Applying constraints to vehicle packaging

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Abstract:

One of the first steps in the design of a new vehicle is the creation of the "occupant workspace". This step involves establishing the interior space, and placing structural components (seats, steering wheel, etc..) in a manner that is consistent with occupant safety, comfort, convenience and accommodation. Current standards are developed and published by the Society of Automotive Engineers (SAE). These standards form the basis for the construction of CAD procedures that attempt to model a basic vehicle package. This paper describes a system that generates and checks vehicle packages based on SAE guidelines. In this system, relationships between vehicle dimensions are represented as SOLVER models. After loading the CAD models, the system establishes initial packaging and awaits user input. The initial package is then refined until a satisfactory model is achieved. This paper outlines the role of constraints in vehicle interior design and provides initial results on existing car models.

1. Motivation:

The first requirements in automobile design is to make sure occupants are placed safely and comfortably. This process of "vehicle packaging" consists of several competing activities. In the preliminary stage, most attention is focused on the manikin in its seated position. A basic package is achieved by establishing front and rear seat geometry, front and rear seat entry and egress as well as seat environment (visibility, reach).

The automotive occupant packaging process relies on a "human factors" database that defines spatial locations for the driver's eye and head, hand reach, preferred seat positions and other related dimensions. Most of these studies are conducted under the hospices of the Society of Automotive Engineers (SAE), which publishes standards ranging from motor vehicle dimensions to headlamps. Many of the studies involved hundreds of human subjects and have resulted in standardized drafting templates and CAD procedures that are used to develop seating packages for combined populations of male and female vehicle users[1]. SAE standards are functional, task-oriented design tools. The accurate application of these tools requires use in accordance with detailed procedures described in the practices. The following procedure taken from SAE J941, describes one such standard for locating the neck pivot and eye points:

1. Determine the SgRP and L40
2. Locate P1 and P2 _ These neck pivot points are linked to eye points near the front of a 95th eyellipse.
The X coordinate of P1 and P2 depends on seat track travel(L23):
a) For L23 from 100 to 133 mm
$(P1)\ X = L31 - 224.01472 + 10.281641*(L40) - 0.032032*(L40)^2$
$(P2)\ X = X(\text{of } P1) + 28$
b) For L23 greater than 133 mm
$(P1)\ X = L31 - 250.01472 + 10.281641*(L40) - 0.032032*(L40)^2$
$(P2)\ X = X(\text{of } P1) + 28$
The Y and Z coordinates of P1 and P2 do not depend on seat track travel
$(P1)\ Y = W20 - 20$
$(P2)\ Y = W20 + 47$
$(P1\ \&\ P2)\ Z = H70 + 645.11757 + 0.398747*(L40) - 0.059301*(L40)^2$
where:
L23 = seat track travel
L40 = Front back angle
L31 = SgRP front (Seating reference point) X coordinate.

As shown in this example, the typical SAE standard involves a set of assumptions, a constructive step-by-step procedure and a set of vehicle dimensions (or variables). One assumption in the example is that the seating reference point and front back angle have already been established (determined by other SAE studies). Traditionally, each study is conducted separately, the first step being the location of the driver seat in the comfort zone. In order to be competitive, a car manufacturer must produce innovative products on a regular basis. In this context, full size 2D side view renderings are considered and discarded very quickly. The necessity for speed in the preparation of these renderings prohibits a full package study (all components). Even with the help of a CAD system, producing a full package requires days and even weeks of tedious work. At each stage of this process, each component must be carefully checked. If a given component necessitates changes in vehicle interior dimensions, all other components have to be checked. A typical component study consists of 10 to 20 variables and about 10 relationships. Certain variables are common to all studies, creating complex dependencies among activities. Each change to a basic dimension needs to be propagated to all the other components.

The traditional CAD approach does not support iteration very well. When a change to a package occurs late in the process, the costs of repackaging are very high considering that each individual study has to be verified. In practice, such an alternative is not even considered. Shortcuts are often taken in order to expedite the process. In particular, very often the package is built around one segment of the population, usually 95th percentile male.

The need to improve this process is key to producing vehicle packages quickly and accurately. Any improvement in this process has to provide a way of capturing each activity's goals, variables and relationships in an active way.

The approach presented in this paper considers the packaging process as one problem consisting of different tasks[2]. It is based on the propose-critique-modify method for Design[7]. The first step of this method proposes a solution, if any. The solution is then critiqued and sources of failure are identified. Finally, the proposal is modified and the system iterates. In our domain, each task is defined by a set of variables (vehicle interior dimensions) and a set of relations (SAE standards). The modification step is done interactively and consists of changing variables and/or relationships.The system described in this paper uses ILOG SOLVER to express the different tasks, ILOG VIEWS for graphics and ILOG DB-LINK for database access. This system is currently undergoing validation using existing vehicle models. Preliminary results are very encouraging. The system designed is described in more details in the next section.

