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AXIOMATIC DESIGN BASED ANALYSIS OF ARTICLES ON UNMARKETABLE COMMODITIES

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ABSTRACT

We picked out fifty "unmarketable commodities" that the market put down against their expected sales and analyzed them with Axiomatic Design. These commodities had been introduced by the Nikkei Business Daily as new products that failed to meet their sales expectations. Our analysis set the selling points to primary functional requirement FR1, and countermeasures against the constraints to FR2. The analysis categorized the failure events into three groups. Group (1) gathered events caused by poor product planning within the organizations. The group had 17 events, 9 of which were decoupled designs where design parameter DPi affected other FRj. Group (2) failures were caused by change in the circumstances outside the organization, and 8 out of the 14 events in the group blamed changes in the design range of FRi at the time of the initial product launches into the market. Group (3) events were due to poor alignment of the designer's concept and the consumer's needs. Small probabilities for aesthetic or cultural DPi to satisfy FRi caused 13 out of the 19 events in the group. Countermeasures to these failures, whatever the event and cause were, included changing the DP system range, FR design range, DP itself, FR itself, scaling down the project or abandoning it, in the order of magnitudes of impact to the projects.

Keywords: Axiomatic Design, Failure Analysis, Product Planning

1 INTRODUCTION

Articles in business newspapers about commodities that did not meet their expected sales are highly popular. Each lesson from an ad-hoc failure analysis, however, gives little worth to those who want to avoid future failures, because we cannot see if the case-dependent lesson would apply to our own special circumstances. This paper reports our development of a universal analysis method based on Axiomatic Design.

Axiomatic Design is effective for engineering design of hardware and software [1]. There have, however, hardly been any reports that applied Axiomatic Design to the upstream thinking process. On the other hand, a large number of researches have been reported that applied project management methodologies to analyzing product planning, which is beyond engineering, where business administration applies. Methodologies of project management are effective for large-scale, long-term projects with fixed goals, like military or space projects, however, have smaller outcome with small-scale, short-term, constantly changing product planning. The study of business administration, of course, has ample researches of a number of methods for product planning. They study each failure case in detail and concentrate on emotions and thinking processes of the managers and designers. Such mind processes, however, have small effect on those who want to learn from the lessons but with different personalities. The constraints of business operations are so different with each failure case, and finding a universally applicable method is difficult.

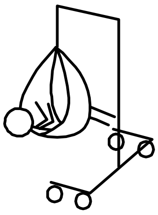
This paper studied articles from newspapers, about failure cases of product planning. The authors of the articles intentionally simplified the causes of poor sales and the countermeasures so that the readers can easily understand the contents. Our study used the simplified causes and set two functional requirements (FR); one is the primary function of the new product and the other the constraint revealed after the product entered the market. We then identified the two design parameters (DPs) to satisfy the two FRs. The reason of poor sales was not necessarily DPs of the design solution not meeting the FRs; for example, there were cases that, even if the FRs were satisfied, the upswing of the market was gone by the time the product entered the market. This paper reviews the scenarios of poor sales of new product by studying the FRs and DPs.

2 ANALYTICAL METHOD

Nikkei Business Daily ran a series of articles "No sales! Studying the Miscalculation" from year 2003 to 2005. We selected

$$
\begin{array}{ccc}
\text{Functional requirement} & \text{Design matrix} & \text{Design parameter} \\
\left\{ \begin{array}{l} \text{FR1: The most important functional} \\ \quad\text{requirement of the commodity} \\ \text{FR2: The strongest constraint} \\ \quad\text{upon commodity's sale} \end{array} \right\} = & \begin{bmatrix} X11 & X12 \\ X21 & X22 \end{bmatrix} & \left\{ \begin{array}{l} \text{DP1: The design solution realized by} \\ \quad\text{new technology satisfying FR1} \\ \text{DP2: The ad-hoc solution with conventional} \\ \quad\text{technology satisfying FR2} \end{array} \right\}
\end{array}
$$

