Case Study: Integrated Approach for Prioritization in Automobile Development Process

Parveen Goel*, Iksung Lim**, Ilseob Koo**, Taesung Kim**
*TRW Automotive, Warren MI 48202, USA
**Namseoul Univ., Dept. of Industrial Engineering

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Abstract

A successful product development process can not be achieved without a proper focus and prioritization. For this research, the priority is defined as the relative urgency of a system compared to other system in order to develop and launch a successful product. The process of integrated approach for prioritization using ID and Goal Programming is developed. The development of a mid-size car by an internationally reputed automotive company is described as a case study.

1. Introduction

A successful product development process can not be achieved without a proper focus and prioritization. Every company has to decide the areas of weakness and concentrate on it for improvement. Prioritization is one of the key input for the successful Product Development (PD) process. It is always necessary even for organizations that are devoted primarily to small projects because talented business and technical resources are always scarce compared to demand. Prioritization is a management decision, which has to be taken at early stages of PD. At early stages of PD information required for prioritization is very uncertain and in many cases that promotes the idea of taking decision just on gut feeling. Another important dimension in prioritization decision is added by organizational politics. Politics is almost always a factor in prioritization decisions, however it need not to be the only or most important factor.

For this research priority may be defined as the relative urgency of a system compared to other system in order to develop and launch a successful product. Priorities are relative within organization at which a product is owned, developed and managed. Systems at any level in product compete for resources, so conflict is inherent in prioritization. Rather than allowing politics and gut feeling to solve priority conflicts, they should be resolved on the basis of perceived value to the organization, customer and society. This requires a framework for decision making that includes process and solution methodologies.

There are several tools/methodologies/techniques available in literature for prioritization. Examples of subjective techniques are; Pareto Analysis or 80-20 rule, analysis based on criticality, Prioritization matrix, full analytical criteria method and Interrelationship Digraphs. Some more mathematically involved techniques are: AHP, Goal Programming and other multi-criteria decision-making methods. These techniques need to be adapted and integrated for prioritization of systems in PD.

Different criteria for prioritization will give different conclusions. For example in identifying priority systems for PD, warranty may be one criterion and we can identify significant systems based on warranty, another criteria may be customer satisfaction and significant systems based on this will be different. Real challenge is how do we decide the final list of priority systems, which are based on considerations of all the relevant factors.

These three decisions need not to be taken separately, for example Goal Programming and AHP combines second and third. There may be more sub decisions to be taken depending upon what method we use. One way to simplify the list of criteria and sub-criteria, to reach a workable list would be using the Interrelationship Digraph (ID). This paper provides an integrated approach for prioritization work in Product Development based on Interrelationship Digraphs and Goal Programming. The approach will be illustrated with the help of an Automotive Product Development example. Next section provides brief introduction to Goal Programming and Interrelationship Digraphs.

2. Integrated Approach

In this research, interrelationship digraph and goal programming will be integrated to prioritize the work in produdct development.

2.1 Interrelationship Digraph

Interrelationship digraph is a systematic technique to identify, analyze, and classify the cause and effect relationships that exist among all critical issues so that key drivers or outcomes can become the heart of an effective solution [1]. It is a team-oriented approach that encourages team members to think in multiple directions. It allows the key issues to emerge naturally rather than allowing the issues to be forced by a dominant team member.

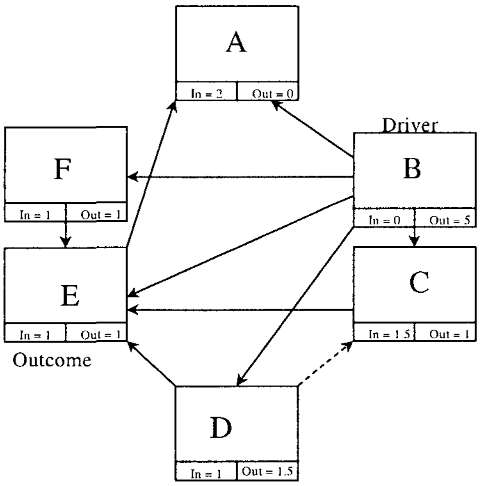

Figure 1: Interrelationship Digraph

Figure 1 shows a typical ID. A high number of outgoing arrows indicates an item that is a root cause or driver. A high number of incoming arrows indicates an item that is a key outcome. This analysis is subjective in nature and team approach is very important for the success of this approach. Issues with close tallies must be reviewed carefully but in the end, it is a judgement call, not science.

2.2 Goal Programming

Goal programming (GP) is an efficient and effective tool for modeling the solution and analysis of mathematical models that involve multiple and conflicting goals and *objectives.* Many researchers have applied goal programming to solve design, development, and planning problems with conflicting objectives [5].

