Qualitative Comparisons of Operation Designs between Mercury Sable and Nissan Maxima Using Suh's Design Axioms

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September 1997

Abstract

Different criteria have been proposed to evaluate design merits. Most of them are quantitative, as qualitative criteria are relatively rare. When qualitative comparisons are possible, however, the telling of the better design is apparent, without resorting to artificially computed numbers.

Independence axiom proposed by Suh (1990) is a useful qualitative criterion. In general, designs with dependent functionalities or design parameters are inferior to designs with independent functions or operations. In this paper, I proposed multiplying technique, which places more stringent requirement on independence than Suh's axiom and uses independence to reduce parameters redundancy. In the operation comparisons between Nissan Maxima and Mercury Sable, the advantage of independence axiom and multiplying technique becomes apparent. Multiplying technique is wisely applied by Nissan, which results in Maxima's design having more options but less physical complications than Sable's. In several cases, Sable's features are coupled and, hence, can be improved by decoupling.

Keywords: Independence axiom; multiplying technique; design functionality; design parameter; radio-cassette; air-conditioning and heater; and wiper.

1 Introduction

Agreement is rare on how to evaluate design merits. Conventional wisdom has entrusted design excellence to a blend of creativity, intuition and experience. Suh and Rinderle (1982) proposed independence axiom and minimum information axiom as the guiding principles in designing a product or process. The two axioms, they suggested, can lead to an objective comparison of product design.

A product must possess a set of features demanded or appreciated by its potential customers. Suh and Rinderle called the minimum set of required features *functional requirements* (FRs). Independence axiom demands that a good design must maintain the independence of its FRs. Minimum information axiom demands that, among all the designs satisfying independence axiom, the best design is the one with the least information content, with information loosely defined as the minimum complete description of a product. Suh and Rinderle (1982) and Suh, Bell and Gossard (1978) provided examples for applying the axioms to improve product designs. They also discussed quantitative measures of dependence and information. Suh (1990) demonstrated how the action of decoupling dependent FRs made a process easier to control and more productive. However, there is no example of applying independence axiom to compare product functionality. The purpose of this paper is to illustrate the application of independence axiom to compare qualitatively designs serving the same FRs. We proposed multiplying technique to further expand the application of the independence. Multiplying technique can significantly reduce the number of design parameters without curtailing functionality. Nissan Maxima GXE and Mercury Sable LS are chosen because both cars are powered by 3-liter six cylinder engines and appeal to the same group of consumers. Both vehicles are priced around twenty-two thousands and can be purchased at about eighteen thousands dollars. The results of comparisons indicate that the design that satisfies independence axiom or multiplying technique offers more options with less physical complications. Independence among FRs can serve as a qualitative criterion for design comparisons.

Before examples are discussed, we give the following brief descriptions of the axioms and the technique.

2 Statements of the Axioms

2.1 The Axioms

FRs are defined as a minimum set of requirements that completely characterize the functional needs of the product/process. By this definition, one FR can not substitute for any other FR. Let the space in which FRs reside be called the *function domain.* Design parameters (DPs) are the minimum set of physical entities created by the design to fulfill the FRs. Let the space in which DPs reside be called the *design domain.* For example, different keys in a computer keyboard are the DPs to enter corresponding symbols (FRs); the automobile wiper control knob is the DP to regulate wiper speeds (FRs); and air/heater control switches are the DPs to turn on/off and to direct air flow. The design task is to create an efficient mapping between design domain and function domain.

- **Independence axiom:** the impact of modification made to any design parameter is limited to its referent functional requirement.

- **Minimum information axiom:** Among the designs satisfying independence axiom, the best design is the one that has the least information content, while information may be defined as the inverse probability that FRs meet its design tolerance. The larger the probability, the less the information required. This axiom implies that when two designs have the same range of perturbation (tolerance) for its FR, the design with a wider allowable DP range of perturbation (design specification) needs less information, hence, is easier to manufacture or operate. The less the information, the better the design. In this author's opinion, information can also be defined in terms of the dispersion of FR. Minimum information axiom can be converted to state that the best design is the one with the smallest FR dispersion when its corresponding DPs are comparably perturbed. This change of criterion from design domain to function domain makes the verification of information content easier and more straight-forward.

