# AN APPROACH TO SUPPORT INTERDISCIPLINARY VARIANT DIVERSITY OPTIMIZATION

## *Planning Variant Diversity – Beyond Complexity Reduction*

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Abstract: The increasing number of variants in manufacturing companies' product ranges leads to rising costs due to process and product complexity. The expected profit of higher diversity is often overrated while its costs are underestimated because of missing methods and insufficient process transparency. This paper introduces a methodical approach to identify the optimal diversity considering available capacities and the effects on profit and costs for each variant to support variant decisions within the product and process planning. Therefore a mathematical model of the described diversity planning problem is developed. This complex decision problem is solved using a particle swarm algorithm, which is able to compute the optimal solution within reasonable time. The found solutions can be discussed and evaluated by an interdisciplinary planning team considering even qualitative aspects, leading to an increased transparency in the decision process.

## 1 INTRODUCTION

Manufacturing companies have to take great challenges in a globalized competitive environment. To face these challenges most European companies follow the strategy of differentiation to improve their competitive situation. This differentiation strategy leads to greater variant diversity in the companies' product ranges. Higher diversity causes higher complexity in involved business and manufacturing processes due to the increasing number of different items which are to be handled. Furthermore national norms, standards and laws, as well as differentiated customer requirements enforce globally operating companies to develop country-specific product variants.

On the one hand companies benefit from variant diversity because of increasing sales. On the other hand increasing diversity means more complexity in all business and manufacturing processes. Complexity in turn leads to increasing costs because the capacity of each involved department has to be expanded. These costs rise exponentially with increasing variant diversity. In contrast, benefits have a concave development (Alders, 2006).

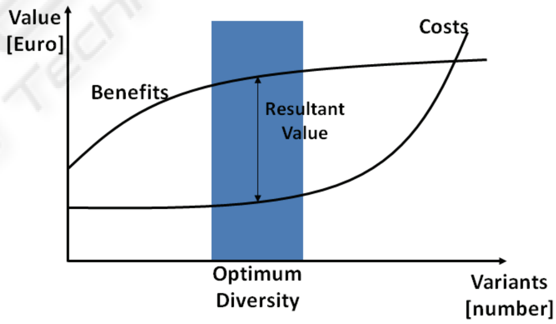


Figure 1: Optimum diversity regarding benefits and costs.

Figure 1 shows that the optimal diversity lies in between the two extrema of very high and very low variant diversity. In fact the optimum diversity is characterized by the maximum difference between benefits and costs. Finding this maximum resultant value is a typical decision problem. In the following we characterize this problem in the context of an interdisciplinary product planning process. Our approach is to support this decision process with the methods of Operations Research. For this purpose we describe the problem mathematically and will show that solving this mathematical problem with


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the help of a particle swarm algorithm promotes the optimal decision under given constraints.

## 2 PROBLEM DESCRIPTION

Variant decisions are the result of a multilevel problem solving process (Heina, 1999). First of all the sales department performs a market analysis to identify customer needs. Taking into account the sales volume of previous products and forecasts for the new product, the sales department proposes different "variant scenarios" (Alders, 2006). Though these scenarios imply a combination of different product variants they often have the same diversity. These scenarios are then analysed and evaluated by an interdisciplinary team in terms of profits and costs. This process may take up to one week for only one part or assembly. It is assumed that most of the time is wasted with recurring discussions about capacities and costs (Alders, 2006).

The variant decision process is often dominated by the sales department because of their knowledge about markets and customer demands. The sales department benefits from higher product diversity through increasing volumes but does not bear the costs of the increasing process complexity, like for example the departments of production and logistics. This is the reason why benefits of additional variants are often overrated while their impact on process complexity and costs is underestimated (Rathnow, 1993).

Moreover, as human capacity is limited, only a few alternative scenarios can be analysed. It is unlikely that the optimal solution is one of these.As a result, this process tends to expand production capacities and human resources instead of questioning the demand for a variant.

In the following we introduce an approach to solve these problems with the help of a decision support system.

## 3 SUPPORTING INTERDISCIPLINARY VARIANT DECISIONS

Our approach is based on the variant decision process described in section 2. To avoid recurring discussions about capacities and costs we propose to support this decision process by a decision support system (DSS). This system analyses and evaluates the whole solution space of the variant decision problem simultaneously, instead of discussing three or four "scenarios" sequentially. The required data, profits and costs are still forecasted by the experts of each department (cf. section 2). Based on this data we introduce the Interdisciplinary Variant Optimization Model IVOM. This mathematical description of the variant decision problem allows computing the optimal diversity considering all effects on business profits and given capacity constraints.

Decision problems are represented mathematically by optimization models. They consist of an objective function $F(\vec{x})$ which has to be minimized or maximized and one or more constraints $g(\vec{x})$ which define the possible solution space of that particular problem either by equations or inequations.

$$Maximize\ or\ Minimize \quad F(\vec{x}) \tag{1}$$

$$subject\ to \qquad g(\vec{x}) \begin{Bmatrix} \leq \\ = \\ \geq \end{Bmatrix} Y \qquad x \in \{\mathbb{R}^+, \mathbb{Z}^+, B\}; Y \in \{\mathbb{R}^+\} \tag{2}$$

Based on this general optimization model we define the Interdisciplinary Variant Optimization Model IVOM as a specialized knapsack problem.

### 3.1 The Interdisciplinary Variant Optimization Model (IVOM)

IVOM represents the variant decision problem described in section 2. The objective of the variant decision problem is the identification of the optimum diversity given by the maximum difference of profits and costs. According to formula (1) the objective function of IVOM is

$$Maximize \quad F(x) = \sum_{j=1}^{n} v_j x_j \tag{3}$$

Where $x$ is a binary variable to decide whether variant $j$=1,...,n is selected or not. The resultant value of a variant is given by the difference of its profit $n$ and its costs $c$ (cf. Figure 1):

$$v_j = n_j - \sum_{i=1}^{m} c_{ij}\,; \tag{4}$$

The indices $i$ and $j$ specify that variant $j$ causes costs in the departments $i$=1,...,m.