Goal programming optimizes multiple objectives simultaneously by setting a goal for each objective and determining its priority. Priorities may be preemptive or weighted, with preemptive priorities we get a lexicographic minimum.

$$Z=\sum_{i=1}^{n}\sum_{j=1}^{m_i}P_i\{W_{ij}d_{ij}^{+}+W_{ij}d_{ij}^{-}\} \quad (1)$$

Subject to:

$$f_{ij}(x_1,\ldots x_k,\ldots x_p)-d_{ij}^{+}+d_{ij}^{-}=G_{ij} \qquad \forall i \text{ and } j \quad (2)$$

$$\psi_{ij}(x_1,\ldots x_k,\ldots x_p)\ge a_{ij} \qquad \forall i \text{ and } j \quad (3)$$

$$\xi_{ij}(x_1,\ldots x_k,\ldots x_p)\le b_{ij} \qquad \forall i \text{ and } j \quad (4)$$

$$\zeta_{ij}(x_1,\ldots x_k,\ldots x_p)= c_{ij} \qquad \forall i \text{ and } j \quad (5)$$

$$x_1,\ldots x_k,\ldots x_p;d_{ij}^{+},d_{ij}^{-}\ge 0 \quad (6)$$

We have n different products, and each product has m_i distinct objectives to be optimized by deciding the level of p systems. Variables x_k represent the controllable decision parameters for the prioritization problem. G_{ij} is the jth goal of the ith product; d^-_{ij} and d^+_{ij} represent under- and over-achievement of the corresponding goals. P_i represents the priority for the ith product. W_{ij} is the weight associated with over- or under-achievement of G_{ij}. The objective function (1) to be minimized is the weighted sum of deviations from the ideal or best-expected values for all objectives. Equation (2) represents the goal constraints for all of the objectives. All objectives should be expressed as a function of controllable decision parameters. Equation (3), (4), and (5) represent the other organizational or market constraints. Equation (6) is a non-negativity constraint.

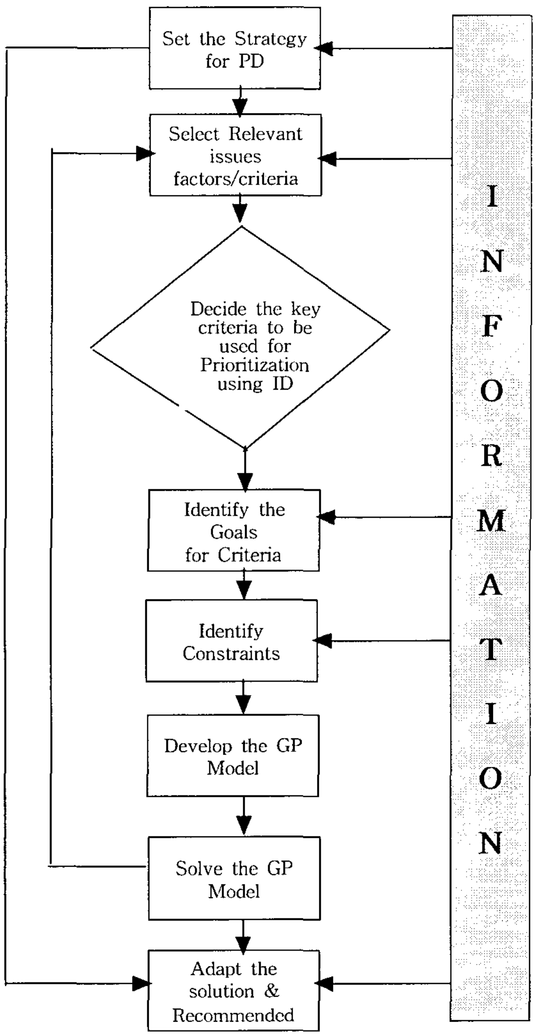

Figure 2: Integrated Process for Prioritization in PD

Figure 2 shows the process of integrated approach for prioritization using ID and Goal Programming. This process and techniques imbedded into this process will provide a framework to the organizations for prioritization of PD resources. This will avoid failures from prolonged decisions over resource allocation, as it gives a simple mechanism for prioritization. Next we describe a case study of the development of a mid-size car by an internationally reputed auto-motive company.

3. Case Study

An internationally reputed automotive company is planning to develop and launch a mid-size car, in several markets worldwide. This car based on an existing car company is producing in its home country for last twenty years. This car has been a great success and company has launched a new model of this car every year. However there has been only four major design upgrades in last twenty years. The last design upgrade was only two years back and it represent the latest technologies used by auto manufacturers in this market segment.

