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PRODUCT VARIETY MANAGEMENT AS A TOOL FOR SUCCESSFUL MASS CUSTOMIZED PRODUCT STRUCTURE

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Abstract: Successful and efficient product mix requires balancing process and market trade-offs. This is especially applicable in mass-customizable (MC) productions making products in number of configurations according to customers' preferences. Such a variety brings complexity into production processes as well as in product management level. This paper presents a methodology for quantifying product variety induced complexity (VIC) as a number of available product configurations in a case product line. The model of MC assembly product line is further optimized respecting a demand for products. Finally, mutual relations of the VIC metric before and after product line optimization are presented, what evidently justifies a usability of the VIC metric.

Key words: complexity, metric, design optimization, configuration, demand, product line heterogeneity

Introduction

A successful product must satisfy customer requirements and preferences. This market property has many facets and is highly complex in its nature, it is complexity inherently linked to benefit for producer. To comply with these diverse demands, companies design their product portfolios accordingly, i.e. they introduce variety to their products. This, in turn, increases not only the product's complexity but affects the complexity within the entire company and brings enormous problems in different aspects of company management (Ptak and Piechna, 2003; Tabor, 2014). This enterprise-internal complexity spreads to all functional areas (product development, logistics, production, and sales, to name a few) and is called internal complexity. The products of an enterprise are exposed to external complexity and cause internal complexity. Therefore, products must be designed to cope with the implications of both external and internal complexity because they are a very important instrument for achieving sustained profits and assuring long-term survival.

This section introduces concepts that – from a complexity management point of view – provide conceptual framework to cope with a product configuration (external) complexity situation. Other supplementary methods provide a broader picture to overall optimization of a company's complexity.

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Mass Customization

In 1987, Davis (1987) for the first time argued, that the mass customization (MC) strategy and mass production are not necessarily opposites. In the early 80s, it was generally believed, that only a "lean" strategy with specialized systems is able to produce massively, as can be seen in Fig. 1. Thirty years later, mass customization became a very important business strategy through the production of customer specified products for reasonably higher price. Tseng and Jiao (2001) define complexity similarly as a way to produce goods and services to meet individual customer's needs with near mass production efficiency and price.

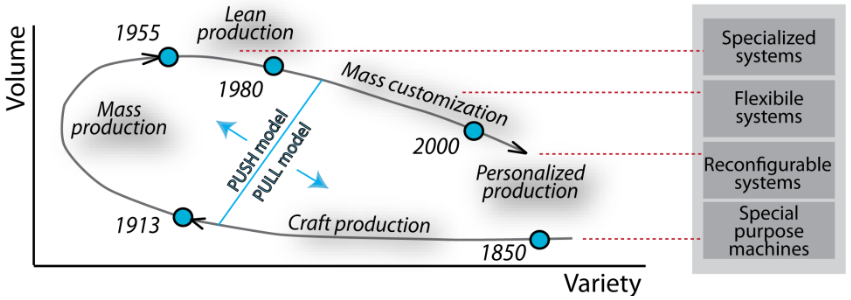

Figure 1. Development stages of production *(Daalboul et al., 2011)*

Mass customization represents a hybrid competitive strategy that overcomes the traditional hypothesis of Porter (1980) that an enterprise must either embrace a strategy of cost leadership, pursue a differentiation strategy, or follow a focus strategy to prosper. It is has been widely held opinion that the cost leadership and differentiation are incompatible (Davis, 1987). In contrast to that, mass customization as modern direction now presents a strategy that allows customizing a company's products at a cost level approaching that of a mass producer (Modrak and Semanco eds., 2014).
As an example of partial MC assembly, the following assembly setup resulting with 14 possible car body colour mix can be presented (see Fig. 2).

The assembly consists of single stable component "S" (car body) and voluntary optional assembly components "VO" represented by four car body colours for customer selections. Optional components may then be combined in any combination among them. Moreover, only customer is responsible for the appropriate price level depending on the number of colours he chooses into combination. If a customer, for example, chooses a three-color combination, he receives a car painted in three colours (roof, side mirrors and the rest of the car) and he obliged to pay the price level four for this configuration. Such a price levelling satisfied the basic precondition of MC strategy – reasonably higher price for customer specified product.