At first, we want to define the optimum diversity for the given capacities. In a second step one could discuss the expansion of specific capacities considering this method's results. The given capacities of the involved departments are represented by constraints in the form of inequations. In general, a constraint for a capacity $l$=1,...,u is defined as shown in formula (5).

$$\sum_{j=1}^{n} \kappa_{lj}\, x_j \leq K_l \qquad (5)$$

$K$ is the limit of capacity $l$. The variant $j$ exploits $\kappa$ units of capacity $l$. We call $\kappa$ the capacity driver of variant $j$. This inequation assures that the chosen variants ($x$=1) do not exceed the capacity limit. Inequations can be defined by the experts of each department for all kinds of limited capacity (e.g. storage capacity, machine time). To enhance transparency, the data and the capacity constraints should be published. The constraint that affects all involved business processes is human ressource. Hence, we introduce the manpower-constraint exemplarily.

Increasing diversity strains human resources. That is why the given manpower resources are a very important constraint.

The mathematical definition of the manpower-constraint is defined as follows:

$$\sum_{j=1}^{n} (\kappa_{j\_time} + \kappa_{j\_trans}) x_j \leq K \qquad (6)$$

For human resources both, time and transaction drivers can be taken into account: $\kappa_{time}$ and $\kappa_{trans}$. Normally a work step is characterized by the time that is needed to accomplish it. Sometimes, especially for administrative tasks, this cannot be detected separately. A time lump-sum per transaction is needed. Potential units for the capacity drivers as well as the capacity limit $K$ are man-day, man-month or man-year.

In the same manner we defined transaction and stock constraints for the purchasing and logistics department. A special stock constraint for the production area considers the limited space for different variants in an assembly area to avoid special picking areas:

$$\sum_{j=1}^{n} z_j d_j \cdot x_j \leq K \qquad (7)$$

For assembling, variant $j$ is provided in a standard box that occupies the space $d$. In conjunction with the number of boxes ($z$) that have to be provided for variant $j$ and the total space available $K$, this constraint assures that the production area does not need cost-intensive picking areas.

And finally we defined a production constraint to take machine hours and set-up time into account. Many more are imaginable for different problems.

## 3.2 Solving IVOM

At this stage the variant decision problem is split and formulated in the objective function and the constraining inequations. In the next step the described model of the variant decision problem has to be solved by an applicable algorithm.

Algorithms were developed for different types of problems. First of all we have to characterize IVOM as a specific problem type. Secondly we select one of the possible algorithms for this type of problem that promises the best and efficient solution.

The variant decision problem as it is represented by IVOM is a special knapsack problem. It has more than one constraint; strictly it might have multiple constraints for every department and all kinds of capacities. This type of problem is called a multidimensional knapsack problem (Kellerer, 2004).

Concerning its computing time, a study by Kennedy and Spears (Kennedy, 1998) came to the conclusion that particle swarm algorithms are most suitable for complex multidimensional binary problems. Hence, to find the optimum solution of IVOM we used a particle swarm algorithm.

## 3.3 Qualitative Aspects of the Variant Decision

After IVOM is properly defined for a given variant decision problem the swarm algorithm is able to identify its optimal solution. The found quantitative optimal solution might be in conflict with qualitative constraints, e.g. the brand image.

The proceeding of the particle swarm algorithm allows saving several very good solutions, delivering optimal valid solutions within the defined constrains. In every step of the algorithm the best position of each particle is saved. This arises the opportunity to add a qualitative analysis made by the interdisciplinary team after the algorithm identified a set of the best solutions, giving optimal decision support.

## 3.4 Decision Support through IVOM

The result of the IVOM approach is a list, consisting of all valid, optimum solutions found by the particle swarm algorithm. Every solution is described by its values for the parameters and the objective function, which were calculated by the swarm particle at its position in the solution space. For each solution the consequences for the company, explicit the benefits, the costs and needed resources in general can be calculated. The list can be used to discuss all options by the decision team, to consider undefined constraints like e.g. corporate strategy.

## 4 CONCLUSIONS

Current strategies of complexity reduction and complexity control are time consuming, recurring and often do not take all major constraints into account. Especially in interdisciplinary teams the team members trade for their own account with their own perception of possible solutions (e.g. the sales department). Finding the optimal diversity is a key factor for success for manufacturing companies in today's globalized competitive market. We achieve this by substituting sales department's perception by an impartial algorithm, based on interdisciplinary expert knowledge. The optimal solution for a company as a whole can be identified. Preventing complexity by planning variant diversity in early development phases of a product has the potential to design future product lifecycles much more efficient. It allows concentrating on the optimal variants, rather then spending much time and assets in the development and sale of barely demanded variants.

In this paper we presented the mathematical concept, we called "Interdisciplinary Variant Optimization Model" (IVOM), to define given constraints in diversity problem discussions, as well as the definition of an objective function which allows computing the optimal diversity considering all effects on business profits and costs. The proposed particle swarm algorithm is capable not only to find the best solution, but even computes and stores local optima and delivers multiple very good solutions. These can be discussed in interdisciplinary decision teams, concerning even qualitative aspects.

IVOM has a major impact on decision making processes to find optimal diversity and thus reducing complexity within the whole product lifecycle. It deliveres qualitative solutions within the solution space in reasonable time and highly supports decision discussions, allowing to elaborate the consequences of the expansion of capacities or the cancellation of a product variant.

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