Figure 1: Design equation used in the Axiomatic Design based analysis



● Before the market entry

$$
\left\{ \begin{array}{l} \text{FR1: Care-take easily in a} \\ \quad\text{Japanese style room} \\ \text{FR2: Ease the back pain} \\ \quad\text{for the care-taker} \end{array} \right\} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \left\{ \begin{array}{l} \text{DP1: Mobile electrical lifter} \\ \text{DP2: Power doubling mechanism} \end{array} \right\}
$$

● After the market entry

$$
\Rightarrow \left\{ \begin{array}{l} \text{FR1: Care-take easily in a} \\ \quad\text{Japanese style room} \\ \text{FR2: Ease the back pain} \\ \quad\text{for the care-taker} \end{array} \right\} = \begin{bmatrix} X & 0 \\ -X & X \end{bmatrix} \left\{ \begin{array}{l} \text{DP1: Mobile electrical lifter} \\ \text{DP2: Power doubling mechanism} \end{array} \right\}
$$

The care-talker didn't like longer care-taking time

● After the countermeasure

Minor design change for shortening care-taking time

$$
\Rightarrow \left\{ \begin{array}{l} \text{FR1: Care-take easily in a} \\ \quad\text{Japanese style room} \\ \text{FR2: Ease the back pain} \\ \quad\text{for the care-taker} \end{array} \right\} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \left\{ \begin{array}{l} \text{DP1: Mobile electrical lifter redesigned with} \\ \quad\text{the wheels for the Japanese style room} \\ \text{DP2: Power doubling mechanism} \end{array} \right\}
$$

Conduct seminars about shortening care-taking time

Figure 2: Example of design equation of the mobile electrical lifter

50 articles about industrial commodities of automobiles, electronic appliances, food products, internet services, housing, and clothing.

For each commodity we identified the most important functional requirement that is the selling point, and set it to FR1, and the strongest constraint upon its sale, e.g., cost, appearance, compliance, or continuation of business, to FR2. Figure 1 shows the FR1 and FR2 with the corresponding design parameter DP1 and DP2. The DP1 tended to be the design solution the manufacturers emphasized which was realized by new technology in engineering; The DP2 tended to be ad-hoc solutions with conventional technology. The elements of the 2x2 design matrix in the design equation show the dependency of FR, i.e., when the non-diagonal elements X12 and X21 in the figure were zero, the FRs were independent.

The articles allowed us to describe the design equations at three different timeframes. The first was immediately before the product's market entry when production started as planned, the second just after the market entry, and the third after the countermeasure was taken to modify the product.

Figure 2 shows an example of the design equations. A manufacturer of care-taking machines developed a "DP1: Mobile electrical lifter" for "FR1: Care-take easily in a Japanese style room". The manufacturer, from the beginning, recognized that the customer was the care-taker, not the patient, and for the "FR2: Ease the back pain for the care-taker" developed "DP2: Power doubling mechanism". Before entering the market, the FRs looked were independent and the engineers concentrated on their own part of the project.

Contrary to their expectation, the care-takers turned out to be hesitant to purchase the machine. The machine would move into position to hang the patient in a hammock, instead of the care-taker having to hold the patient in the arms. This caused longer care-taking time; the care-taker didn't want to use it. The negative symbol of "-X" in the matrix in the figure indicate a large complaint. If the manufacturers had tested a prototype, they would have recognized this short-coming that DP1 was affecting FR2. The design matrix had a non-diagonal component indicating a decoupled design.