2. System description:

The current implementation supports three distinct modes of interaction:

- **Constraint checking:** This mode uses the knowledge-base as a basis to check that the basic relationships between vehicle dimensions are satisfied. This mode is interactive, with the system performing verification in the background. When constraints are violated, the user is notified through error messages and warnings.

- **Package generation:** When a vehicle package has been completed, it is still possible for the user to change one or two dimensions(usually, to accommodate engineering/manufacturing). In this case, the system regenerates the package taking into account the new values.

- **Goal-driven design:** The design of a new vehicle is a carry-over process. Existing designs are improved upon to meet marketing and product objectives. The current system allows the user to specify an existing base-vehicle and a goal such as: "improve the legroom by 5%". The system then derives the new package, taking into account basic relationships.

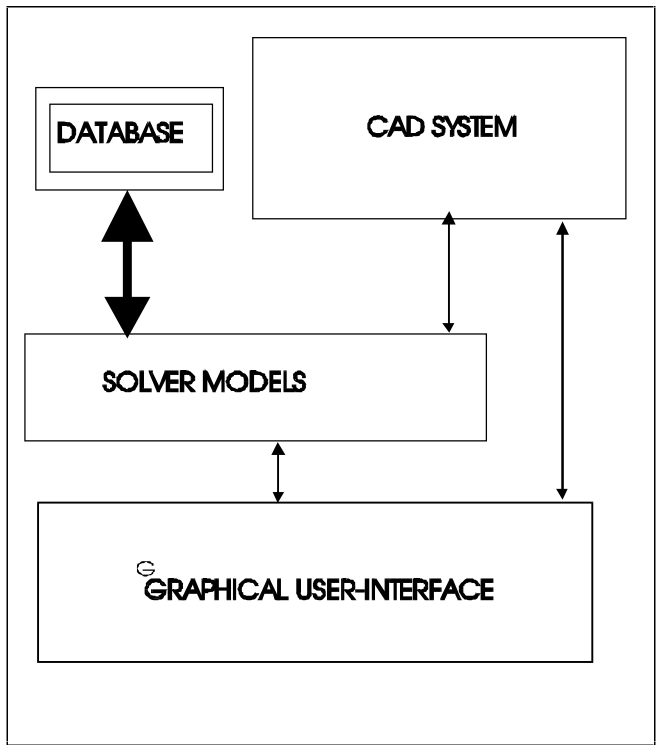

Fig. 1

The basic architecture of the system consists of a relational database, a CAD model base, a set of SOLVER models and a user-interface. The database provides the interior and exterior dimensions for each vehicle. The CAD system is used for vehicle outlines and various components parts. The SOLVER models currently consist of two tasks, the manikin's placement task and the visibility studies[6]. The graphical user-interface provides basic drawing for packages.

The SOLVER component is comprised of several models all tied through a common core. The current implementation includes models for manikin placement, seat track travel estimation and "legroom maximization". The core model is responsible for maintaining the manikin geometry as well as ensuring that at least 95% of the driving population is seated "comfortably".

In this system, the user specifies a vehicle model, seat height and accommodation level (population percentile). Based on this input, the system retrieves the proper vehicle dimensions from the database and the CAD geometry from CATIA[8] libraries. The system generates components placement based on vehicle dimensions and input. The graphical user interface is updated during the search for solutions, thereby giving the user some insight on what the system is doing. If the user is satisfied with the current solution, the database is updated. Otherwise, values can be changed and the search is reiterated with the new parameters accordingly. Figures 2 and 3 of the appendix, show snapshots of the user interface. The viewer screen is used for graphics manipulation and display. Initially, the manikin is not lined up correctly. The "KBE" screen displays the initial data as well as the results of the placement. After the initial placement, the user may change the numbers in the spreadsheet and check the constraints again.

What follows is an overview of the elements that make the manikin placement task. All other tasks, including future tasks, are dependent on the manikin's position.

2.1. Manikin placement task:

The preferred position of a driver using a horizontally adjustable seat is dependent on the driver's interaction with the vehicle space arrangement. Studies conducted on a number of vehicles indicated a relation between preferred horizontal seat position and seat height. A driver selected seat position standard has been developed to describe where certain percentages of drivers are positioned[3].

- **Variables:**

H-point: A point which simulates the pivot center of the human torso and thigh, and provides a landmark reflecting where people sit in a seat. The H-point is intrinsic to the seat.

Hx, Hz: H-point X, H-point height resp.
Accelerator heel point: HeelX
Ball of foot plane: (BOF)
Pedal angle: θ

- **Relationships: (See fig. 4)**

1. Accommodation curves:

Two dimensional side-view curves which express driver seat positions for populations ranging from 2.5th to 97th percentile. These curves relate Hx to Hz.

2. Heel to H-point: A second degree polynomial that determines θ as a function of Hz.

This model provides a method for deriving the H-point, the Heel-point and the pedal angle based on accommodation curves and heel-to-H constraints. The user specifies a seat height and an accommodation level (2.5 to 97.5) and the system computes the best seating package. Based on the position of the H-point, the manufacturer derives a Seating Reference Point for subsequent studies.

