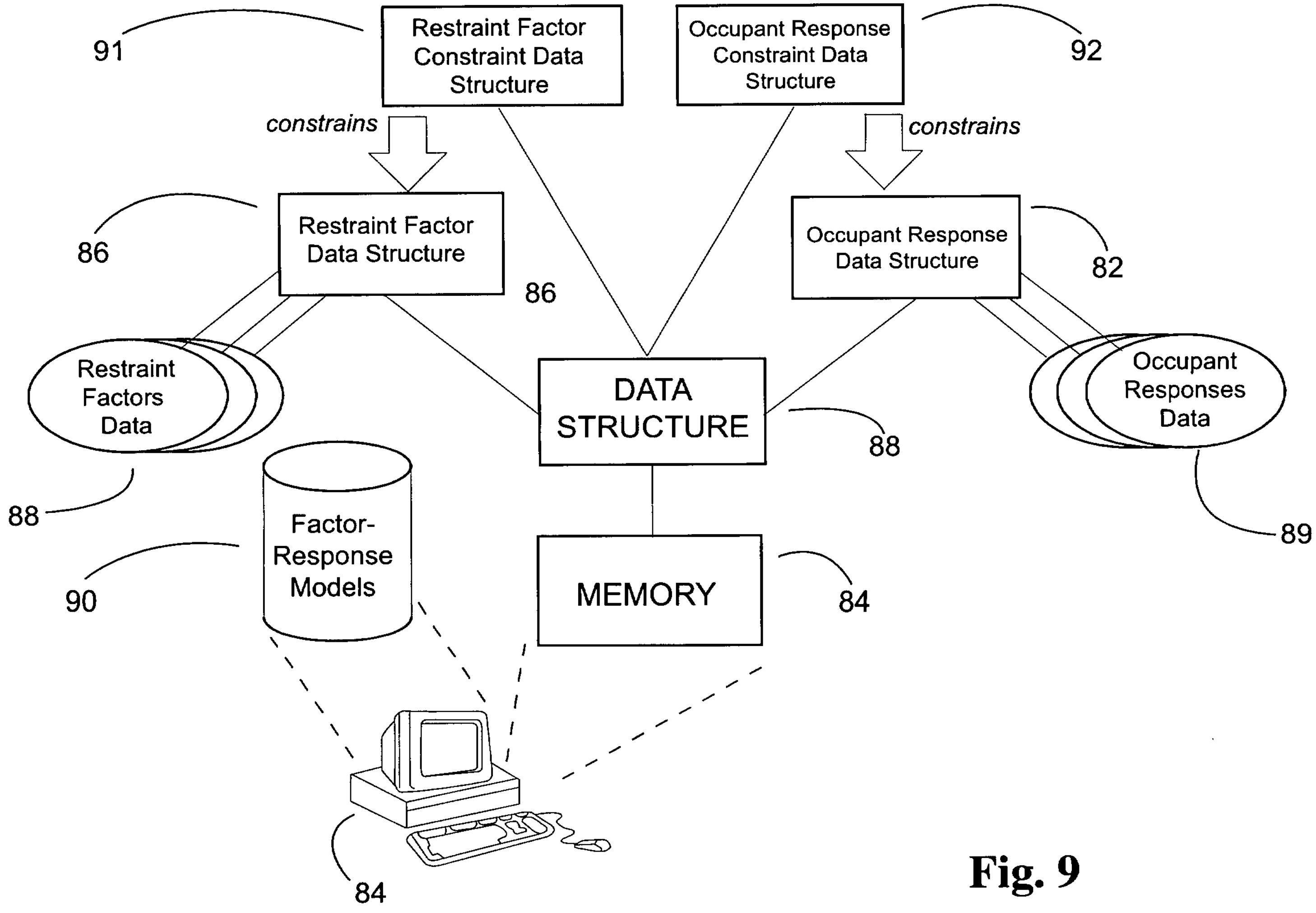
91
Restraint Factor Constraint Data Structure
Occupant Response Constraint Data Structure
92
constrains
constrains
86
Restraint Factor Data Structure
86
Occupant Response Data Structure
82
Restraint Factors Data
DATA STRUCTURE
Occupant Responses Data
88
88
Factor-Response Models
89
90
MEMORY
84
84

Fig. 9