Table 1: Relation between event and cause. (n=50)

Event \ Cause	(a) Decoupled design that FRi affects DPj	(b) Time-dependent change of design range of FRi	(c) Small probability of meeting FRi with DPi	Total
(1) Poor planning within the organization	9	2	6	17
(2) Circumstantial change outside the organization	2	8	4	14
(3) Misalignment of designer's intention and customer's needs	1	5	13	19
Total	12	15	23	50

Table 2: Relation between event and countermeasure. (n=50)

Event \ Counter-measure	(A) Change system range of DP	(B) Change design range of FR	(C) Change DP itself	(D) Change FR itself	(E) Reduce or abandon the project	Total
(1) Poor planning within the organization	3	3	6	2	3	17
(2) Circumstantial change outside the organization	0	3	4	2	5	14
(3) Misalignment of designer's intention and customer's needs	4	2	8	3	2	19
Total	7	8	18	7	10	50

Table 3: Relation between cause and countermeasure. (n=50)

Cause \ Counter-measure	(A) Change system range of DP	(B) Change design range of FR	(C) Change DP itself	(D) Change FR itself	(E) Reduce or abandon the project	Total
(a) Decoupled design that FRi affects DPj	2	2	4	1	3	12
(b) Time-dependent change of design range of FRi	2	1	7	1	4	15
(c) Small probability of meeting FRi with DPi	3	5	7	5	3	23
Total	7	8	18	7	10	50

The manufacturers then redesigned the wheels so the machine was easier to move inside a Japanese style room with straw mats, and conducted seminars about shortening the care-taking time, finally reducing the non-diagonal component to zero. Their own efforts changed the DP1 system range to match the FR1 design range.

We can describe all the cases with the design equations like the Figure 2. As they show, before the market entry, the manufacturers were only concerned with FR1 and DP1, and hardly gave any thoughts to the constraints FR2 and DP2, or the non-diagonal components (If they did they would not have made it to the dishonorable articles). Figure 3 later shows only the second and third design equations after the market entry and after the countermeasures.

3 ANALYTICAL RESULTS

3.1 ANALYZING THE DESIGN EQUATION AFTER THE MARKET ENTRY

We then analyzed the design equation after they found that the product sales did not meet the expectations. We categorized the failure events into groups (1), (2), and (3), and the failure causes based on Axiomatic Design into groups (a), (b), and (c). The three event groups are as follows:

(1): Poor planning within the organization (e.g., lifter in Figure 2), 17/50 (34%)

(2): Circumstantial change outside the organization, 14/50 (28%)

(3): Misalignment of designer's intention and customer needs, 19/50 (38%)

Group (1) gathers events that the engineer failed in the design definition. Simulating and testing at the timing of market entry, customers needs, product operation, sales channel, maintenance, disposal, and side effects could have been identified, however, the designer did not recognize it. Group (2) collected the cases that circumstances outside the organization, like regulations, weather, market, people's taste, or competitor's product, changed rapidly while the designer was in the midst of development and could not make the sudden turns. Group (3) has cases that the industrial design, marketing strategy, or the advertisement unfortunately failed to capture the consumer's desire to make purchases.

The causes, on the other hand, form the following three categories:

(a): DPi affected FRj in a decoupled design (e.g., lifter in Figure 2), 12/50 (24%)

(b): The design range of FRi changed time-dependently, 15/50 (30%)

(c): DPi had a small probability of meeting Fri, 23/50 (46%)

The causes in Category (a) are frequent with physical designs, e.g., asbestos have high heat resistance, however, 30 years later were identified as environmental hazard to cause cancer. The Japanese engineers were only concerned with the heat resistance and, although the problem had been discussed in the United States, did not admit the negative effects until 2005. Category (b) covers the causes with error in the initial sales projection, e.g., "Apple's iPOD" sold out in 6 hours after the initial launch in 2004 in Akihabara, Japan, and during the 2 months of being out of stock that followed, was caught up by a similar product by a Japanese manufacturer. Failure in sales projection was not just poor sales, but it also included loss of opportunity by being out of stock. Category (c) has the causes that the consumer did not support the design or product concepts. The aforementioned iPOD later occupied 51% of the Japanese market in 2005 with its brand, and the Japanese manufacturer's similar product that is technically equivalent only has 16%.