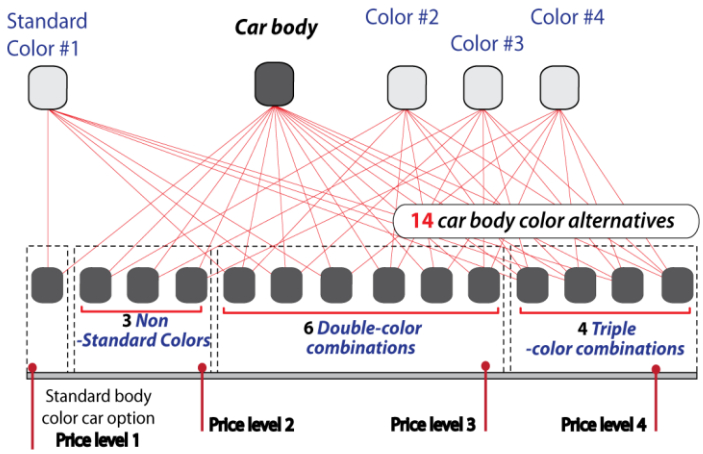

Figure 2. Example of MC assembly variety

Concept of Optimum Variety – Theoretical Background

In order to proceed an optimization of the product line, we firstly need to summarize the most important historical and recent contributions to the product line optimization literature. These include approaches from marketing and management science as well as two engineering-based approaches. Green and Krieger (1985) proposed a binary programmed methodology including selection of products to be part of the product line in order to maximize both, sellers' and buyers' satisfaction. This way they were able to determine specific product and their utility values based on the demand prediction. Other authors later proposed alternative integer programming techniques and heuristics for solving product line optimization problems (Dobson and Kalish, 1993; McBride and Zufryden, 1988). Moreover, Dobson and Kalish (1993) introduce economic parameters, namely fixed and variable costs as criterion for each individual product alternative. Another method is using producers' utility data instead of customer demand-based information about sales. Subsequently, a single stage binary programming formulation selects product lines based on their attribute levels (Kohli and Sukumar, 1990). Chen and Hausman (2000) performed a choice-based analysis very similar to the choice customers perform in real life. For a long time, this method has been the best for extracting individual consumer preferences. Method of Green and Krieger (1996) proposes a non-linear programming technique with homogeneous consumer preferences, and therefore, it cannot be applied in product line design optimization due to disparate needs of the real consumer populations.

One of the very recent contributions is that of Steiner and Hruschka (2003) applying genetic algorithms to determine almost optimal product line design through number of product configurations. Another recent method captures information entropy of the product/system in the context of process design (Krus, 2013) or as a tool applicable in HR environment of any company (Głowacki, 2014). Methods similar to the aim of this paper have been proposed recently by authors of this paper (e.g. Marton and Bednar, 2013; Modrak et al., 2014; Bednar and Modrak, 2014; Modrak and Marton, 2014; 2015) and by others through a system simulation, e.g. (Simsik, 1992; Modrak and Mandulak, 2009; Grabara et al., 2011; Czajkowska and Minda, 2014). Although these methods originally analyse product structures in an abstract manner (using abstract quality levels) rather than provide a unified decision-making computational support tool.

Despite the number of available solutions to the variety management, a number of main problems remain in this research area. Specifically, majority of the approaches mentioned above: lack the understanding of the manufacturing and engineering terms; do not effective employ demand vs. utility model; lack basic computational methods to quantify the variety; and finally require understanding of both, product offering and production structure, as they are inherently linked.

The scope of this paper is on the intersection of the two important areas – complexity in mass customized manufacturing (MCM) and variety management as part of management science.

Complexity can be observed from many aspects. Moreover, every research area defines complexity differently. In terms of manufacturing, Hernandez (2008) defines complexity as: "a system attribute depending on the composition of system elements and relations among them."

Assembly process complexity measures can effectively help in quantification of variety induced complexity (VIC) in terms of any variant production. Applying effective quantification methods to variety management helps researchers to exactly determine optimal variety of the product line, and therefore, maximum net benefit for the producer, as can be seen in Fig. 3(a).

