Determining the Product Mix Using Multi-Criteria Decision Making

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Abstract. At present, many manufacturing companies face with the problem of setting their production plans taking into account existing liming factors that can be of both internal and external nature. This task is known as determining the product mix – the scope and volumes of products that should be manufactured and sold. Solution of this task is a decision making process: it is necessary to select an optimal (regarding one or several criteria) combination of products and their production volumes. The paper focuses on two approaches dealing with the product mix task. One of the approaches is based on management accounting calculations: the product mix is selected to maximize profitability, by ranking the products according to their contribution-earning ability per unit of the limiting factor. Certain limitations of the management accounting approach are the problems with forecasted assumptions, using only financial considerations, ignoring the degree of preference of one product in comparison with another, as well as missing information about possible states of the external environment. Another approach relies on multi-criteria decision making methods and expert estimates. This approach allows decision makers to take into account non-financial factors, including qualitative information, as well as to consider the power of distinction between products and environmental aspects. In the paper it is argued that combination of the two approaches may be used within common task of determining the product mix. The combined approach supported by appropriate information systems makes the decision making process more efficient and justifiable.

Keywords: Product Mix, Management Accounting, Multi-Criteria Decision Making, Situation Analysis, Expert Based Approach.

1 Introduction

Determining the product mix is one of the most important tasks in production management. This task is related with planning of manufacturing and sales volumes for each product of an enterprise, within the market demand. Often the demand exceeds an enterprise's production capacity which is determined by scarce resources called bottleneck resources or limiting factors. According to the theory of constraints [1], an organization should determine its product mix with the aim to maximize its perfor-

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mance expressed as sales revenue less material and other variable costs. At this, an enterprise should focus its attention on scarce capacity which act as set of constraints to such maximization.

This task is solved in the management accounting theory relying on ranking products according to their financial performance. However, there are outstanding issues regarding availability of additional criteria (including issues of non-financial and qualitative nature), as well as evaluation of appropriate management information during the decision making process.

2 The Traditional Approach to Determining the Product Mix

The traditional management accounting approach to determining product mix [2, 3] is based on distinction between fixed and variable costs, in the conditions of availability of scarce resources (limiting factor). From this point of view, a company would select a product mix that would maximize overall profitability, and so maximize total contribution (the difference between revenue and variable costs). The approach for establishing the product mix is to rank the products in order of certain criteria – contribution-earning ability per unit of the limiting factor (for example, per one working hour of limited labor or equipment). When there are some external restrictions (for example, a limit of sales demand or a limit of raw materials) the products should still be ranked according to the same criteria. However, the decision will be to produce the top-ranked products within the limits of the external constraints.

Despite the obvious advantages, the traditional approach has some limitations.

First, all the calculations are based on forecasted assumptions regarding markets and prices. However, such forward-looking information is not always reliable.

Second, only financial characteristics are taken into account. Of course, they are essential, but on the hand, there also may be some important qualitative (non-financial) considerations.

Third, ranking of the products is executed according to exact results of the calculations. However, the degree of preference of one product over another is not taken into account. As a result, the ranking may be affected by small (immaterial) differences in product performance, especially in the assumptions are not reliable.

Finally, management decisions often depend on the external environment and its possible states in the future. At the same time, situation analysis is not used within the traditional model.

3 Additional Factors of Products Ranking

There are few additional factors which may appear essential for ranking products and subsequent determining the product mix.

One of such factors is related with perspectives of manufacturing certain products. According to the product lifecycle theory [4, 5], the profitability of a product changes over time. The life cycle of a product includes such stages as introduction, growth, maturity and decline. The Boston Consulting Group (BCG) advanced a matrix allow-

ing to classify products in terms of expenditures and potential cash generation [6, 7]. Within the model, products are classified as stars, cash cows, question marks and dogs (associated with modest expenditure and income, but may be important for completeness of a product range or for competitive purposes). Stars require significant capital expenditure, but promise high return in the future. Cash cows require little capital expenditure and generate high income. Question marks require considerable capital expenditure for increasing their market share, or may be allowed to die. Finally, dogs are associated with modest expenditure and income, but may be important for completeness of a product range or for competitive purposes. The position of a particular product in the frames of such models may have impact on the significance of the product and its position in the product mix.

Customer loyalty [8] is another factor that may appear essential for determining product mix. The matter is that decision of declining output or discontinuance of some products may have negative impact on general firm's attractiveness for its customers.

Competitive position [9] may also be influenced by product related decisions. Particularly, if some products are discontinued, it is likely that competitors will take over the appropriate market segments.

Sustainable development paradigm [10] also seems important, because for general success a company should be compliant with its external economic, social and physical environment. Again, ranking the products may facilitate or inhibit corporate sustainability.