Table 1 then shows the events vertically and causes horizontally to see where each event falls within the causes. Each group has about 1/3 of the 50 events. The largest cause group for each event group was; for Group (1), it was Category (a) with 9/17 (53%), for Group (2), Category (b) with 8/14 (57%), and Group (3), Category (c) with 13/19 (68%). The diagonal components are the largest for all groups. These large diagonal components indicate the following:

(1) x (a): Poor planning is mainly caused by interference that is hard to find in the early stage.

(2) x (b): Circumstantial changes are primarily due to sudden changes in the consumer's need.

(3) x (c): Most misalignments are due to design concepts not being accepted by the consumer.

3.2 ANALYZING THE COUNTERMEASURE MODIFYING THE PRODUCT

Once a product is found to sell poorly, the analysys based on Axiomatic Design suggests the following 5 remedy groups:

(A) Engineer group changes the system range of DP (e.g., lifter in Figure 2), 7/50 (14%)

(B) Sales group changes the design range of FR, 8/50 (16%)

(C) Engineering group changes the DP itself, 18/50 (36%)

(D) Sales group changes the FR itself, 7/50 (14%)

(E) Without an effective countermeasure, executive managing group reduces or abandon the project, 10/50 (20%)

Groups (A) and (C) are countermeasures that the engineers strive to enhance the performance of the product. Groups (B) and (D) are ways by the sales and marketing to point to different consumer groups without much change in the product itself. For example, one of the authors of this paper, through his experience in developing hard disks, explains these remedy groups with the following countermeasures:

(A) Adjust the magnet composition to gain the coercive force to the customer request

(B) Switch from 3.5 inch customers to those with 1 inch small diameter products

(C) Purchase a sputtering machine for multi-layer production with base films which meets the customer request

(D) Market 1 inch disks to the music industry as high reliability products

(E) Close the 3.5 inches mainframe computer business

The magnitude of modification increases as we travel this list of remedies from (A) to (E). In addition, those involved have to give more explanation to outside investors, sales channels, and customers, and the cost involved in the countermeasure is greater. The articles qualitatively revealed that the effect of remedies were greater with those lower in the (A) to (E) list, however, there were no quantitative measures.

Table 2 shows the events horizontally and the countermeasure in the vertically. They spread the map uniformly without significant correlation. Table 3 indicates no correlation between the cause and countermeasure, either. In other words, effective remedies are case-dependent and there are none that always work. Most likely, those involved must have evaluated the actions in (A) to (E) and decided on the countermeasure that worked and was least expensive.

3.3 EXAMPLES OF FAILURE CAUSE ANALYSIS BASED ON AXIOMATIC DESIGN

The four design equations in Figure 3 show an example of failure cause analysis based on Axiomatic Design.

(i) is the design equation for an image recording device with an internal hard-disk drive (HDD). The solution “DP1: internal HDD (instead of a video deck)” was set for the requirement of “FR1: Record long hours of TV programs”. The second solution “DP2: Playback DVD” was for the additional requirement of “FR2: Want to view movies”. The marketing of the project failed (Event (1)) to identify that although the HDD successfully recorded 80 hours of TV programs, what the consumer really wanted was permanent recording with the DVD that came with DP2. The quick countermeasure was to shift the target market from Japan that prefers permanent recording to other Asian countries where permanent recording is not that important (Countermeasure (B)). Moreover, engineers noticed that when the product entered to the market, the consumers already compared conventional “Playback DVD” with new “Recording DVD” and even though the latter cost twice as much, they shied away from “Playback DVD” (Cause (b)). Eventually, the manufacturer changed the DP2 to “Recording DVD” and developed an expensive next model (Countermeasure (C)).

(ii) is the design equation for a underwear that grease easily lifts off when washed. For the requirement “FR1: Keep the underwear clean (without turning yellow)”, the solution was “DP1: Hydrophilic cotton fiber”. The development, however, took 6 years, and the new younger generation preferred underwear with colored patterns and the need itself was lost (Event (2), Cause (b)). The manufacturer then changed the requirement to “FR1: Make less impact on the environment (by rinsing without detergent)”, named the product “Ecomagic” and placed it in the market (Countermeasure (D)). The consumers then bought the product even with a “DP2: 50% higher price” to the “FR2: Keep the price increase small”.