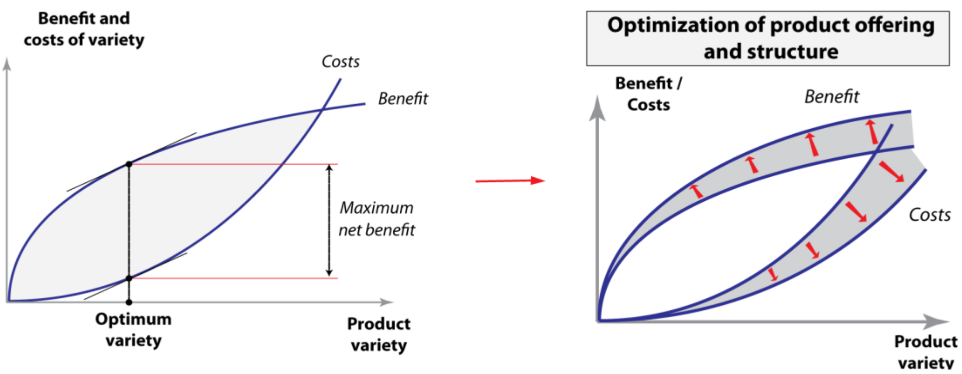

Figure 3. (a) Conceptual description of costs and benefit linked to product variety; (b) Determining the optimum variety by increasing benefit and decreasing costs for producer *(adopted from Rathnow, 1993 and Matern, 2000)*

Firms implementing MC strategy are necessarily involved with managing both, product and process complexity. Such companies are highly motivated to follow the right demanded level of customer satisfaction and to establish an optimized balance between internal – structural and process complexity and external – customer-based complexity. Although product line design is considered in the MC concepts (without quantification of product complexity), the architecture needs to be always up to date due to rapidly changing customer preferences in current configuration offer.

In the work of Rathnow (1993), three individual concepts to optimize product variety have been proposed, as can be seen in Fig. 3(b). The first concept optimizes *product offering* as a way to increase customer benefit. In order to proceed this concept, customer preferences have to be recorded and validated to decide about the best sold product alternatives.

The second concept optimizes *production structure topologically* based on the data obtained from the benefit analysis. Applying the first two concepts (product offering and structure optimization) on desirable product structure, overall optimization of both, costs and benefit curves can be performed to maximize the net benefit for the MC producer.

In this paper, only the benefit analysis will be a matter of interest. Process complexity affecting cost of production and structure and then the overall optimization can be provided only through optimization of both benefits and costs of the MCA.

Proposed Methodology

It is easily understandable, that the growing number of available product configurations have profound impact on the product-based complexity and partially on production complexity of the system. Due to this fact, it is important to reveal and understand the linkage behind variety induced complexity and the product offer size.

Based on our previous works (Bednar and Modrak, 2014; Modrak and Marton, 2014; Marton and Bednar, 2013), a methodological framework for the generation of all possible product configurations have been presented, including quantification method for VIC, so called Configuration complexity (CC). The framework assumes the existence of three types of so called entry components, namely stable components ’*i*’, voluntary components ’*j*’ and compulsory optional components defined by variables “*k*” and “*l*” according to combinatorial number $\binom{k}{l}$, where “*l*” is number of selected items from a collection ’*k*’, so that (unlike permutations) the order of selection does not matter. Then, configuration requirements in relation to MCA process can be specified using these elements.

Case Product Structure Optimization

It is easily understandable, that the growing number of available product configurations Case set of MCA operations performed on nodes result with number of product configurations, as can be seen in Fig. 4. In order to simplify a graphical representation of all possible configurations, we model on the exit from assembly node only one (customer selected) configuration as single stable component represented by the number of all possible customer selections.
The model of MCA is an adaptation of the realistic customizable assembly of desktop personal computer (PC) stations from Puget Systems (US) transformed into a simplified model (Puget Systems© 2015). This model consists of total 21 individual decision situations in two main assembly branches depending on the two motherboard types on the higher layer of the model decomposition.

