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CREATING ROBUSTNESS IN PRODUCT AND PROCESS DESIGNS

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SUMMARY

Interactions among variables in products and processes require expert human intervention to produce acceptable results. Similarly, correlated output characteristics require a delicate balance either in manufacture by production personnel or in use of the products by the users. Robustness concepts in product and process designs can deal with both of these situations effectively. In first case, robustness can minimize or eliminate human intervention. In second case, robustness can detach the correlation between output characteristics no longer requiring a delicate balance in manufacture or use of the products.

KEY WORDS

Robust design, Robust process

INTRODUCTION

Variations in operational environment, ambient conditions, and human tendencies make products and processes susceptible to failures. To some extent product and process designers intuitively include effects of these variation when creating products and processes. However, inclusion of these considerations are highly dependent on individual engineering instinct rather than disciplines that are practiced. ***Designing for robustness*** is that discipline. Robustness captures the idea of minimizing failures by understanding the interactions between uncontrollable variables and controllable variables in inception stages and then designing appropriate mechanisms either in product designs or in process designs to deal with them without any human intervention. Thus, ***robustness can be defined as an attribute of design that integrates the interactions between uncontrollable variables (noise variables) and controllable variables (signal variables) requiring no human intervention for acceptable performance.***

This definition of robustness is not broad enough to include a wide variety of applications where human interventions are expected to manufacture or to operate product properly. For example, take a case of the products where two or more negatively correlated output characteristics define the goodness of the product. That is, any attempt to improve one will degrade the other. Product and process designs try to strike a delicate balance between the two requirements. To maintain the balance requires human intervention either in user environments or in manufacturing environments. With robustness concept it is possible to detach this negative correlation so that each output can be individually improved and human intervention is minimized. This line of reasoning could also apply to positively correlated characteristics as well. The concept of robustness can thus be broadened to include the case of correlated characteristics and is redefined as follows. ***Robustness can be defined as an attribute of design that integrates the***

interactions among variables requiring no human intervention for acceptable performance with respect to a single or multiple correlated characteristics.

ROBUSTNESS OPTIONS FOR PRODUCT OR PROCESS DESIGNS

There are three options available to create robust products or processes. They are: (1) Detach interaction between uncontrollable variables and controllable variables, (2) Automate interactions between uncontrollable and controllable variables, and (3) Detach relationship between two or more output variables. These possibilities are listed in Table 1.

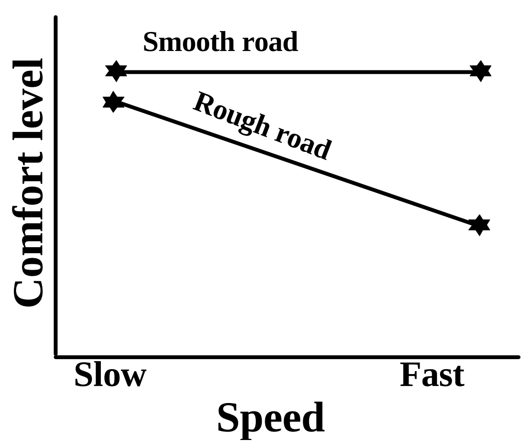
Table 1 - Robustness Options

	Detach Interactions between Uncontrollable variables and Controllable variables	**Automate Interactions between Uncontrollable variables and Controllable variables**	**Detach relationship between two or more output variables**
Product Design	**Category 1**	**Category 2**	**Category 3**
Process Design	**Category 4**	**Category 5**	**Category 6**

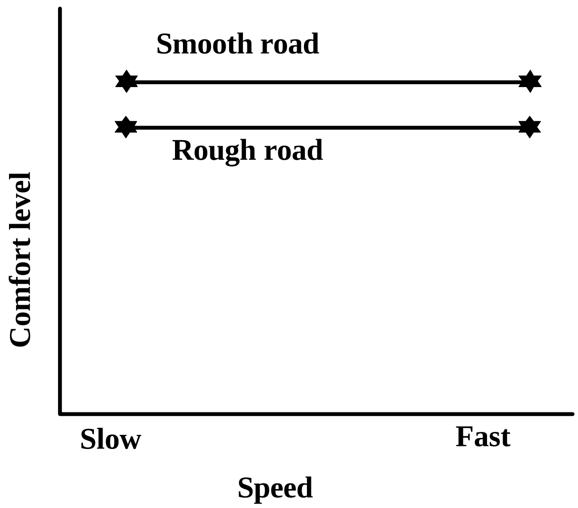
The following examples clarify the robustness concepts in each category.