(iii) is the design equation for a CD-RW media with fine art pattern on the surface. The requirement of “FR1: Differentiate from competitors (currently at the 4th position)” led to “DP1: Fine design of animals or vehicles on the CD-RW surface”. The constraint of “FR2: Give fun and peace of mind to the customer” led to “FR2: A variety of design line-up”. The prior market research found the customer’s voice of wanting different disk; however, most customers worked in offices and would not choose unconventional designs. The 27 types of new designs kept piling in storage (Event (3), Cause (c)). The manufactures then picked out only the modest designs and reduced the variety (Countermeasure (B)).

(iv) is the design equation for a premium bicycle for women. The “DP1: Design with straight lines and calming colors” was set to meet the requirement “FR1: Gain acceptance by female users”. The model was a sequel to a hit model with high performance and thus had the “FR2: Provide high functionality to the bicycle” with the “DP2: Rubber cushion and aluminum frame”. The design of DP1 was not well accepted by the female consumers and the ratio of female customer to all customer dropped from 30% to 10% (Event (3), Cause (c)). The next model then changed the first design parameter to “DP1: Round design with partial use of primary colors” and succeeded (Countermeasure (C)).

As if these examples show, we could set two FRs and two DPs to all cases and analyze them to make the aforementioned Table 1, 2 and 3.

4 DISCUSSION

We then evaluated complexity of the three groups of causes.

(a): Decoupled design where DPi affected FRj, and this case contained imaginary complexity.

(b): Design range of FRi unexpectedly changed over time and thus contained time-dependent combinatorial complexity.

(c): The probability of DPi meeting FRi was small and thus had real complexity.

It is desirable to eliminate these complexities to succeed in product planning. The following four methods are effective in general [2].

(I): Minimize the number of FRs. The approach we took in our study in this paper simplified the event to have only two FRs and we could not further reduce them.

(II): Eliminate the time-independent real complexity of FRs. Cause (c) contains real complexity. In the cases of CD-RW in Figure 3 (iii) or bicycle in (iv), the manufacturer changed the FR and DP to accomplish this countermeasures.

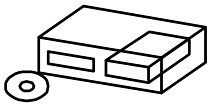
(III): Eliminate the time-independent imaginary complexity. Cause (a) contains this imaginary complexity, and the remedy in 3.2 is needed. Like the case of lifter in Figure 2 or DVD in Figure 3 (i), we need to set the non-diagonal components to zero by altering a FR or DP.

(IV): Transform a system with time-dependent combinatorial complexity into a system with time-dependent periodic complexity by introducing functional periodicity and by reinitializing the system at the beginning of each period. Articles that we studied introduced particular products. But the case of DVD in Figure 3 (i) or bicycle in (iv) is an example of industry with a short development cycle. The next model planning took the lessons learned from the previous model. Thus, seasonal products can enforce annual cycle periods, and cellular phones and digital cameras a shorter cycle periods of three months to eliminate complexity.

Customers want to record TV programs permanently [cause (a)]
Customers notice a new recording DVD [cause (b)]

- After the market entry

$$\begin{Bmatrix} \text{FR1: Record long hours of TV programs} \\ \text{FR2: Want to view movies} \end{Bmatrix} = \begin{bmatrix} X & -X \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Internal HDD} \\ \text{DP2: Playback DVD} \end{Bmatrix}$$



- After the countermeasure

Export the device to other Asian customers who didn't want permanent recording [countermeasure (B)]

$$\Rightarrow \begin{Bmatrix} \text{FR1: Record long hours of TV programs} \\ \text{FR2: Want to view movies} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Internal HDD} \\ \text{DP2: Playback DVD} \end{Bmatrix}$$

eventually

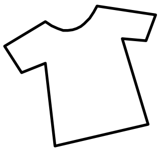
$$\Rightarrow \begin{Bmatrix} \text{FR1: Record long hours of TV programs} \\ \text{FR2: Want to view movies} \end{Bmatrix} = \begin{bmatrix} X & X \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Internal HDD} \\ \text{DP2: Recording DVD} \end{Bmatrix}$$