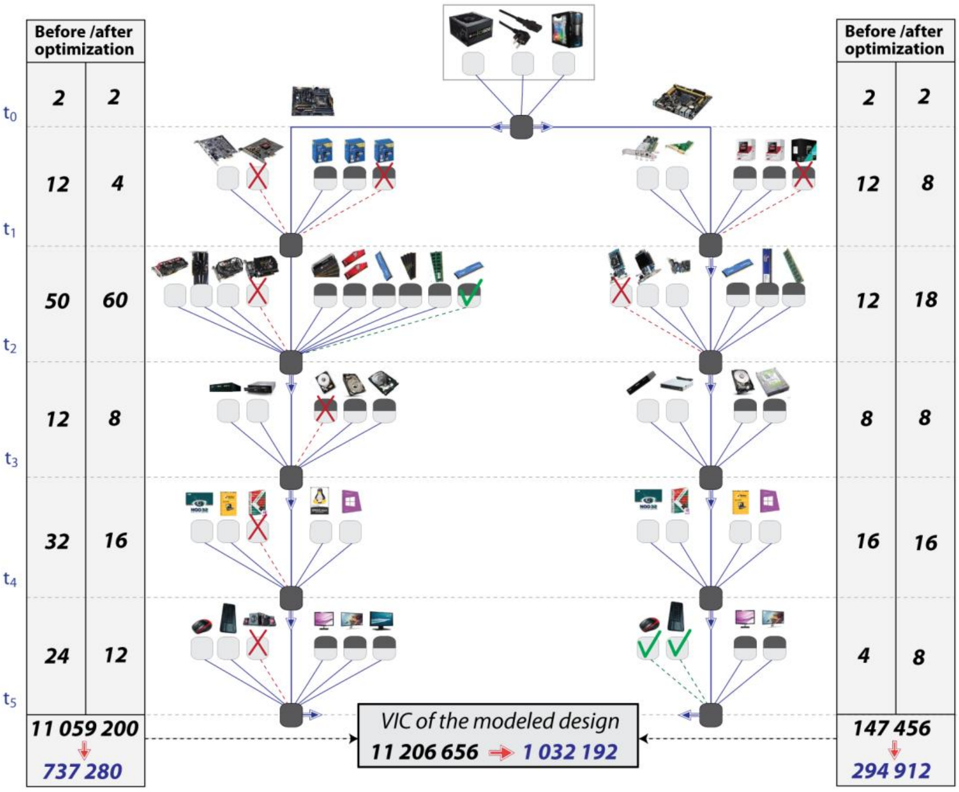

Figure 4. Realistic model of MC assembly with variants before and after product structure optimization

The model is proposed such that the left assembly branch assembles more expensive component types, and at the same time, price of the final desktop PC is higher. The right branch of the model consists of standard components for average users.

As it was already mentioned in the previous chapter, we focus on product offer optimization. Prices of individual components as well as prices of the final product are not considered. We perform an optimization of the desktop PC configurations offered for customers related to the increase of benefit for MCA producer (Fig. 3(b)).

Each level of component model decomposition ($t_{0\text{-}5}$) offers a number of available product configurations. Moreover, each assembly operation (node) consists of specific component composition of three component types. The basic – stable components entering case assembly are power supply, case and cables. These three stable components are part of every assembled computer within this model.

For example, the subsequent assembly layer t_1 provides:

- optional assembly of TV tuner card and sound card,
- compulsory optional assembly of CPUs.

Next assembly layer t_2 offers:

- optional assembly of graphic cards,
- compulsory optional assembly of RAMs (combination of 2 RAM are allowed).

Assembly layer t_3 offers:

- optional assembly of Blue-ray and DVD-RW drives (left branch) and DVD-RW and Card reader drive (right branch),
- compulsory optional assembly of hard drives.

Assembly layer t_4 provides a selection of:

- only optional component assembly (installation) of Operating system and
- Anti-virus software.

Final assembly layer t_5 offers a selection of:

- optional desktop PC equipment,
- compulsory optional selection of screens.

The original modelled structure offers number of available customer product selection on each assembly (decision) level and results in the 11 206 656 product alternatives in both branches.

Based on the simulation of MCA and its structure, one may perform a simplification of product offer based on the demand analysis provided by the company. Such analysis includes definition of low-selling product, or specific components. This way, managers are able to decide on the elimination or on adoption of components to the product line, as can be seen in Fig. 4. For example, assembly node in the left branch of the layer t_1 follows the demand, so that the sound card and one of the CPUs are eliminated due to low interest from the side of customers. This way the number of node assembly VIC is eliminated from 12 product configurations (PCs) to only 4 PCs.

