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Impact of Different Financial Evaluation Parameters for Reconfigurable Manufacturing System Investments

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Abstract. The need for frequently adapting manufacturing systems to dynamic market demand, short product lifecycles, technology evolution, and sustainability requirements is increasingly challenging manufacturing companies. To this end, Reconfigurable Manufacturing Systems (RMSs) are relevant, however, still far from their wide implementation in industry. In this regard, a main barrier to the introduction of reconfigurability is the justification of investments in developing and purchasing reconfigurable systems and equipment. Often such reconfigurable systems have high initial investments that provide returns in the mid/long-term, while at the same time being subject to and dependent on high uncertainty in product and market evolutions. Thus, uncertainty in different aspects of demand and the time-horizon of evaluations are main aspects in evaluating the financial benefits of reconfigurability. Therefore, this paper investigates how different choices of financial evaluation parameters affect the financial feasibility of reconfigurable manufacturing compared to more traditional manufacturing concepts. The findings of the paper provide valuable insights on how practitioners should proceed in adequately capturing the value of reconfigurability during investment decisions.

Keywords: Reconfigurable manufacturing, Changeable manufacturing, Reconfigurability, Financial evaluation, Financial simulation

1 Introduction

Designing manufacturing systems may have a huge impact on a company's competitiveness, since the design determines a wide range of performance measures ranging from cost to quality [1, 2] Reconfigurable manufacturing systems (RMSs) are widely recognized as key to competitiveness in highly volatile and uncertain manufacturing environments [3, 4]. Compared to both very dedicated manufacturing systems and highly flexible manufacturing systems where functionality and capacity boundaries are static, pre-planned, and a-priori, the RMS has the reconfigurability capability, i.e. it is dynamically changeable towards shifting functionally and capacity requirements [5]. Thus, RMSs have the exact capacity and functionally needed, exactly when needed, through enablers of convertibility, scalability, modularity, integrability, customization, and diagnosability [6]. However, while benefits of the reconfigurability capability are

obvious, reconfigurability principles are only scarcely implemented in the manufacturing industry [7, 8]. Furthermore, with only few available examples RMS introduction into companies, literature lacks best practices driving industrial companies in the transition toward this new industrial paradigm [9]. In this regard, one of the main barriers is to justify the investment in developing and purchasing reconfigurable systems and equipment [10-12]. Some of the main issues in justifying reconfigurability from a financial standpoint are:

- Reconfigurable system and equipment concepts are often more expensive in terms of initial development and investments costs, however, less expensive during the operating life-time if and when changes in system requirements occur [13].
- Reconfigurability allows for prolonging the life-time of manufacturing systems, going beyond the product or part that it was initially designed for [14]. However, this also means that surplus initial investments in reconfigurability should be cancelled out over longer time periods than traditionally dedicated manufacturing systems [15].
- Reconfigurability benefits such as easy conversion of functionality and scaling of capacity in small increments should match the specific change requirements in the manufacturing company, i.e. systems and equipment can be more or less reconfigurable depending on the specific need [16]. Thus, considering the specific uncertainty parameters to the company is needed in order to evaluate investments [13, 17].
- Reconfigurability of a manufacturing system allows for continuously meeting functionality and capacity demand, thereby mitigating risks of having either too much or too little capacity and functionality [6]. Thus, these longer-term benefits should be evaluated during investment decisions against the inherent market uncertainty [17].

Evidently, various trade-offs exist during evaluations and investment decisions related to reconfigurability. However, previous research provides only limited support for conducting explicit evaluations of these in a manufacturing company. Kuzgunkaya and ElMaraghy [11] proposed a fuzzy multi-objective mixed integer optimization model incorporating both financial and strategic perspectives on investing in both reconfigurable and flexible manufacturing systems. Furthermore, Niroomand et al. [18] investigated the impact of different reconfiguration characteristics for capacity investment strategies. Aiping et al. [19] proposed to use the “dynamic” real options analysis to deal with the disadvantages of traditional methods for the financial evaluation of RMS and to give the capacity to include in the evaluation both the uncertain and active decision. From a purely qualitative standpoint, Zhang et al. [20] performed an analytical comparison of dedicated, flexible, and reconfigurable manufacturing systems. Wiendahl and Heger [13] outlined the concept of a scenario approach to justifying the investments in changeable manufacturing, while Andersen et al. [17] proposed an investment evaluation model of changeable and reconfigurable manufacturing concepts utilizing a simulation approach to account for uncertainty in requirements.