Therefore, solution of the task of products ranking requires combining traditional financial calculations with assessment of non-financial qualitative factors.

4 Using Multi-Criteria Decision Making for Products Ranking

It is essential that management accounting may be combined with expert based assessment of qualitative factors within a common decision making task. The results of management accounting calculations may be used either separately from qualitative estimates, or as a source information for formulating experts' opinions, for subsequent developing an integrated indicator [11]. The second option seems more useful for management purposes, because both financial and non-financial issues are considered within the same decision making task, representing different criteria. So using expert based multi-criteria decision making allows managers to look at the problem from different angles and to apply their informal judgements. This approach is more useful for managerial purposes, in comparison with pure management accounting.

One of the multi-criteria decision making methods that can be applied for the product mix task is the analytic hierarchy process (AHP) [12, 13]. This method allows us to formalize the decision making task in the form of a hierarchical structure that includes the goal, criteria, and alternatives. Each element in the hierarchy represents a specific aspect of the decision making process. In this case, we can use both quantitative and qualitative characteristics which can be related not only with objective data, but also with subjective expert estimates.

The analytic hierarchy process includes the following steps.

On the first stage, the problem should be determined, and the goal of decision is to be formulated.

On the second stage, the decision hierarchy is constructed. This is done using top-down structuring – from the goal and more detailed objectives, through decision making criteria (that also may be organized hierarchically), to a set of the alternatives situated at the lowest level of the hierarchy.

On the third stage, a set of pairwise comparison matrices is developed. For this, each pair of elements located in the same hierarchical level and allocated to the same upper level element are compared using "the fundamental scale". This scale has nine numeric levels representing the power of importance of one element regarding the second element in a pair: from 1 (equal importance) to 9 (extreme importance). The results of such comparisons are placed in the appropriate matrix.

Finally, on the fourth stage, priorities of all the elements are calculated. For this, expert estimates are generalized, and this results in determining priorities of all the alternatives regarding the general goal. In is important to notice that such priorities are dimensionless, making it possible to compare heterogeneous factors.

According to the purposes of the product mix determining task the analytic hierarchy may be organized by the following way.

The goal located at the top of the hierarchy is to rank (prioritize) products, for subsequent determining the production program, relying on the selected criteria.

One of the decision making criteria is related with short-term financial performance of the enterprise's activities. It completely matches the criteria used in the theory of management accounting – overall profitability which is achieved through maximization of total contribution (the difference between revenue and variable costs), and therefore through determining contribution-earning ability of products per unit of the limiting factor. In addition, the set of criteria may include long-term financial consequences, as well as non-financial considerations, such as perspectives of products from the point of view of their lifecycles, customer loyalty, competitive position, sustainable development issues, etc.

In the analytic hierarchy process criteria may be organized hierarchically. In this case, some criteria may have subordinated and more detailed sub-criteria. For example, the sustainable development criterion may be subdivided into economic, social and environmental sub-criteria.

Alternatives of the decision making task are products that can be manufactured by the enterprise. This is explained by the fact that determining the product line and production volumes is based on ranking (prioritization) of particular products.

An additional question arises regarding the way of processing management accounting information. In this regard, there are two possible options. According to the first option, the results of management accounting calculations are used "as is", without any additional interpreting and evaluating. To do this, there must be pre-defined rules describing relationships between management accounting figures and ranks in the AHP fundamental scale. Such rules should be applied for each pair of products during pairwise comparisons. The second option assumes using of additional expert judgments for pairwise comparison of products in respect to the short-term financial

performance criteria. Of course, in this case management accounting information is also applied, but all the conclusions regarding attractiveness of one or another product are made by experts.

Processing of expert estimates within one or another multi-criteria decision making method usually requires quite complex mathematical calculations. Such calculations may be performed using special software called decision support systems.

One of such tools that support the analytic hierarchy process methodology is Super Decisions software. The system provides the possibility to set the relative significance of criteria. There are four ways to set the relative significance for each pair of criteria: graphic, verbal, matrix, and questionnaire. Within the graphical method, the ratio of the relative significance of the criteria is set in the form of circular or bar charts. The verbal method involves answering the question of how much some criterion is more important than another one (slightly, moderate, strong, etc.). The matrix approach deals with construction of a square matrix, along the axes of which the same criteria are laid, and intersections contain indicators of the dominance of some elements over others. The questionnaire method involves presenting the relative significance for pairs of criteria using a quantitative scale. For each matrix of pairwise comparisons, the inconsistency of the entered data is checked. Relying on the expert assessments entered, the system allows us to calculate the coefficients of relative significance (weights) of the criteria and alternatives.

Examples of other systems that support the analytic hierarchy process methodology are Decision Lens, Expert Choice, Transparent Choice, MPRIORITY, WinExp+, and some others.