Accordingly, all individual assembly nodes have been reconsidered in the initial component setup, so that all individual assembly layers are reconsidered and related values of VIC reflect the real demand for MC products.
Subsequently, flow values of the VIC of the model have been obtained. Complexity of left model branch deceased from 11 059 200 configurations to only 737 280 configurations. In opposite, complexity value of the right branch increased from 147 456 configurations to 294 912 configurations. Due to the combinatorial nature of the VIC, only a small change in the combinatorial setup results in major change in the number of VIC. The total VIC of the model is the sum of two individual branch flow complexities, obtained by multiplying all upstream VICs. Summary complexity value of the model is 1 032 192 PCs.

Conclusions

Marketers and producers of MC products remain challenged to cope with customer preferences and selections each time a product is bought. In this context, the assessment and measurement of existing and new product varieties is needed.
To summarize the obtained findings based on the combinatorial approach, it can be recommended that for the practical use in mass-customized manufacturing one can determine the configuration complexity rate through computation of the number of product configurations and through variety. Performed product demand-based analysis decreased the overall VIC of the model in 90.8%, which is now considered as the *optimal product variety*. Such optimization of product offer decrease of the: amount of material in the store, amount of money fixed in stored material, and the value of VIC, therefore, complexity of customized assembly.
The core and very important future research scope is finding the optimum variety of products directly linked to product and process complexity. Although, the second type complexity (process) was not considered, the future research efforts effort should be focused on an exploration of mutual relation between the rate of overall complexity and usability.
Finally, we may state, that the combinatorial-based method for the quantification of product configurations can be considered as the supplementary tool for determination of configuration complexity and optimal variety of products. Such tool may become part of a universal comprehensive method to assess current and future product varieties in line with sustainable manufacturing and management.

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References

Bednar S., Modrak V., 2014, *Mass customization and its impact on assembly process' complexity*, "International Journal for Quality Research", 8.

Chen K.D., Hausman W.H., 2000, *Technical Note: Mathematical Properties of the Optimal Product Line Selection Problem Using Choice-Based Conjoint Analysis*, "Journal of Management Science", 46.

Czajkowska A., Minda P., 2014, *Zastosowanie narzędzi zarządzania jakością do analizy procesu logistycznego w wybranym przedsiębiorstwie*, [in:] Komplementarność koncepcji zarządzania i logistyki. M. Kadłubek (Ed.), Częstochowa, Sekcja Wydaw. WZ PCzęst.

Daalboul J., Da Cunha C., Bernard A., Laroche F., 2011, *Design for mass customization: Product variety vs. process variety*, "CIRP Annals of Manufacturing Technology", 60.

Davis S.M., 1987, *Future perfect*, Reading (MA), Addison-Wesley.

Dobson G., Kalish S., 1993, *Heuristics for Pricing and Positioning a Product-Line Using Conjoint and Cost Data*, "Journal of Management Science", 39.

Głowacki T., 2014, *Assessment of motivation by entropy*, "Polish Journal of Management Studies", 10(1).

Grabara J.K., Dima I.C., Kot S., Kwiatkowska J., 2011, *Case on in-house logistics modeling and simulation*, "Research Journal of Applied Sciences", 6(7).

Green P.E., Krieger A.M., 1985, *Models and Heuristics for Product Line Selection*, "Marketing Science", 4.

Green P.E., Krieger A.M., 1996, *Individualized hybrid models for conjoint analysis*, "Journal of Management Science", 42.

Hernandez A.M.J., 2008, *Design for Manufacturing Systems from Automotive Industry Perspective*, El Paso, University of Texas.

Kohli R., Sukumar R., 1990, *Heuristic for Product Line Design Using Conjoint Analysis*, "Journal of Management Science", 36.

Krus P., 2013, *Information entropy in the design process*, [in:] "Research into Design", 4th International Scientific Conference, January 7-9, Chennai, India.

Marton D., Bednar S., 2013, *Approaches to complexity assessment of manufacturing process structures*, [in:] "Applied Machine Intelligence and Informatics", IEEE 11th International Symposium, February 1-2, Herlany, Slovakia.