While previous research presents some models for evaluating investments in reconfigurability, limited explicit consideration has targeted the exploration of uncertainty as a key premise for the justification of reconfigurability. Furthermore, previous research presents no explicitly investigations of which financial evaluation parameters that affects the feasibility of reconfigurability from a financial standpoint. However, uncertainty in terms of different aspects of demand volatility combined with the time-horizon of evaluations represent a main aspect in evaluating the financial benefits of reconfigurability compared to more conventional manufacturing concepts. Therefore, this paper addresses the following research question:

- How do different choices of financial evaluation parameters affect the evaluation of reconfigurable manufacturing concepts?

The remainder of the paper is structured as follows; Section 2 present the research methodology and outlines the simulation model used for addressing the research question. Section 3 presents the results, while Section 4 discusses implications of the results. Conclusively, the contribution is summarized and future work is outlined in Section 5.

2 Methodology

The research question is addressed by performing a number of simulations and comparing the financial performance of three different manufacturing system concepts for a particular manufacturing scenario. The manufacturing scenario is a case where a demand exists for 8,000 units/month, growing at a randomly distributed rate over a five-year period. When the demand grows, the manufacturing system will eventually need to scale to meet the demand. To address the research question, a base case simulation is performed, and following this, specific model parameters are changed to evaluate how this affects the indications of the economic evaluation.

The base case is a Net Present Value (NPV) calculation based on a Monte Carlo simulation, where the demand is characterized by a trend over a five-year period according to a triangular distribution, minimum 8.000 units/month, mode 10.000 units/month, maximum 16.000 units/month. Also, a normally distributed noise factor is applied to generate monthly demand fluctuations. The scenarios and the concepts applied in the simulation were based on data determined during a workshop as part of an industrial research project, related to reconfigurable manufacturing, for an actual development project. In the simulations, no turnover and thus profit figures have been included, since the turnover would not be different between the scenarios, as demand is always met. Furthermore, the net present value is the value of investments and cost, and thus a value of e.g. 1000 implies a negative cash flow of 1000 has occurred.

The simulation period is five years, and a Monte Carlo simulation is performed, where 200 simulations runs are performed, each simulating the five years. For each simulation run, a demand scenario is generated, and within each month of the scenario, the actual period demand is calculated by applying the noise factor. A three-month running average is applied to the monthly demand, to simulate levelling capacity by stocking or doing back orders. Within each month, the simulation determines whether the

current capacity is sufficient. If not, a scaling of capacity is performed. After the simulation, the net present value of investments and variable costs are calculated. Internal interest rate (IRR) was set to 10% annually. The simulation Model was implemented in a Python script, including the libraries Numpy, Math, and Pyplot.

Three concepts are synthesized, 1) one where manufacturing relies solely on manual work and does not require automation, and thus scales only by adding variable cost, and also has no capacity limit, 2) one dedicated concept, where a major investment is made to establish production, with lower variable cost, and scaling is done by replicating the production line, and 3) one reconfigurable concept, that requires a higher initial investment but can add capacity at a much lower cost. The characteristics of the manufacturing concepts are outlined in Table 1.

Table 1. Concept characteristics

Concept	1 – highly manual	2 - dedicated	3 – reconfigurable
Initial investment	No investment	5.000.000	6.000.000
Initial capacity	No upper limit	10.000 units/month	10.000 units / month
Scaling increments	Not relevant, pure manual work	10.000 units/month	2000 units/month
Scaling cost	Not relevant, pure manual work	4.500.000	800.000

Once the base case simulation was performed, a number of simulations were performed changing model parameters and evaluating the impact on the simulation results. The following simulation parameters were changed: a) changing the simulation to a two-year timespan rather than five, b) removing monthly noise factor, c) removing the moving average, d) narrowing the triangular distribution, e) reducing the interest rate, f) increasing the interest rate.

3 Results

Simulating the base case and evaluating for the lowest NPV, showed that concept 2 – the dedicated concept performed best in 22 simulations, whereas concept 3, the reconfigurable concept, performed best in 178 cases, and concept 1 – the manual concept, never performed best. Fig. 1 illustrates this in a scatter plot, plotting the net present value on the Y axis, and the final demand after five years on the X axis.