Change of the sub-device [countermeasure (C)]

(i) Image recording device [event (1) (2)]

- After the market entry

Younger generations change to prefer underwears with colored patterns [cause (b)]



$$\begin{Bmatrix} \text{FR1: Keep the underwear clean} \\ \text{FR2: Keep the price increase small} \end{Bmatrix} = \begin{bmatrix} -X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Hydrophilic cotton fiber} \\ \text{DP2: 50\% higher price} \end{Bmatrix}$$

- After the countermeasure

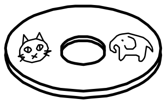
Change the selling point [countermeasure (D)]

$$\Rightarrow \begin{Bmatrix} \text{FR1: Make less impact on the environment} \\ \text{FR2: Keep the price increase small} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Hydrophilic cotton fiber} \\ \text{DP2: 50\% higher price} \end{Bmatrix}$$

(ii) "Ecomagic" underwear [event (2)]

- After the market entry

$$\begin{Bmatrix} \text{FR1: Differentiate from competitors} \\ \text{FR2: Give fun and peace of mind to the customers} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & -X \end{bmatrix} \begin{Bmatrix} \text{DP1: Fine design of animal or vehicles on the CD-RW surface} \\ \text{DP2: A variety of design line-up} \end{Bmatrix}$$



Customers cannot use unconventional design in offices [cause (c)]

- After the countermeasure

$$\Rightarrow \begin{Bmatrix} \text{FR1: Differentiate from competitors} \\ \text{FR2: Give fun and peace of mind to the customers} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Fine design of animal or vehicles on the CD-RW surface} \\ \text{DP2: A variety of design line-up} \end{Bmatrix}$$

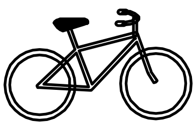
Pick out only the modest designs [countermeasure (B)]

(iii) Fine designed CD-RW [event (3)]

- After the market entry

Female customers didn't like the design [cause (b)]

$$\begin{Bmatrix} \text{FR1: Gain acceptance by female users} \\ \text{FR2: Provide high functionality to the bicycle} \end{Bmatrix} = \begin{bmatrix} -X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Design with straight lines and calming colors} \\ \text{DP2: Rubber cushion and aluminum frame} \end{Bmatrix}$$



- After the countermeasure

Major design change [countermeasure (C)]

$$\Rightarrow \begin{Bmatrix} \text{FR1: Gain acceptance by female users} \\ \text{FR2: Provide high functionality to the bicycle} \end{Bmatrix} = \begin{bmatrix} X & 0 \\ 0 & X \end{bmatrix} \begin{Bmatrix} \text{DP1: Round design with partial use of primary colors} \\ \text{DP2: Rubber cushion and aluminum frame} \end{Bmatrix}$$

(iv) Premium bicycle [event (3)]

Figure 3: Examples of design equation analyzed by Axiomatic Design

5 CONCLUSIONS

We analyzed 50 newspaper articles from Nikkei Business Daily about commodities that did not sell as expected by applying Axiomatic Design. Our failure analysis set the commodity's selling point to FR1, and the countermeasure to the constraint upon market release to FR2.

We categorized these failure cases into the following three groups.

(1): 34% of the events were poor planning within the organization. Among these cases, 53% were due to DPi which intended for FRi but affected other FRj (decoupled).

(2): 28% of the cases changed in external circumstances. Among these cases, 57% were due to unexpected change of the design range of FRi.

(3): 38% was misalignment of the designer's intent and the consumer's need. 68% of these events were caused by DPi of aesthetics or cultural concept having small probability of meeting FRi.

Countermeasures to these designs, whatever the events and causes were, involved changing the system range of DP (14%), design range of FR (16%), DP itself (36%), FR itself (14%), and reducing or abandoning the project (20%). The effect on the project is greater in this order.

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