The company needs to build its image in new international markets and will use this car as their flagship product. There is extreme competition in international markets and therefore it has to be launched as soon as possible with minimum PD cost. Based on the latest international treaty on green house effect, engine of this car will need some modifications to meet new emission standards. In recent years company's sale volume has increased, however its profit margin has declined and its warranty cost is high compare to the competition. Board of directors has set a corporate imperative for warranty cost and company's CEO is very serious about meeting this imperative and cutting PD cost in order to improve the profit margins.

It is a very common scenario for many companies operating in a global competitive environment. One of the very important decision in this situation is prioritization and focusing all the efforts and energy on high value items. Integrated approach for prioritization using ID and Goal Programming described earlier in this paper will be used for selecting the systems and their level of improvement for this case study.

Following factors, which were obtained through customer requirements feedback data, were identified as important for the case of mid-size car project:

1. Product Quality
2. Warranty
3. Things Gone Wrong (TGW)
4. Things Gone Right (TGR)
5. Number of Repairs
6. Profit Margin
7. Customer Satisfaction
8. Resources
9. PD Lead Time
10. Brand Image
11. Market Share

All of these factors were used in developing Interrelationship Digraph as shown in Figure 3. The interrelation between factors in Figure 3 was developed with the aids of engineers consensus. Analysis of this ID indicates that quality, customer satisfaction and warranty are the most important factors for this project. We also looked at what factors influence quality and warranty. We found that TGW, number of repairs, resources, and lead-time have influence over quality and warranty. We considered all these influencing factors customer satisfaction and warranty in constructing Goal Programming model for prioritization. Since quality is subjective we considered only the factors influencing it rather than quality itself as a factor.

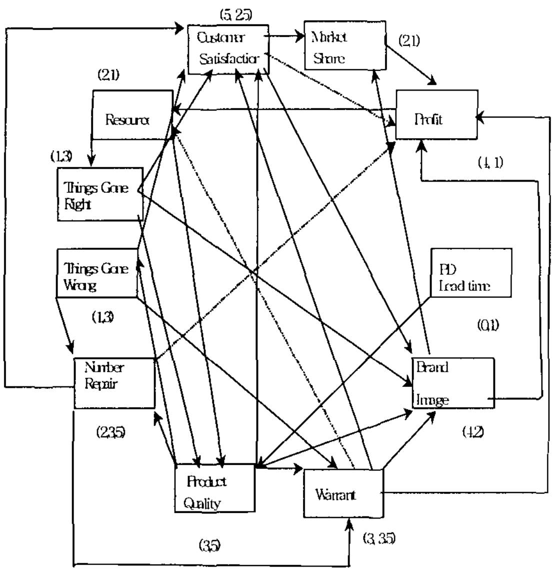

Figure 3: ID for Case Study

We will consider car consisting of eighteen systems listed in Table 1. Our objective is to decide what level of improvement we should be doing in each of these systems so that we can meet all the goals as closely as possible. We will consider following four levels of improvement for each system.

- No Improvement (Carry over system)
- Minor Improvement
- Major Improvement
- Significant Improvement

Table 1 shows the historical data for all the systems based on one year in service (one YIS) performance. TGW, Repairs and warranty shows the negative side of quality and smaller the number better it is. Customer satisfaction is rated on one to five scale, one indicates complete dissatisfaction and five indicates complete satisfaction or a thrilled customer. Market Position (MP) indicates where we stand relative to the competition, one indicates being leader and three shows a bad reputation and two means somewhere between two extremes. Table 2 lists the information related to efforts and time required for improvement and Customer Desirability Index (CDI) for each system. The CDI shows how much customer care about that particular system. CDI and efforts both are based on one to twenty scale. Time is given on a one to three scale, three indicates a long-term project and any significant improvement can not be achieved within one program timing. Two indicates that significant improvement can be achieved within one program timing. One indicates that the system can be significantly improved in a relatively shorter time period.