Suh (1990 p.187) proved that the information required to change the state of FRs, such as on/off, is greater for a coupled design than for a design satisfying independence axiom. Hence, both axioms support using the independence among FRs as a qualification criterion.

2.2 Multiplying Technique

Independence axiom is automatically satisfied if the mapping between DPs and FRs is one-to-one and each DP can be operated independently from the rest of the DPs. However, in many design situations, one DP for each FR is both inefficient and costly, because it can result in a large number of DPs to be designed into a limited physical space. For example, a typical computer keyboard needs to enter a minimum of 256 symbols, but it can accommodate less than one hundred keys physically. One DP (key) for one FR (symbol) would make the keyboard too large to be usable. In this product, the number of DPs is far less than the number of FRs. The saving of DPs is a consequence of the *multiplying technique.* For a computer keyboard , the design satisfies the following properties.

- a) each of the sixty-eight **alpha-numeric** keys is operated independently;

- b) the three special keys: **shift**, **ctrl** and **alt** are operated independently of the **alpha-numeric** keys; and

- c) the special keys can be combined within themselves and then operated simultaneously with every **alpha-numeric** key.

Consequently, the total number of keyable combinations is $(1 + C_0^3 + C_1^3 + C_2^3 + C_3^3) \times 68 = 544$. The design of computer keyboards not only satisfies the independence axiom but also achieves good efficiency, which is realized via the multiplying technique: unrestricted combinations between independent groups of independent DPs. The one-to-one correspondence and the multiplying technique are depicted in Figure 1 and Figure 2, respectively.

Figure 1 and Figure 2 about here

Multiplying technique requires both within-group orthogonality and between-group orthogonality for its DPs, while independence axiom only demands between-group orthogonality. The mathematical formulations of the orthogonalities are detailed in the Appendix. In the following, we shall use independence axiom and multiplying technique to compare feature designs between Nissan Maxima and Mercury Sable.

3 Comparisons Between Maxima and Sable

3.1 The Design of the Radio-Cassette Deck

Figure 3 and Figure 4 are sketch diagrams of the tape deck for a 1995 Mercury Sable and a 1992 Nissan Maxima, respectively. Both sketches are also good representations of their respective 1997 models. Automobile manufacturers periodically update the external appearance of a car but keep their interior control panel relatively stable.

Both radio designs satisfy independence axiom, i.e. each functionality is individually controlled. Sable's design, however, achieves independence via a one-to-one correspondence between DP and FR, whereas Maxima utilizes the multiplying technique. The result is that Sable has more control buttons but fewer functions. In Maxima, the same eight tape operation buttons are also used for radio operation. In Sable, the five buttons are exclusively for the tape operation. The three missing functions in Sable are **STOP**, **APS-REW** and **APS-FF**. The two search functions, **APS-REW** and **APS-FF** are quite convenient to repeat or skip a section of the cassette tape. The **STOP** button in Maxima facilitates the switching from tape player to radio and keeping the cassette inside the deck. After the switch, the six radio preset bottoms become cassette operation bottoms. This is a typical application of multiplying technique. In Sable, the switch from tape to radio is accomplished by pushing the **EJECT** button, which results in cassette loosely hanging outside the deck and it becomes a source of noise. The one-to-one correspondence in Sable not only reduces the functionality, but also crowds the panel. It makes the physical design more complicated.

Figure 3 and Figure 4 about here

Each of the **Vol/on**, **Bass/balance** and **Treb/fade** knobs in Maxima serves two functions, which create a total of six different tone controls. The tone control in Sable also has three buttons: **Power**, **Audio** and **- /+** buttons. Here, Sable has applied the multiplying technique. Each time the **Audio** button is pushed, one of the five tone templates appears in the display. The **-/+** button is used to decrease or increase the intensity of a specific tone characteristic. Both designs have the same number of DPs and achieve the same functionality, except the selection of tone characteristic in Sable is strictly sequential. Maxima's conventional knob design seems to be a little bit more user-friendly.

