IMPACT OF AMT INVESTMENTS ON EFFECTIVENESS AND COMPETITIVENESS OF MANUFACTURING SYSTEMS

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Abstract:

Every manufacturing company is a system of individual manufacturing units, which have to be carefully laid out taking into account time, space, technology, and organization perspective in order to deliver maximum final product. In order to secure absolute effective and efficient functionality of manufacturing process all manufacturing units have to be reviewed already in stage of its planning and organizing. Only continual process of measuring, evaluating and managing effectiveness of individual manufacturing units as well as whole manufacturing system will provide sustainable competitive advantage. The goal of the article is therefore propose methods of evaluation of effectiveness of Advanced Manufacturing Technology (AMT).

Keywords: effectiveness, layout, manufacturing system, evaluation

1. ADVANCED MANUFACTURING TECHNOLOGY (AMT)

An effective manufacturing system seems to be one of the most critical competitive advantages. The way of organization and management of production has huge impact on success or failure of entire company. Maintenance or enhancement of competitive advantage depends on appropriately choose investments on new and more efficient systems of manufacturing. One of possible investments is advanced manufacturing technologies, which can optimize existing manufacturing system and enhance competitiveness of our company thanks to improving the level of flexibility.
AMTs involves a very wide spectrum of automated (computerized) process. AMT can be connected to any kind of manufacturing process technologies which are using information technologies to the storage and subsequent data-processing and communication [1]. AMTs refers to the family of technologies that include computer-assisted design and engineering systems, materials resource planning systems, automated materials handling systems, robotics, computer numerically controlled machines, flexible manufacturing systems, and computer-integrated manufacturing systems [2]. Sun [3] summarizes the manufacturing issues (for which AMT investment can provides benefits) as follows:

- Reduction of lead time to satisfy customer
- Getting new product to market more quickly
- Flexibility to adapt to changes in market
- Improvement of product quality
- Reduction in cost
- Customer service [3]

Meredith and Suresh [4] described new manufacturing continuum in terms of level of integration, which can be applied on AMT [5] classify 14 technologies within those three groups (please reformulate this sentence). Small and Chen [5] classified technologies as:

- Stand-alone (not integrated) – robots, NC machines, etc.
- Linked – group technology (GT, flexible manufacturing systems (FMS), computer aided design (CAD) with computer aided process planning (CAPP), manufacturing resource planning (MRP) etc.
- (Fully) integrated – computer-integrated manufacturing (CIM)

Dangayach and Deshmukh [6] usefully classify AMTs according to the level of technology integration:

- Direct AMT – technology used on the factory floor to cut, join, reshape, transport, store or modify materials (CNC, DNC, robotics, FMS, AS/RS, AMHS, AGV, RP, etc.)
- Indirect AMT – technology used to design products and schedule production (CAD, MRP, SPC, BC, MRP II, etc.)
- Administrative AMT – technology used to give administrative support to the factory and integrate its operations with the rest of the organization (ERP, ABC, OA, etc.)

Information and communication technologies are without any doubt one of the greatest phenomenon of ending 20th and beginning 21st century. Foregoing aspirations of
automation and targeting to supply-side production (cost effective production of one type product – Economies of Scale) are changed by advanced technologies and others flexible automate and productive systems, which are aimed to demand-side (New Economies of Scope). It means the production of huge variety of product, bigger degree of variant individual products and customization by final customer decreasing non-systematic risks for the company and at the same time increasing competitiveness and labour productivity.

According to Meredith and Suresh [7] standard economic justification approaches can be used with an allowance for additional economic benefits or costs. More analytical procedures are needed when synergy, flexibility, risk, and non economic benefits are expected. Strategic approaches are needed with full integrated systems where is necessary to consider competitive advantages, firm’s business objectives etc. [7] Standard economic justification approaches can be used with an allowance for additional economic benefits or costs. More analytical procedures are needed when synergy, flexibility, risk, and non economic benefits are expected. Strategic approaches are needed with full integrated systems where is necessary to consider competitive advantages, firm’s business objectives etc.

There has been much debate about the types of appraisal strategies and techniques that constitute meaningful justification for AMT. Some of underlying concerns are [5]:

- The fact that many of the benefits offered by AMT are considered to be intangible and hence difficult to quantify (for this issue we offer to consult Balanced Scorecard and concept of strategy maps [8]).
- The lack of readily accessible and acceptable techniques for appraising all the benefits offered by the AMTs (this lead us to offer an EFQM Excellence model as a potential framework).
- The ability to assess the true performance of the AMT is diminished if all benefits (tangible and intangible) are not quantified in the justification process (for this issue we offer to use Economic Value Added as a tool for quantification of the impact of AMTs on the firm value).

Inability to address the above concerns has often resulted in management being forced to adopt one of the following strategies [5]:

- Refusing to undertake AMT projects that could be beneficial to the firm
- Investing in AMT as an "act of faith", or
- Using creative accounting to achieve the expected hurdle rates.