In addition to the information given in the tables, we also need to know organizational constraints, availability of resources and corporate imperatives for TGW warranty and repairs. This additional information, whose values are typical numbers used at the company for its purpose, is as follows:

- Resources = 200 units
- Corporate imperative for TGW = 500
- Corporate imperative for Repairs = 700

Table 1. Historical Information based on 1 YIS

SYSTEM	TGW (/1000)	Repairs (/1000)	Warranty /Unit	Customer Satisfaction	Market Position
1. Braking System	75	100	5	3	2
2. Chassis	25	39	2	2	2
3. Climate Control	100	90	6	4	1
4. Electrical System	40	50	3	3	2
5. Engine	100	125	18	3	2
6. Entertainment	25	20	1	5	2
7. Glass	20	50	1.5	5	1
8. Instruments	60	125	4.5	4	2
9. Interior Trim	100	85	3.5	2	3
10.Instrument Panel	50	60	3.5	2	2
11. Lighting System	30	45	1	3	2
12.Paint Appearance	120	90	1	4	1
13. Restraints	30	20	0.5	3	2
14. Seating	45	25	1	2	3
15. Sheet Metal	105	75	5	4	1
16. Steering	35	90	6	2	3
17. Transmission	100	145	25	1	3
18. Wiper	45	70	0.5	3	2
Total	2,105	2,304	88	55	36

- Corporate imperative for Warranty = 45
- Corporate imperative for Customer Satisfaction = 75
- Any system with CDI greater than 15 needs at least minor improvement
- Systems with market position 3 should have major or significant improvement
- Systems with time '3' should not be selected for significant improvement

For resource calculations we will multiply level of improvement by efforts required for improvement. Scale of 0, 1, 2, and 3 are used to represent levels of improvement.

3.1 Goal Programming Model for the Case Study

Based on the information provided here and general model described in earlier section, the Goal Programming (GP) model is constructed. The results of ID graph can be used to develop the Goal programming. The GP model will consider following four factors, output from the ID graph, as objectives:

Table 2. Relative efforts, time, and customer desirability

SYSTEM	Efforts	Time	CDI
1. Braking System	10	2	20
2. Chassis	20	3	16
3. Climate Control	8	2	9
4. Electrical System	8	1	8
5. Engine	20	3	20
6. Entertainment	2	1	4
7. Glass	2	3	8
8. Instruments	5	1	12
9. Interior Trim	5	1	9
10. Instrument Panel	5	2	9
11. Lighting System	5	1	16
12. Paint Appearance	15	3	10
13. Restraints	6	2	18
14. Seating	8	2	12
15. Sheet Metal	12	3	10
16. Steering	18	2	17
17. Transmission	17	3	18
18. Wiper	2	1	8

- Things Gone Wrong
- Repairs
- Warranty
- Customer Satisfaction

Objective of the GP model is to minimize the weighted sum of the deviations from the Goals (Corporate Imperatives) of these factors. GP Model objective is represented by equation (7). Equation (8) to (16) represent various constraints of the model.

$$Z = M_T(d_T^+ - d_T^-) + M_R(d_R^+ - d_R^-) + M_W(d_W^+ - d_W^-) + M_C(d_C^- - d_C^+) \quad (7)$$

Subject To:

$$\sum_{i=1}^{n}\left(\frac{T_i}{(S_i+1)^{0.4}}\right) - d_T^+ + d_T^- = G_T \quad (8)$$

$$\sum_{i=1}^{n}\left(\frac{R_i}{(S_i+1)^{0.4}}\right) - d_R^+ + d_R^- = G_R \quad (9)$$

$$\sum_{i=1}^{n}\left(\frac{W_i}{(S_i+1)^{0.4}}\right) - d_W^+ + d_W^- = G_W \quad (10)$$

$$\sum_{i=1}^{n} C_i(S_i+1)^{0.4} - d_C^+ + d_C^- = G_C \quad (11)$$

$$\sum_{i=1}^{n} S_i E_i \le U_E \quad (12)$$

$$S_i \le 3 \quad \forall i \quad (13)$$

$$S_j \ge 1 \qquad for\, CDI \ge 15 \quad (14)$$

$$S_k \ge 2 \qquad for\, MP = 3 \quad (15)$$

$$S_l \le 2 \qquad for\, Time = 3 \quad (16)$$

$S_i,\ d_T^+,\ d_T^-,\ d_W^+,\ d_W^-,\ d_R^+,\ d_R^-,\ d_C^+,\ d_C^- \ge 0$ *and*

S_i *are* integer

Where:

S_i = Decision variable indicating level of improvement selected for the i[th] system

n = Number of systems (in our case it is 18) *MT, MR, MW, and MC* = Weights to represent the priority of respective objective

T_i = Things Gone Wrong for the i[th] system, values are given in Table 1

GT = Things Gone Wrong (TGW) Goal in our case it is 500

R_i = Repairs for the i[th] system values are given in Table 1

GR = Repair Goal (in our case it is 700)
W_i = Warranty Cost for the i^th^ system values
GW = Warranty Cost Goal (in our case it is 45)
C_i = Customer Satisfaction for the i^th^ system
GC = Customer Satisfaction improvement Goal (in our case it is 25)
E_i = Efforts for the i^th^ system values are given
UE = Upper Limit of Efforts (in our case it is 150)
$d_T^+, d_T^-, d_W^+, d_W^-, d_R^+, d_R^-, d_C^+, d_C^-$ = Over and under achievement of respective goals
i, j, k, l = indexes for decision variable on level of improvement