Maxima's design uses multiplying technique for its radio and tape operation, which results in a saving of six buttons. Sable's one-to-one mapping between FRs and DPs is more complicated and less efficient. Maxima's deck has more functions than Sable but less keys. Sable's design uses multiplying technique with the **Audio** key serving five templates. This dose not, however, result in lessening the number of control keys.

3.2 The Air-Conditioning and Heater Control

Figure 5 and Figure 6 represent the air-conditioning and heater panel of Sable and Maxima, respectively. Sable has three knobs: the left-side knob is the fan speed knob, the center knob is the temperature knob, and the right-side knob is the system control knob. The right half-circle of the system control knob turns on heater, heater/defrost, or defrost, while the left half-circle turns on air-conditioning or vent. The fan speed knob has no **off** selection; the fan is turned off when the system is at the **off** position, and the fan comes into operation when the system control knob is not at the **off** position. This dependence could create inconvenience. For example, Sable's fan cannot be turned off at **vent** or **heater**, although it may become desirable to have heat without fan blowing on a cold autumn morning.

Figure 5 and Figure 6 about here

Maxima has six mutually independent groups of keys: {A/C}, {inside/outside air circulation}, {four fan speeds plus the **off** key}, {five combinations of air flow direction}, {temperature selection}, and {direct fresh air vent}. The between-group independence enables the user to select one option from every group, hence, creating many combinations unavailable in Sable. For example, there are three outlets for airflow: lower-downward, middle-horizontal and defrost-upward. The total possible number of combinations is seven. Maxima offers five air flow combinations for both air-conditioning and heater. Between A/C, inside/outside and five air directions the total number of combinations created by these seven push buttons becomes $5 \times 2 \times 2 = 20$, while the coupled design of Sable offers only five.

The dependence between fan, system-control and airflow significantly limits the number of options in Sable; the direction of airflow is completely coupled with system selection. When **Vent**, **Normal A/C** or **Max A/C** is selected, airflow can only be from the middle outlets. This restriction makes it impossible to direct air conditioning to the defrost outlet on a hot and rainy summer day.

Applying independence axiom and multiplying technique to the full extent, Maxima offers far more options than Sable in terms of choice, comfort and convenience. The deficiency in Sable's design is caused by its violation of independence axiom. Sable's design left no choice about the air outlet once vent, heater, or air-conditioning was selected. Suh and Rinderle (1982) called design with completely dependent FRs coupled design. They recommended to break up, or decouple, the coupling to achieve functional independence. In many instances, coupling reduces the design domain, hence, inhibits the range of creativity.

3.3 The Wiper Control

Nowadays, all wipers have three speed settings: intermittent, slow and fast. Sable's wiper control is a knob located at the tip of its turn-signal control rod. A driver must use his/her left thumb together with another finger to turn the wiper knob. The first three notches regulate three intervals for intermittent motion and the last two notches are for slow and fast speed, respectively.

Maxima's wiper control is a separate short rod located on the right side of the driving column. To select a wiper speed, the driver simply push the wiper rod upward. First notch up is for the intermittent motion, while second and third notches up are for slow and fast speed, respectively. On the tip of the wiper rod is a turning knob for selecting a desirable intermittent duration from a continuous interval. To clear foggy condensation, a long-interval suspension of the wipers are desired; for drizzle, a short-interval suspension is called for. In this aspect, Maxima offers a considerably wider range of intermittence than Sable's discrete choices.

However, it is not the domain of selection, but the easiness of operation which gives Maxima a clear operational advantage. To turn on-off the wiper in Maxima, driver can use any part of his/her hand to push the wiper rod up/down, while Sable driver must use his/her thumb and finger together. The wiper can be turned on in Maxima even when the driver is holding a cellular phone or a cup. In order to understand better the design difference in wiper operation, we direct our attention to the comparison of a bathroom faucet and a kitchen faucet. They are depicted in Figure 7 and Figure 8, respectively. A faucet has two basic functions: to regulate the amount of water flow and to select water temperature. The two operational DPs are equivalent to the two forces exercised to fulfill each of the two functions. To use a bathroom faucet, one needs to first grasp the faucet knob with thumb and fingers. The pulling force increases the volume and the turning force selects the temperature.