The use of SOLVER models allowed us to generate and compare various seating positions for every population mix.

2.2 Fully articulated model with track-travel generation:

This model builds upon the core model by adding the Knee-point and its relations to the H-point and Heel-point. By varying the level of accommodation from the smallest to the largest, we are able to accurately determine the minimal value for a seat track travel. This model provides a method to verify that a given vehicle accommodates the entire driving population.

2.3 Legroom maximization model:

This model incorporates the features of the articulated model with a difference in the way the package is generated. An objective function is introduce that describes the driver's legroom. A seating package is calculated so that the legroom is maximal. This model is important in that it makes possible the improvement of a given seating package by providing more legroom.

Fig. 4

3. Preliminary results:

The system has been used to check existing vehicles for manikin accommodation and seat track travel. Table 1 summarizes the findings. In some cases, the actual seat track travel is less than the minimum generated. In such cases, some percentage of the population will not be accommodated properly. In other cases, the use of SOLVER allowed us to study high-seating vehicles such as the LNDROV93 whose seat height exceeds the upper bound of the original SAE domain.

VEHICLE	SEAT	Hx	Hx	SEAT TRACK	MIN SEAT TRACK

	HEIGHT	(SAE)	(SOLVER)	(DATA)	(SOLVER)
PAJERO91	450	820.3	820.3	175	92.14
BRONCO86	257.9	957.4	957.3	172	193.04
GEO89	254.8	958	958.06	172	193.5
4RUNR86	152.8	970.8	970.78	161	212.15
LNDROV93	467	801.3	801.24	200	93.34
CAMRY94	274.5	950.8	950.9	224	190.5
ACCRD95	240	962.4	962.4	208.1	195.9
CAMRY95	274.5	950.9	950.9	225.5	190.51
LEXUS95	202.7	969.6	969.6	239.1	202.4

Table 1. (Unit mm)

Next, we have taken existing vehicle models and tried to improve the legroom while accommodating 95% of the drivers. Table 2 shows the results of such improvements.

VEHICLE	SEAT HEIGHT	HX	LEGROOM (ACTUAL)	LEGROOM (IMPROVED)

PAJERO91	450	820.3	781.4	801.6
BRONCO86	257.9	957.04	897.115	902.14
GEO89	254.8	958.06	897.1	902.14
4RUNR86	152.8	950.3	904.77	907.04
LNDROV93	467	801.24	769.7	807.6
CAMRY94	274.5	950.92	889.3	901.44
ACCRD95	240	962.4	904.75	905.4
CAMRY95	274.5	950.92	889.3	901.44
LEXUS95	202.7	951.2	896.98	902.14

Table2. (mm)

4: Evaluation and conclusion:

This section discusses the advantages of using a constraints library such as SOLVER to put in place a vehicle package. In the early days, placing a manikin consisted of sliding a two dimensional template around the interior space until a reasonable solution was reached. A different manikin template is used for each percentile of the population. Recently, a CAD approach using manikin kinematics has been undertaken. In this approach, joints are introduced to capture pairwise relationships between variables. For instance, the KNEE-Point is a joint whose distances to the Ankle-point and Hip-Point are held constant. This technique is very useful in early stages for its simplicity and ease of use. However, it suffers from the fact that only pairwise relations are captured but most importantly, it suffers from not allowing optimization and what-if scenarios.

The use of ILOG SOLVER offered many advantages over traditional methods including,

• Many SAE guidelines operate in very restricted domains. In the manikin placement model, the seat height for class A vehicles is given in the range [100, 400]. Many 4x4 vehicles are beyond this range. In SOLVER, it is just a matter of increasing the domain of variables to handle this type of vehicles.

• Most of the models developed so far have provided the users with a way to look at packaging problems from new angles. In the manikin placement situation for example, it is now possible to start from a heel-to-H input instead of the traditional seat height. It is also possible to leave major variables unknown. The system is able to generate first-cut placement positions that provide a good starting point for new designs. This feature is instrumental in the case where a new vehicle package is started from scratch. This situation arises often when a package is based on a model with incomplete information.

• Through the use of SOLVER's optimization capabilities, it is now possible to generate a vehicle package by stating design goals. In the current system, one such goal consists of improving the legroom while ensuring comfortable seating for 95% of the drivers. Other goals under consideration include, headroom and visibility.

• The expressive power of SOLVER combined with C++ allowed us to build models that are easier to change. Each manikin category is represented by its own class for geometry and constraints. As a result, adding new manikins such as "child manikin" is a matter of creating a new class and providing the appropriate anthropometric measurements.

• System performance has been very good. Generating all possible placement solutions, requires about 5 sec on a PowerPC running AIX.

• By introducing secondary variables, SOLVER allowed us to discover interesting relationships and provided more information to our users. Examples include, the Knee angle and the Ankle-to-Heel orientation.

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