AN EXAMPLE IN CATEGORY 1

This example is about product design. Take a case of driving an automobile on varying road conditions. The designers know that it is natural to expect rough road conditions in some segments of travel. We will refer to the *rough road condition as an uncontrollable variable*. What is driver likely to do when he/she perceives that rough road condition is approaching? Most likely the driver might slow down. The *driver's action we will refer to as controllable variable*. Thus, we can see in this example that there is a definite interaction between road condition and driver's reaction.

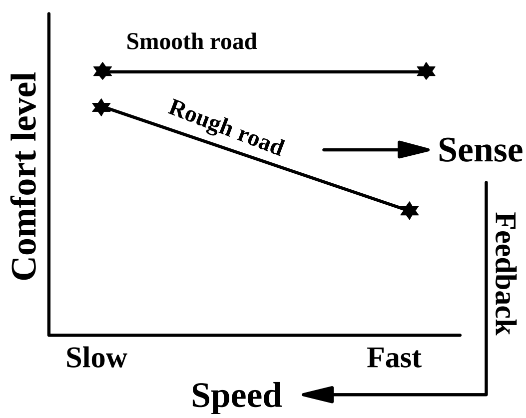


The design objective should be to understand and to control this interaction to provide a smooth ride as well as to minimize damage to the automobile. Now we can think about how to design product that will either minimize or eliminate human intervention altogether. One idea is that we can design a suspension such that it would adjust automatically and continuously to a varying degree of roughness. If such design is feasible then driver neither has to slow down nor feel any discomfort when rough road conditions are encountered. Thus, the interaction between uncontrollable and controllable variables is successfully detached. This product design will be labeled robust against rough road conditions.



AN EXAMPLE IN CATEGORY 2

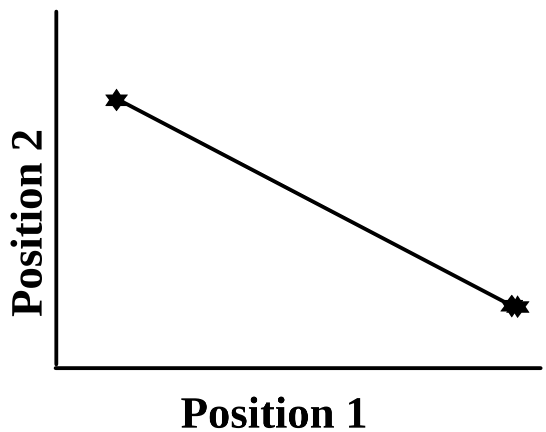
The interaction between driver and rough road conditions in the preceding example can be approached in another way. Suppose we incorporate a sensor to sense the rough road conditions in the form of an acceleration and to provide a signal to a controller to adjust the speed in accordance with what drivers would consider to be a smooth ride.



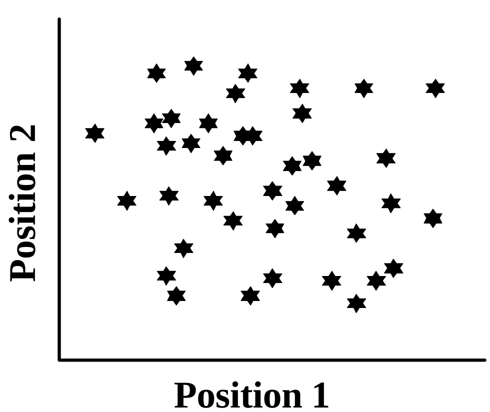
With this design concept, the resulting smoothness will be the same as that in category 1, however, the automobile speed will have to be slower to get equivalent results. Also, there will be a time lag between sensing an acceleration due to rough road conditions and corresponding reaction. The concept of robust design in category 1, on the other hand, responds instantaneously to the rough road conditions. In any case, both designs will be considered robust because they would have removed human intervention to deal with uncontrollable rough road conditions. The economics and marketing of implementing such robust design ideas need to be considered to make a final choice.

AN EXAMPLE IN CATEGORY 3

A teeter-totter design is exemplary of robustness option in this category. Position 1 and position 2 at the teeter-totter ends are negatively correlated. That is, if position 1 person goes up, the position 2 person comes down.



Now, let us say that we wish to detach correlation between two positions, so that one person can go up and down independent of other person's movement. We could design a torsional spring integral with the hinge such that one half of the teeter-totter board would be attached to one end of the spring and the other half would be attached to the other end of the spring. This concept would successfully detach the correlation between two positions. That is, persons at each end can move up and down independently.