Matern C., 2000, *Systemwirtschaftliches Variantenmanagement: Operationalisierungund Quantifizierung des integrierten Variantenmanagements*, Göttingen, Vandenhoeck und Ruprecht.

McBride R.D., Zufryden F.S., 1988, *An Integer Programming Approach to the Optimal Product Line Selection Problem*, "Marketing Science", 7.

Modrak V., Bednar S., 2015, *Using Axiomatic Design and Entropy to Measure Complexity in Mass Customization*, "Procedia CIRP", 34.

Modrak V., Mandulak J., 2009, *Mapping development of MES functionalities*, [in:] "Informatics in Control", 6th International Conference, July 2-5, Milan, Italy.

Modrak V., Marton D., 2014, *Configuration complexity assessment of convergent supply chain systems*, "International Journal of General Systems", 43.

Modrak V., Semanco P., 2014, *Handbook of research on design and management of lean production systems*. Hershey, IGI Global.

Modrak V., Radu S.M., Modrak J., 2014, *Metrics in organizational centralization and decentralization*, "Polish Journal of Management Studies", 10(2).

Porter M.E., 1980, *Competitive Strategy*, New York, Free Press.

Ptak A., Piechna J., 2003, "*Ocena efektywności zastosowania algorytmów genetycznych do zadania transportowego*, "Informatyka Teoretyczna i Stosowana", 3(4).

Puget Systems, 2015, Custom computers for everyday use efficiently and economically, https://www.pugetsystems.com/nav/spirit/customize.php, Access on: 13.10.2015.

Rathnow P.J., 1993, *Integriertes Variantenmanagement: Bestimmung, Realisierung und Sicherung der optimalen Produktvielfalt*. Göttingen, Vandenhoeck und Ruprecht.

Simsik D., 1992, *Simulation and optimization of FMS material flow logistic*. [in:] "Competitive performance through advanced technology", Third International conference Factory 2000, July 27-29, York, UK.

Steiner W., Hruschka H., 2003, *Genetic algorithms for product design: how well do they really work?* "International Journal of Market Research", 45.

Tabor J., 2014, *Maintenance management and occupational safety in manufacturing organizations*, "Polish Journal of Management Studies", 10(2).

Tseng M.M., Jiao J., 2001, *Mass customization*, [in:] Handbook of industrial engineering: technology and operations management, G. Salvendy (Eds.), New York, John Wiley.

ZARZĄDZANIE RÓŻNORODNOŚCIĄ PRODUKTU JAKO NARZĘDZIE SKUTECZNEJ, MASOWO ZINDYWIDUALIZOWANEJ STRUKTURY PRODUKTU

Streszczenie: Skuteczna oferta produktów wymaga procesu równoważenia i kompromisów rynku. Jest to szczególnie stosowane w masowo konfigurowalnych (MC) produkcjach wytwarzających produkty w wielu konfiguracjach, w zależności od preferencji klienta. Taka różnorodność wnosi kompleksowość do procesów produkcyjnych oraz na poziomie zarządzania produktem. Niniejszy artykuł przedstawia metodykę ilościowego określania różnorodności produktów indukowaną złożonością (VIC) jako liczbę dostępnych konfiguracji produktu w przypadku linii produktów. Model linii produktów montażu MC jest następnie optymalizowany uwzględniając popyt na produkty. Ostatecznie, przedstawione są wzajemne relacje metryki VIC przed i po optymalizacji linii produktów, co wyraźnie uzasadnia przydatność metryki VIC.
Słowa kluczowe: złożoność, metryka, optymalizacja projektowa, konfiguracja, popyt, heterogeniczność linii produktów

產品種類繁多管理作為成功的大規模定制的產品結構的工具

摘要：成功和有效的產品結構需要平衡過程和市場的權衡。這是特別適用於大規模定制（MC）的製作使得產品在根據顧客的喜好配置數。這樣的品種帶來的複雜性的生產過程，以及在產品管理水平。本文提出了量化產品品種引起的複雜性（VIC）為許多可用的產品配置的情況下生產線的方法。
MC組件生產線的模型被進一步優化尊重對產品的要求。最後，之前和之後的產品線優化VIC指標的相互關係呈現，有什麼明顯證明的VIC度量的可用性。
關鍵詞：複雜性，指標，優化設計，結構，需求，產品線異質