Processing of expert estimates in the frame of pre-defined sets of criteria may also be performed by other decision making methods, such as ELECTRE family [14], PROMETHEE family [15] and some others. These methods and appropriate software are also applicable for the problem of determining the product mix.

5 Considering Multiple Expert Estimates and External Conditions

Another way of using multi-criteria decision making for products ranking (and subsequent determining product mix) is related with methods that take into account availability of few experts assessing the alternatives, as well as few possible external situations.

An expert group may consist of several specialists with appropriate competences. Each of them will take part in the evaluating process, independently from other persons.

A set of external situations may be formed in different ways. The easiest way is to create a simple list of possible situations. This approach is preferable when the total number of situation is low, and all the situations are easily identifiable. In more complex cases, there are several factors which in aggregate determine the state of the external environment. Each of the factors can take two or more possible values. In this case, the total number of situations is determined as a result of multiplying numbers

of possible values for all the factors. However, if some combinations of values are impossible or unlikely, they can be excluded from consideration.

Perhaps the most popular and widely used in practice (among the methods taking into account availability of multiple experts and situations) are methods based on the majority principle. According to this principle, one alternative is preferable in comparison with another one if such preference is available for the majority of criteria (considering their significance), in the majority of possible situations (taking into account probabilities of their appearance), and from point of view of the majority of experts (considering differenced in their competences and/or voting power). The appropriate preferences (experts' estimates) may be expressed either in the quantitative, or in the ordinal scale. As a result of calculations, an integral indicator of preference is formed. In turn, this indicator can be used for ranking of alternatives (products).

Additional methods may be used in the conditions of uncertainty, when the probabilities of situations cannot be determined. In such cases, there are two options: either do not consider the probabilities, or assume them equal. At the same time, consolidation of the estimates by criteria and by experts, as before, is carried out using the majority principle. Thus, the difference between additional methods and the main one (as well as from each other) is the way of situations treatment.

Additional methods can use the principles of pessimism, optimism, Hurwitz, and Laplace. All these principles do not require determining probabilities of the situations.

According to the pessimism principle, the decision maker keeps in mind the situation which is the most adverse from the point of view of potential benefits. Using the optimism principle the decision maker is focused on the most favorable environmental conditions. The Hurwitz principle is often called the pessimism–optimism approach: it deals with weighted conjunction of the pessimism and optimism principles. For this purpose, a weight with a range of values from zero to one is applied (zero corresponds to the pure optimism, one – to pure pessimism). Finally, the Laplace principle assumes that probabilities of all the situations are equal.

As in the main method, all additional methods provide calculation of an integral indicator that gives reasons for ranking.

Ranking products within the product mix task may also be performed in the conditions of availability of multiple experts and multiple states of the external environment. Particularly, the group of experts can include employees of the company (commercial director, chief operating officer, etc.), as well as external consultants.

Regarding the state of the external environment, there are few factors which in aggregate form a set of possible situations. First (and perhaps the most important) factor is general economic conditions affecting demand and manufacturing resources. This factor may have such values as favorable economic environment, availability of some difficulties or hard crisis. Another factor is exchange rates of foreign currencies are essential when the manufacturing process requires some imported components. The possible values of this factor are stability of the exchange rate, its growth or declining. Since 2020, it seems reasonable to take into account such factor as epidemiological situation (in the short-term or long-term perspectives): the situation may remain unchanged, become mitigated or escalated. Appearance of a strong competitor may also be considered as an external factor, in this case the possible values are: the competi-

tor's entrance into the local market in the near future, entrance in the long term perspective, or the competitor's abstinence from entering the local market. Different combinations of values of the factors mentioned form the total set of possible external situations.

Functionality related with multiple situations and experts is available in Expert Decision Support System (EDSS) – specialized information system developed in the National Research University Higher School of Economics [16]. One of the features of the system is possibility of copying source data (information about criteria, situations and experts) from one task to another. This function allows users to arrange calculations using the same source information, but different methods of data processing. As a result, managers can investigate the same task using different computational methods, with subsequent comparison of the results obtained.

6 Conclusion

Combining management accounting and the expert based approach within the task of determining the product mix allows us to take into account all the information that is relevant to the decision making, including not only financial characteristics, but also a range of non-financial and qualitative issues. Additionally, considering the degree of advantage of one product over another (regarding all the criteria applied) improves the decision making process. As a result, it becomes possible to make a comprehensive evaluation of products and their ranking (prioritization), and then – to provide reasonable selection of the product mix and production volumes. All this significantly improves analytical capabilities and provides reliable background for more justifiable decision making. In addition, modern decision making software ensures practical feasibility of the proposed approach.

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