AN EXAMPLE IN CATEGORY 4

This case is about process design. The process designers know that the material to be machined is received with a varying degree of hardness. The hardness variation experienced is natural and is within specification limits for the product application. However, previous experience has shown that such hardness variation causes chatter in the machining process which ultimately results in an unacceptable finish. The operator's most likely reaction is to play with the machine speed and the tool feed to deal with chatter conditions. On some occasions operator's actions are helpful. On other occasions they are not. Thus, this scenario can be labeled as *not-robust process*. Here, *uncontrollable variable is material hardness* and the *controllable variables are machine speed and tool feed*. A conventional way of handling this problem is to tighten the specification limits on material hardness. However, tightening the hardness spec may not be an acceptable solution if heat treat process capability is not compatible. Another possible solution is to examine robustness design concepts.

One of the possibility is to divide material hardness variation in to two groups - relatively hard and relatively soft. There are two types of tools available - one type works better with harder materials, where as the other type works better with softer materials. A mechanism could be designed to hold both types of tools in the machine which can be called upon depending on the workpiece hardness. Suppose we design a process to automatically measure hardness of every incoming piece. Then, we can electronically send a signal for a matching tool to come into action. Thus, we could successfully eliminate the human intervention with the speed and feed.

Another solution is to discover the material having machining properties that can be machined at constant machine speed and tool feed to produce acceptable finish regardless of its hardness variation. Such a material will have to satisfy all the product functional and reliability requirements. If such material can be found, then process would be considered robust. Once again economics will play a role in selecting robustness options that are feasible and marketable.

AN EXAMPLE IN CATEGORY 5

The preceding example can be treated in this category. We could consider automating the interactions among material hardness, speed, and feed. A designed experiment would be necessary to determine the relationships among material hardness, machine speed, and tool feed. As a result, the complete process map would be known for these three variables showing the effect of multiple settings on surface finish. We can feed hardness signals electronically to the process map to select the most appropriate values of machine speed and tool feed. In this manner, the machine will be automatically adjusted to obtain an acceptable machined surface without the chatter. Such a process design would be considered robust. Once again we note that we have removed human intervention from tackling natural hardness variation (uncontrollable variable).

AN EXAMPLE IN CATEGORY 6

This case considers a correlated process output characteristics requiring delicate balance. A powder press is producing a pressed-metal part. There are two characteristics of importance - weight and height of the part. These characteristics are positively correlated. That is, when height is higher the weight is higher. The sequence of operation in the present process is: fill the cavity with powder, wipe the cavity surface, and hit the punch to finish the product. This process sequence results in the weight and height being correlated. The experience has shown that it is very difficult to control these characteristics within desired limits and maintain the positive relationship between them. It has been desirable to detach the relationship between the two characteristics so that they can be independently controlled. The process sequence could be altered as follows: measure the powder volume to reflect the weight of the part proportional to powder density, fill the cavity just below the cavity surface, and hit the punch. This sequence would successfully detach the correlation between the part weight and the part height so that they can be independently controlled.

ROBUSTNESS CHALLENGE

The following is a description of challenging problems which could use robust design ideas. Try to match each problem with a robustness option which would make the product or process designs robust. Conceptually describe how you will execute this robustness idea.

PROBLEM 1

Seat belt design has two output requirements that require delicate balance. These requirements are: (1) for passenger comfort seat belt should be snug to the body without excessive force in normal driving conditions and (2) for passenger safety, seat belt should be holding passenger in place during sudden deceleration to avoid bouncing. The first requirement is stated as maximum belt force and the second requirement is stated as minimum belt force. In the present seat belt design a single spring mechanism is used to provide the belt force. It's value is slightly biased in favor of safety. The passengers many times are known to create a slight slack between the body and a belt to increase the comfort level. However, this is undesirable because in a collision situation the belt will lock in a slack position with a possibility that a passenger can slide out. Thus, the seat belt purpose is defeated. Conceptually suggest a robust design idea that will detach the relationship between the comfort level belt force and the safety level belt force.

PROBLEM 2

In a rubber molding process, rubber has been found to stick to the mold cavities. This problem has been found to be seasonal. In summer, this problem is more likely, than any other season. The humidity variation is high on the molders' list of suspects. Molders prefer to maintain molding variables constant. Conceptually suggest how you will handle the interaction between humidity variation and the mold variables.