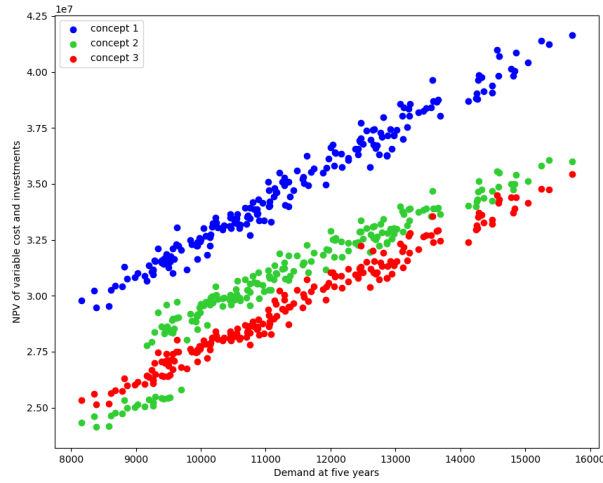


Fig 1. Base case scatter plot of NPV of variable and investment cost vs. Demand after five years

The results of the simulations when changing the model parameters are indicated in Table 2, showing the number of simulations, where each concept turned out with the lowest NPV for each model parameter change. The results are also illustrated in Fig. 2., where each simulation is illustrated as a scatter plot, as in Fig. 1.

Table 2. Number of simulations where each concept provided the lowest NPV

Concept	1	2	3	Fig. ref.
Base case	0	22	178	1
Two year simulation period	140	60	0	2 (a)
No monthly fluctuations	0	40	160	2 (b)
No moving average	0	5	195	2 (c)
Narrow demand distribution	0	101	99	2 (d)
Half IRR	0	17	183	2 (e)
Double IRR	0	24	176	2 (f)

The six simulations changing model parameters show significant impact on which concept appears more profitable. Changing the simulation time horizon to a two-year horizon clearly makes the highly manual concept and the dedicated concept more favorable, and the reconfigurable concept less favorable. Removing the monthly fluctuations shifts the dedicated concept to be slightly more favorable compared to the base