These two different forces are exerted by two different groups of muscles in the arm and wrist. However, since both operations depend on the grasping force exerted by the fingers, the DPs are not independent. This is an analogy to the wiper operation in Sable. On the other hand, the kitchen faucet is designed to facilitate operation without the prerequisite grasping force. To turn on or increase the water volume, one lifts or pushes the lever with either fingers, the back side of a hand, or even with the arm. To change the water temperature one pushes the lever left or right with any convenient part of the hand, arm or head. A senior with arthritis can operate a kitchen faucet, not necessarily a bathroom faucet. This difference in operational convenience is comparable to the difference in the wipers' operation between Maxima and Sable.

Figure 7 and Figure 8 about here

Maxima's wiper control design satisfies independence axiom, which fulfills two separate FRs (speed and intermittent interval) with two independent DPs (rod pushing and knob turning). It offers operational convenience and a continuous domain for interval selection. Sable's design is to fulfill the same two FRs with one turn of the knob. It violates independence axiom. All the operations must begin by grasping the knob with force exerted by the fingers. This exercise can be inconvenient to some drivers and impossible for drivers with sever arthritis. Sable's coupled design also limits its choices of intermittence intervals, which can be a handicap in certain driving conditions.

4 Discussions and Conclusion

It has been shown that product/process can be improved via decoupling FRs. For example, a manual typewriter has its key pressure coupled with key selection. Electric typewriters improve the operation by decoupling them. For other examples about decoupling, readers are referred to Suh's (1990) book.

To satisfy independence axiom, the conventional wisdom is to have a separate DP for each independent FR. This practice, though consistent with independence axiom, may require too many DPs to be physically possible. Multiplying technique suggests dividing the functionality into independent groups of independent DPs and rendering independent FRs by combining one DP from every group. This is an effective way to reduce the total number of DPs. The Japanese automobile designers conscientiously use multiplying technique. The comparison between Maxima and Sable is a typical delineation of two different design approaches.

The designs of Maxima's and Sable's radio-tape deck, heater/air-conditioning and wiper are compared. Maxima uses the same six keys for both radio station memory and deck operation, which results in a significant saving of physical DPs. Maxima has five less push buttons but three more functions than Sable. Sable's radio design uses one-to-one mapping to achieve independence, while Maxima uses multiplying technique. With regard to heater/air-conditioning control, Maxima has five independent groups of DPs and one DP from any group can be combined with DPs from any other groups. In Sable, no option is available after vent, heater, air-conditioning or defrost has been selected. The applications of multiplying technique observed in Maxima contrasts vividly with the coupled design in Sable. To compare the wiper controls on Maxima and Sable, we used the bathroom and kitchen faucet to depict their differences in DP's dependence. In Maxima, the speed FR is independent of the intermittence interval selection FR. The independence makes Maxima's wiper more convenient to operate than Sable's, in the same fashion as the kitchen faucet is easier to use than the bathroom faucet.

Suh, Bell and Gossard (1978) stated that "The axiomatic approach is heuristic and more human oriented. It attempts to bring order to human creativity by stating a few general rules that will always lead to good results". And one of the benefits of following the axioms is to "narrow the range of possibilities that the mass of detail to be considered is within the capacity of the designer and planner." Their idea is to use these two axioms, especially independence axiom, as a qualification test: restrict considerations only to designs which satisfy independence axiom. Hence, their advice about design process begins with very general guidelines (the axioms), rather than specific design details. Designer's creativity and training can be better utilized when they restrict their consideration to designs with uncoupled FRs or DPs.

The benefits of independence axiom include:

1. functionally independent designs are user-friendly;
2. a design satisfying independence axiom usually offers more options than coupled design;
3. multiplying technique: mutually independent groups of independent DPs simplify the design task because it partitions the design task into independent sub tasks, each of them is unconstrained by the rest of the sub tasks.
4. enhance the creativity in two aspects:
   (a) narrow the design domain to those leading to good results; and
   (b) relieve the burden to ensure that some kind of consistency must be maintained with other design tasks.

