Towards Measuring Investment in Flexible Foundry Manufacturing

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Abstract

Manufacturing flexibility is an important instrument to ensure the success of manufacturing systems in the modern day competitive and uncertain environment. The major hindrance in integrating flexibility into decision making process is that it is difficult to measure and be compared to future indefinable manufacturing scenarios. This paper presents a methodical concept utilizing real options to evaluate flexible foundry manufacturing system.

Keywords: *Foundry Manufacturing System Automation, Manufacturing Flexibility, Norway.*

1. Introduction

Globalization has created an environment of similar opportunities for manufacturing competitors around the world [3]. To succeed in highly competitive global markets, manufacturing companies need to employ modern, state-of-the-art manufacturing and management methodologies that included computer aided design and computer integrated manufacturing, concurrent engineering, design for manufacturability, just-in-time manufacturing and total quality management. To enhance success of manufacturing industries by increasing the competitiveness of manufacturing systems (by use of robots and other automation technology), flexibility in manufacturing becomes an important instrument to handle an uncertain environment.

Flexible manufacturing automation allows rapid reconfigurability of the production system in order to manufacture several different products, achieving high degree of machine utilization, reduction of in-process inventory, as well as decrease in response times to meet the changing customer preferences. Automation is the force behind the rationalization of manufacturing processes to increase competitiveness and productivity. Foundry SMEs in particular are in need help from automation technology, and some of the drivers are listed below

- Intensive in manual labour
- Have high variation in parts, due to multiple environmental variables such as temperature of molten metal, metal solidification defects etc. which is a huge detriment to automation
- The extreme environmental working conditions of foundries necessitates the need for automation
- HSE issues in foundries are an important driver for automation in the foundry as well.

Manufacturing flexibility displays the ability to reconfigure and adjust production resources under the effect of environmental impacts (external from market, and internal from manufacturing variation) in such a manner that the manufacturing of different products is efficient and posses acceptable quality. In the last decade different approaches for new types of responsive manufacturing systems, providing manufacturing flexibility, have been developed. From an investment in flexibility perspective, some important questions could be

- How is foundry manufacturing flexibility measured?
- How much flexibility is necessary?
- Does the most flexible technology available, suit the business needs?

The difficulty in flexibility implementation and investment decision process lies in the inadequacy to consider foundry manufacturing flexibility, especially when there are no quantitative measures available even for general manufacturing flexibility attributes. Many academic publications have attempted out the quantification of general manufacturing flexibility, even though approaches for its evaluation for both investment and production decision making are few, mostly limited to few special cases and difficult to handle.

In this paper we propose a conceptual approach on the basis of Real Options Analysis (ROA)[5] for the holistic evaluation of production flexibility in manufacturing companies, which extends the traditional net present value (NPV) method for investment calculation. It incorporates the possible external environmental factors to characterize system flexibility. One can then evaluate the aspect of long term flexibility that is needs in manufacturing and process planning.

2. Production Flexibility

The analysis of the literature regarding the topic of manufacturing flexibility, highlights the presence of four main categories of scientific works. [1,4] The publications in the first group deal with the analysis of the interpretation of manufacturing flexibility and their relationships with manufacturing problems. The second group of publications deal with classification of existing flexibility forms through conceptual frameworks. The third category focuses on the development of approaches and models, both qualitative and quantitative, to support the system design while considering the given system flexibility forms. The fourth group of research aims at systemizing the higher number of flexibility definitions related to the real implementation of various forms of flexibility in a manufacturing system.

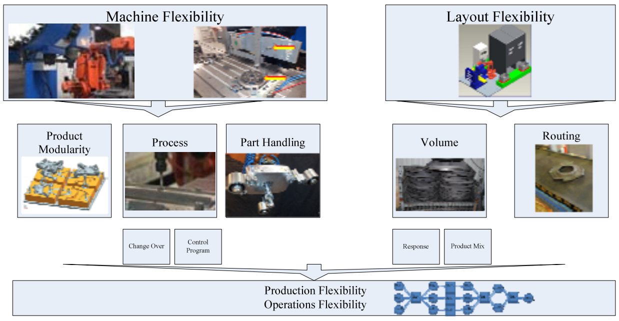

Fig. 1. Essential spheres of foundry manufacturing flexibility

Future investment decision for flexible production systems requires flexibility for the constantly changing manufacturing structures, engineering progress and long term use of the equipment. Costs involved in implementing manufacturing flexibility via automation, to meet customer demand are more important in foundry companies, when located in a high labor cost country such as Norway. Here, flexibility could be characterized as the ability of the production system to cope with the disturbances. Two factors that make it necessary can be identified [2]:

- Unstable environment (for example, External and Internal)
- Variability of products and processes (for example, casted part and machine variability, machining process variability)

The first factor, can be categorized into external (change in competitive environment, market conditions etc.) or internal unstableness (machine breakdown, casting melt variation etc.) The second factor, variability of products and processes, could deal with the need to produce the parts with different manufacturing processes, or deviations caused within the same process.