PROBLEM 3

A plant is using corrugated boxes to ship products. These boxes are used on the automated packaging line. Occasionally packaging lines get jammed with these boxes. Thickness variation of incoming boxes from the suppliers is blamed. Present packaging line is designed to accept boxes in a flat-folded condition. A leaf spring is used as a stopper for the incoming box. A kicker bar comes in and opens the box so that it can be filled with the product. The reason for machine getting jammed is that a box either travels too much or not enough into the leaf spring. Both conditions of travel result in a jammed machine. The customer blames this on too much thickness variation of the incoming boxes. Conceptually suggest how you would make the interaction between the thickness variation and the spring robust.

PROBLEM 4

There are two mating parts with a fit requiring certain amount of gap. The gap cannot be too small because it will result in an interference fit. On the other hand, the gap cannot be too large, otherwise, it will result in a sloppy fit. The individual parts are toleranced to assure this gap requirement. Unfortunately, the process capabilities are not compatible with specifications. Both processes are incapable. Suggest a solution to this problem without having to buy new machines.

PROBLEM 5

A process makes corrugated board. Raw material consists of paper rolls from paper mills. The critical output characteristic is paper joint strength. Occasionally, joint strength is not met. Operators feel that this is due to varying amount of moisture in the rolls of paper they purchase. Current procedure is to adjust temperature and speed settings to compensate for varying degree of moisture. This procedure is considered clumsy because temperature and speed settings are not conveniently located for ease of adjustments. Even if these controls were accessible, operators dislike the idea that they have to play continuously with machine settings. Suggest a robust solution to moisture variation in the incoming paper rolls.

PROBLEM 6

A food company is developing a recipe for muffins. Food chemists have come up with a procedure that requires preheating the oven to 400 ^{o}F, using ½ cup of water to be mixed with one egg, and baking it until golden brown. The recipe developing team realizes that there are many operational variables that can grossly vary in spite of the recommendations printed on the back of the box. For example, a consumer may start baking immediately after turning the oven on instead of preheating, some what carelessly measure ½ cup of water, and may use any size egg. Develop a robust recipe that will result in edible muffins against these operational variables.

HOW TO MEET ROBUSTNESS CHALLENGE

	Problem category	Development of Robust Solution
Problem 1	Problem of two correlated outputs.	• Seat belt mechanism have to be modified to come with one value of belt force under normal driving condition and another value of belt force under sudden deceleration.
Problem 2	Problem of interaction between ambient condition and molding variables.	• Interactions will have to be understood between humidity and molding variables. Additionally, these relationships will have to be automated. • Another possibility is that humidity-friendly material will have to be researched so that there will be only one set of molding variables regardless of varying humidity condition.
Problem 3	Problem of interaction between a property of incoming material and a process variable	• Packaging machine spring mechanism will have to be modified to accept the natural variation of box thickness.
Problem 4	Problem of interaction between tolerances	• A forgiving mechanism will have to be created which would be insensitive to existing process capabilities. • Another possibility is that classified fits will have to be introduced to obtain the desired gap.
Problem 5	Problem of interaction between a property of incoming material and clumsy adjustments	• The interactions will have to be understood and mechanized. • Another possibility is that a new paper material will have to be researched which will always produce acceptable joint regardless of its moisture content.
Problem 6	Problem of uncontrollable operational variables	• The interactions between recipe ingredients and operational variables will have to be understood to come up with a mixture that can withstand the cooks' habits.

GENERIC ROBUSTNESS PRINCIPLES

The following are generic robustness principles derived from the preceding examples.

1. Correlated output characteristics must be detached so that each output characteristic can be individually manipulated.
2. Designs and processes must be insensitive to user habits.
3. Materials must be developed that are insensitive to ambient conditions.

4. Designs or processes must be made tolerance insensitive whenever process capabilities are not adequate.
5. Ambient conditions must be compensated automatically.
6. Machines should have mechanisms to deal with incoming material variation without human intervention.

To practice these principles, engineering creativity and effective investigative methods are required.

CONCLUSION

Robustness is a necessary element in creating product and process designs to counter natural variations in operational environments, ambient conditions, and human tendencies that make products and processes susceptible to failures. Without robustness, human interventions have to be highly accurate to produce acceptable performance. Such accuracies are impractical to have or to maintain in operational environments.

There are examples of robust products and processes found all around us, but they came into being due to intuition of a handful of designers. To teach robustness as a design discipline we need to explore some age old problems that beg solutions. Through these solutions, we begin to master generic robustness principles identified in this paper. To practice these principles we must follow sound investigation practices and learn serious creativity. The investigation practices help determine the nature of the relationships between noise variables and signal variables. Once the relationships are known, the creativity help us find the most effective solution.