Acknowledgement I thank Dr. Larry Oh of Silicon Valley Group Inc. for suggesting this problem.

Appendix

Figure 1 uses one DP to define a FR. It is a simplified depiction. In most cases, it takes several DPs to fully delineate a FR, hence, the DPs in the design domain need to be partitioned into DP groups. Independence axiom organized DPs into FR-specific groups: for example, the four buttons in the upper right corner of Sable's radio are reserved exclusively for tape operation; and the six buttons in the center are for presetting the radio stations, exclusively. On the other hand, multiplying technique divides DP groups according to their functionality types. The computer keyboard and Maxima's air-conditioning and heater control are two typical examples; DPs in the same group are used to alter the type or mode of the operation. Moreover, DPs of certain groups are designed to add extra dimensions to the functionality and in consequence create attractive quality.

The one-to-one correspondence between a FR and its DP group is expressed as follows:

$$FR_i \;=\; f_i(DP_{i1}, \cdots, DP_{in_i}),$$

where $(DP_{i1}, \cdots, DP_{in_i})$ are n_i DPs for the i^{th} FR. Independence axiom requires that perturbation made to any of these DPs affects no other FRs, except FR_i. Mathematically, it is equivalent to

$$\frac{\partial DP_{ij}}{\partial DP_{kl}} \;=\; 0 \;\text{ for }\; i \neq k, \tag{1}$$

which implies

$$\frac{\partial FR_i}{\partial DP_{kl}} \;=\; 0 \;\text{ for }\; i \neq k,$$

and the variance of FR_i can be approximated via

$$Var(FR_i) \;\cong\; \sum_{j=1}^{n_i} (\frac{\partial FR_i}{\partial DP_{ij}})^2 Var(DP_{ij}) + \sum\sum_{j \neq k} \frac{\partial FR_i}{\partial DP_{ij}} \frac{\partial FR_i}{\partial DP_{ik}} Cov(DP_{ij}, DP_{ik}). \tag{2}$$

Multiplying technique partitions the design domain into qualitatively different groups and each group contributes one DP toward defining a FR. Mathematically,

$$FR_i = f_i(DP_{1i}, \cdots, DP_{ki}),$$

where the first subscript of DP represents the DP group it belongs and there are k DP groups. The within-group orthogonality requires

$$\frac{\partial DP_{ij}}{\partial DP_{il}} = 0 \text{ for } j \neq l.$$

Combining the between-group orthogonality (1) and the above, the variance of FR_i is approximated via

$$Var(FR_i) \cong \sum_{\alpha=1}^{k} \left(\frac{\partial FR_i}{\partial DP_{\alpha i}}\right)^2 Var(DP_{\alpha i}), \quad (3)$$

From equation (3), it can be concluded that the more stringent requirement on orthogonality not only eliminates redundant DPs but also reduces the variance.

References

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Figures Caption

Figure 1. One-to-one correspondence between design parameters and functional requirements

Figure 2. Multiplying Technique

Figure 3. Radio-cassette deck of Sable

Figure 4. Radio-cassette deck of Maxima

Figure 5. The air-conditioning and heater control of Sable

Figure 6. The air-conditioning and heater control of Maxima

Figure 7. A bathroom faucet

Figure 8. A Kitchen faucet

DP_1	FR_1
DP_2	FR_2
$\vdots$	$\vdots$
$\vdots$	$\vdots$
DP_n	FR_n

design domain **function domain**

Figure 1.

DP_{11}	FR_{11}
$\vdots$	FR_{12}
DP_{1n_1}	$\vdots$
DP_{21}	$\vdots$
$\vdots$	$\vdots$
DP_{2n_2}	$\vdots$
$\vdots$	$\vdots$
$\vdots$	$\vdots$
DP_{k1}	$\vdots$
$\vdots$	$\vdots$
DP_{kn_k}	$FR_{n_1 n_2 \cdots n_k}$
design domain	**function domain**

Figure 2.