Manufacturing system having a high degree of flexibility, can rapidly adjust according to the manufacturing task at hand. Therefore, manufacturing flexibility is very important in small to medium sided manufacturing companies. In order to cover a wide range of requirements, manufacturing systems must be flexible in several aspects. The essential spheres could be classified in the hierarchical relationship show previously in Figure1.

3. Measuring Flexibility in Manufacturing Investment

A suitable approach to consider flexibility in investment decisions is to integrate Real Options Analysis into these calculations. The ROA method was originally designed to evaluate the worth of financial options describing the right, but not the obligation, to exercise a feature of the contract at a defined price. This enables the holder to reduce its risk by keeping the flexibility to react to future developments. In contrast to financial options, the real options are usually not tradable. Typically, only the owner has the possibility to adjust an investment.

The techniques for estimating the value of real options refer to the analytical solutions such as the Black Scholes model and numerical techniques, e.g. the Monte Carlo simulation or binomial lattice. The analytical approach of the Black Scholes model requires a significant amount of effort to define and mathematically solve the terms that meet the requirements of investment situations. To resolve the particle differential equation describing the option premium, it is necessary to notice the underlying basic values which refer to a statistical process. The solution is known as the Black Scholes formula:

$$C = S_0 N(d_1) - Xe^{-rT} N(d_2) \tag{1}$$

with

$$d_1 = \frac{\ln(\frac{S_0}{X}) + (r + \frac{\sigma^2}{2})T}{\sigma\sqrt{T}} \tag{2}$$

$$d_2 = \frac{\ln(\frac{S_0}{X}) + (r - \frac{\sigma^2}{2})T}{\sigma\sqrt{T}} = \qquad (3)$$

$$d_1 - \sigma\sqrt{T}$$

and

C: option value
S₀: current price of basic value
N(x): distribution function of normal curve
X: exercise price
r: risk-free interest rate
σ: volatility of basic value
T: exercise time

Unlike the above analytic procedure, Monte Carlo simulation yields the result though calculation of the frequency distribution of possible outcomes. The binomial pricing model offers a more intuitive approach in this respect. The model uses discrete time elements and maps out the below binomial tree for calculating the possible prices of options.

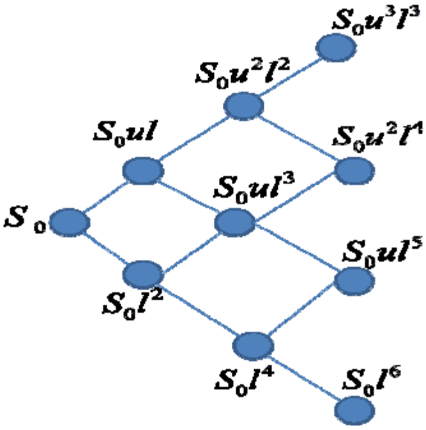

Fig. 2 Binomial Tree

This comprehensive analysis and the structuring of possible scenarios are the main advantages in the application of flexible investment decisions. Starting point for the expansion of the binomial tree is the P_0 as the current price of the basic value. In the following time period the starting value will either decrease by *ll* or increase by *ul* which leads to the price if P_0ll respectively P_0ul by the time Δt. The values for *ll* and *ul* can be derived by below equation:

$$ul = \frac{1}{ll} = e^{\sigma\sqrt{T}}$$

with σ as the volatility of the basic value.To implement the nature of options as a right but not an obligation, the effective value at the nodes of a tree is dependent from the following decision rule:

Value of call option: max $(S - X; 0)$
Value of put option: max $(X - S; 0)$

The option value at all earlier stages now results from the discounted expected value of its later payoffs, increased as well as decreased, weighted with probability *p*:

$$f_t = e^{-r\Delta t}(pf_{t+1;i} + (1-p)f_{t+1;i+1})$$

with $p = \frac{e^{r\Delta t} - ll}{ul - ll}$ and i={1,2,….,t+1}

Processing the calculation at original starting point of the investment analysis, gives us the option value of the investment analysis, which provides information on the strategic impact regarding future risks. Depending on certain specific conditions, each type of production system offers particular advantages that can be thus measured for deterministic as well as non-deterministic situations.

Flexibility in manufacturing systems can be adjusted to several production requirements. As a result, the investment costs of the added machine capabilities rise with attained flexibilities. The application to the presented flexibility taxonomy in a real scenario could help highlight capability and effectiveness of this methodology while the sole use of Net Present Value approach substantially underestimates the flexible manufacturing concepts such as adding flexibility or modularity. The supplemental analysis based on real options suggests that, a significant share of a future potential return on investment could depend on potential features enabling adaptation to new competitive challenges by providing a holistic evaluation of investments.

4. Conclusions and Future Work

Flexibility in manufacturing systems can be adjusted to several production requirements. As a result, the investment costs of the added machine capabilities rise with attained flexibilities. The application to the presented flexibility taxonomy in a real scenario could help highlight capability and effectiveness of this methodology while the sole use of Net Present Value approach substantially underestimates the flexible manufacturing concepts such as adding flexibility or modularity. The supplemental analysis based on real options suggests that, a significant share of a future potential return on investment could depend on potential features enabling adaptation to new competitive challenges by providing a holistic evaluation of investments.

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