Equation (8) to (11) represent the four objective functions, adjusted with deviations and equated to their respective goals. Equation (8) is for Things Gone Wrong and it assumes that with minor improvements we can reduce TGWs by 24%, with major improvements TGWs can be reduced by 36% and with significant improvements these can be reduced by 43%. Similar improvements are assumed for warranty, and repair. Improvements for customer satisfaction are assumed to be 32%, 55% and 74% respectively for minor, major and significant changes. Equation (12) ensures the constraint of available resources and equation (13) ensures the proper selection of the level of improvement. Equation (14) ensures that any system with CDI more than 15 will have at least minor improvement. Equation (15) ensures that systems with market position 3 will have major or significant improvement. Equation (16) ensures that systems with time '3' will not be selected for significant improvement. In the end, the non-negativity constraint for all the variables and integer constraint for S_i are stated.

3.2 Solution of GP Model for case Study

To solve this model we need to decide the weights for each objective to establish the priorities. To start with we are assuming all the objectives to be equally important therefore we will assume weights as (1.5, 1, 15, 10) respectively for TGW, Warranty, Repairs and Customer Satisfaction. This model was solved using Non-Linear GP techniques with the help of a spreadsheet optimization macro solver. This Macro solves NLP problems with the GRG (Generalized Reduced Gradient) method as implemented in Lasdon and Waren's GRG2 code [4]. This method and specific implementation have been proven in use over many years as one of the most robust and reliable approaches to solving NLP problems [2].

Table 3. Prioritization Results Based on Goal Programming Model

SYSTEM	IMPROVEMENT	TGW (/1000)	Repairs (/ 1000)	Warranty / Unit	C.S.
1. Braking System	Minor	57	76	4	4
2. Chassis	Minor	19	30	2	3
3. Climate Control	Minor	76	68	5	5
4. Electrical System	No (Carry over system)	40	50	3	3
5. Engine	Minor	76	95	14	4
6. Entertainment	Significant	14	11	1	9
7. Glass	Major	13	32	1	8
8. Instruments	Major	39	81	3	6
9. Interior Trim	Major	64	55	2	3
10. Instrument Panel	Minor	38	45	3	3
11. Lighting System	Minor	23	34	1	4
12. Paint Appearance	No (Carry over system)	120	90	1	4
13. Restraints	Minor	23	15	0	4
14. Seating	Major	29	16	1	3
15. Sheet Metal	No (Carry over system)	105	75	5	4
16. Steering	Major	23	58	4	3
17. Transmission	Major	64	93	16	2
18. Wiper	Significant	26	40	0	5
TOTAL		848	965	64	76

4. Summary and Conclusion

Table 3 summarizes the solution obtained by the integrated approach for prioritization in PD. Solution recommend No Changes for 3 and 2 systems. It is recommended to have significant changes for remaining systems minor and major changes are suggested. Based on the recommended solution it is expected that TGWs will be reduced from 1,105 to 848, that is a 23 % improvement. On warranty, repairs and customer satisfaction we may expect 26%, 27% and 38% improvements respectively. For better understanding of this solution we solved the GP Model for different values of resources constraint, Figure 4 and 5 graphically shows these results.

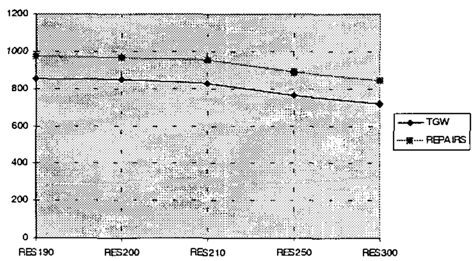

Figure 4. Expected TGW and Repairs based on changes in resources

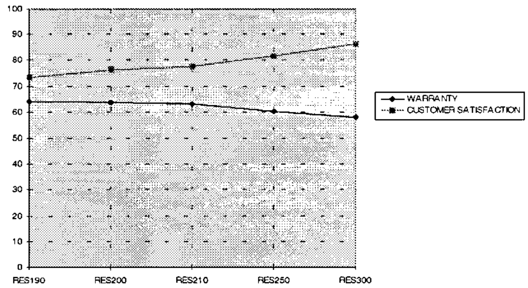

Figure 5. Expected Warranty and Customer Satisfaction based on changes in resources

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