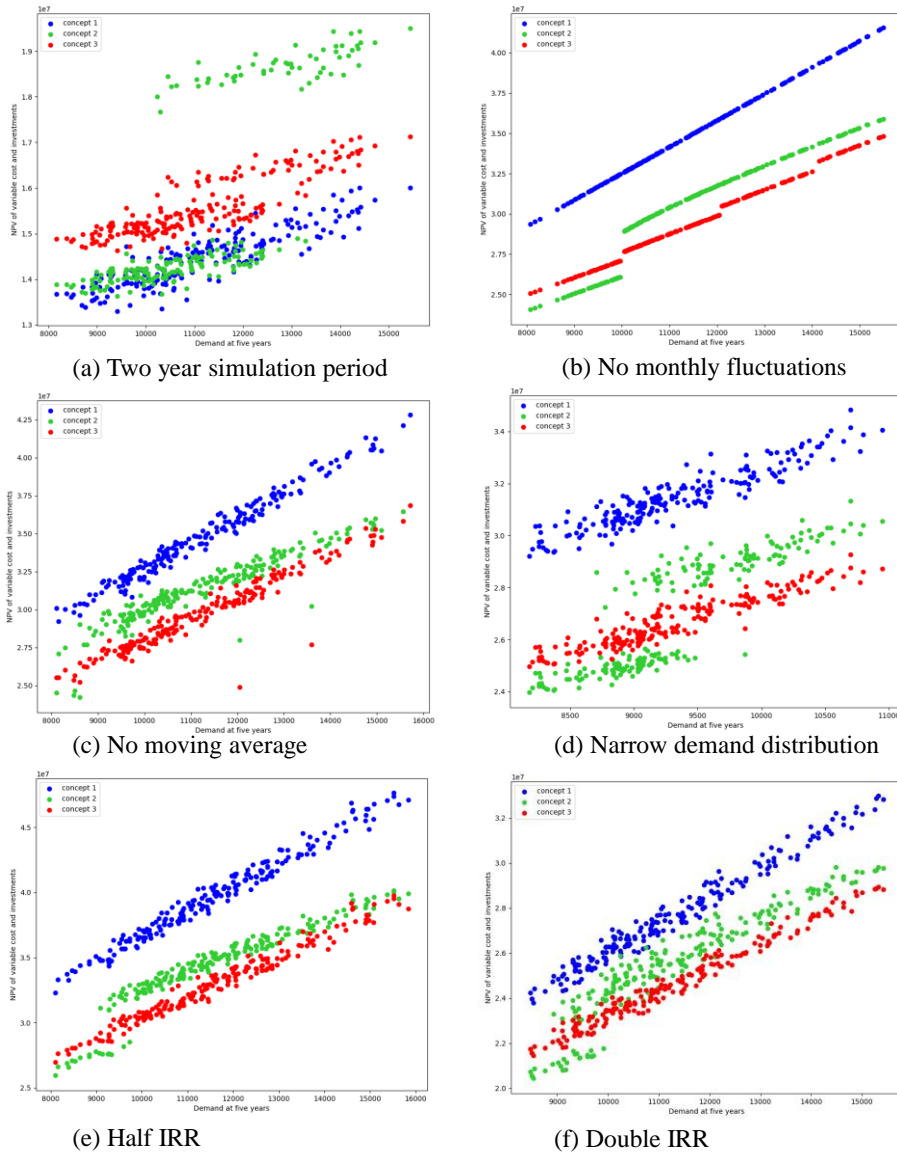


Fig 2. Scatter plot of NPV of variable and investment cost vs. Demand after five years, changing model parameters

case, but still the reconfigurable concept performs significantly better. Removing the moving average on the monthly demand, which was introduced to provide the opportunity to level capacity rather than chasing the demand, made the reconfigurable concept even more favorable, turning out at the best performing concept in nearly all simulation runs. Narrowing the triangular distribution on the demand at five years to introduce less long-term uncertainty, made the dedicated concept perform better compared to the base case, and in this simulation the dedicated concept and the reconfigurable concept performed almost equally good. Changing the interest rate by doubling or halving it had little impact on the results, only making the dedicated concept perform slightly worse with a lower IRR, and slightly better with a double IRR.

4 Discussion

Generally, the results indicate that making slight changes in some of the simulation parameters when performing can have a major impact on the evaluation results.

Previous research has suggested that short-term planning, and short-term evaluation of benefits from manufacturing concepts is a barrier towards implementing reconfigurable manufacturing [21]. This was confirmed by the results from the simulations, clearly showing that lower investment concepts performed better in short term simulations, which intuitively makes sense. However basing investment decisions on short term calculations obviously may prevent companies from achieving full benefits of longer-term investments, which may be more profitable over a longer time perspective. Likewise, company investment policies should support continuous investments in reconfigurability over a longer time-horizon, rather than targeting investment as a project by project matter covering only the initial and immediate usage of the system.

The results of the simulations further indicated that a higher degree of uncertainty in the demand made the reconfigurable concept perform better. This was observed when removing the monthly fluctuations, making the dedicated concept perform better. Furthermore, when the triangular distribution for the five-year demand was narrowed, the dedicated concept performed better. This emphasizes the importance of paying close attention to the uncertainty in demand when evaluating concepts, since it can make a significant difference in what concept performs better. It is the impression of the authors from previous research, and also found in literature [22] that few companies actually incorporate uncertainty when making predictions of demand in relation to planning new manufacturing systems, which then becomes a barrier towards implementing reconfigurable manufacturing that would otherwise have been an advantage to the companies. The simulation where the moving average was removed made reconfigurability even more favorable, which intuitively makes sense, since chasing the demand calls for more rapid changes, which is one of the main advantages of reconfigurable manufacturing. Hence, the ability to stock products or do back orders influence the need for short-term scalability, which should also be paid close attention to, since it will influence the actual need for scalability and thus reconfigurability. Finally, contrary to what might be expected, changing the interest rate had very little impact on which concept turned out as the most profitable.

5 Conclusion

In this paper, the impact of changing simulation parameters on the financial evaluation of manufacturing concepts, comparing reconfigurable manufacturing to traditional manufacturing concepts was evaluated. This was done by applying a Monte Carlo simulation on three manufacturing concepts with a stochastic demand, and calculating the net present value of the different concepts. By changing simulation parameters such as time span, uncertainty and interest rate, the impact of these on the attractiveness of reconfigurability was investigated. The results showed that changing these parameters has a major impact on which concept is predicted as the most profitable. This is particularly true for uncertainty and timespan, but to a lesser degree the interest rate that only a minor impact. The results presented in the paper can be used in future research, where financial evaluation of reconfigurable manufacturing is relevant, as well as in practice as a guidance on the importance of choosing the appropriate model assumptions. However, given that uncertainty by nature is difficult to estimate accurately, the results suggest that performing sensitivity analyses on the most impacting model parameters would provide valuable insight for practitioners in the transition towards reconfigurability. Future research on this topic will include also taking additional paradigms into consideration such as flexible manufacturing systems, matrix production, and swarm production. Furthermore, scaling manufacturing systems will usually happen over a period where also new products are introduced. This implies that systems are reconfigured to address new demand volumes, but also conversions due to new products requiring new functionality. Future research will aim at also incorporating this into the model, since these two aspects will clearly have influence on each other.

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