According to Krar and Gill [9] successful implementation of AMTs depends on careful planning that considers the long/rang benefits and the risks involved. New AMT that involves greater productivity should be evaluated on their projected competitive advantage and related benefits such as:

- Improved product quality
- Greater flexibility
- Shorter throughput and lead time
- Reduced inventory
- Less floor space required (thanks to greater productivity)
- Reduced indirect manufacturing costs that could include material handling equipment, number of machines required, maintenance and disposable tooling costs, light, heat, taxes, insurance etc. [9]

1.1. MANUFACTURING SYSTEM

Manufacturing can be characterised as a vehicle to satisfy the needs through creation of services or goods. It’s a result of purposeful human activity, where by utilisation of inputs particular transformation process delivers the highest output possible. Manufacturing therefore can be defined as effective combination of factors for the purpose of creation of products and services. Manufacturing process is realised by company’s internal throughput manufacturing system. An abstract structure of manufacturing system can be generally described by following scheme. [10]

![Figure 1: Throughput of manufacturing system](image)

Manufacturing system as described is characterised by following elements:

1. **Output** - demand market relevant goods (products or services) of material or non-material matter.

2. **Input** - production factors segmentation (i.e. according to Gutenberg):
   - elementary factors, which create a physical body of manufacturing system, can be viewed as factors:
     - potential factors - means of production used as performance potential in transformation process and available to be used without loosing its production ability in time (i.e. employees, buildings, land, warehouses, transport vehicles, etc.),
     - consumer factors - consumed in manufacturing process without option of reuse such as raw materials, semi finished goods, separate parts and products, standard parts, components, auxiliary material, supplies and indirect material, shopping goods;
   - no mandatory.

3. **Throughput** - defined by combination of factors with following certain procedure.
Manufacturing system as a term includes all factors involved in manufacturing process: operating premises, unnecessary technical equipment, semi finished goods, energy supply, information, human labour involved in manufacturing process, unfinished and finished products and waste. Key in manufacturing management (management of manufacturing system) are material, space and time coordination, eventually coordination of factors involved in or influencing manufacturing processes.

2. METHODS OF EVALUATING OF AN EFFECTIVENESS OF MANUFACTURING SYSTEM

Each of the production system consists of individual production units that can be evaluated mainly by three key generic indicators which are elementary requirements of highly effective manufacturing systems. We talk about:

- **Versatility** - versatility can be viewed from different perspectives - different types of products able to be processed on specific system, different production batch sizes capable, different consequence of production batches set to be produced, reaction time on changes of customer’s requirements. [11]

- **Productivity** - productivity is often in direct conflict with versatility. Increasing productivity means increasing outputs with decreasing production inputs - what requires more productive activities increasing added value of final product, lower wastage of labour, space, time, material, etc. There has to be found compromise between versatility and productivity. [11]

- **Quality** - quality is a standard which does not have to be discussed. Optimal system design includes also quality measures, therefore no additional arrangements or costs will be required to achieve or enhance quality standards (i.e. output control, repair works, etc.). [11]

Above mentioned generic measures may be a source for selection of methods, procedures or indicators for effectiveness measurement of designed layouts. Following sections will mentioned the key ones in detail.

2.1. PRODUCTIVITY

Productivity in simple is a measure explaining how efficiently someone uses inputs to produce desired products or services. [12] The most common formularisation is input output ratio. Generic formulation for productivity calculation is as follows:

\[
P = \frac{\text{output}}{\text{input}}
\]  

(1)

Output may be expressed in units or volumes such as tons, litres, pieces, products, etc. In case an output cannot be defined individually, we can use financial valuation in
specific currency in a form of cover price etc. Inputs are generally categorised into i.e. labour force, manufacturing equipment and machinery, material or capital.

For other uses we can modify productivity formula into following three ratios, which are commonly used to communicate productivity in real life:

- partial productivity
- productivity index
- total productivity

**Partial productivity – PP**

\[
PP = \frac{\text{output quantity}}{\text{category of input quantity}}
\]  

**Index productivity – IP**

\[
IP = \frac{\text{actual productivity}}{\text{standard productivity}} \times 100
\]  

**Total productivity – TP**

\[
TP = \frac{\text{output quantity}}{\text{input quantity}}
\]

Partial productivity is a basic measure to evaluate each specific process or source. To calculate partial productivity we have to rate process output (quantified by defined set of measures) against each input (source). For more robust analysis we can divide each source into more detailed units especially in cases when searching for specific production activity or process with productivity increase potential. [12] Productivity measurement would be a waste of time if not carried continually and results are not reviewed and interpreted continuously. Results are often presented in comparison with and difference to set standard of productivity. We call this ratio as productivity index. Productivity index is a measure showing, whether we win or loose the battle for high productivity. Productivity standards may be set differently:

- based on results of previous periods (month, year, etc.)
- based on exceptional results of previous periods
- based on results delivered by competition
- based on results of analysis provided by industrial engineers [10]
Such set of standards gives us a tool to set specific productivity targets. Total productivity is total output to total input ratio. To be able define this ratio we have to quantify all consumed inputs (expressed in different units) in universal monetary expression. [13]

Among basic factors which allows us analyse reached productivity levels as well as search for potential for improvement belongs:

- U - utilization (rate of use)
- P - performance rate
- Q - quality rate
- M - method level

Rate of use reflects the level in which are all inputs (sources) converted into outputs (products). Performance rate measures speed and rate in which the conversion is carried out. Quality rate records precision and quality, in which is defined activity realised and desired output delivered. Method level describes methods and procedures used in manufacturing process.

**Rate of use**

Factor of utilisation rates how efficiently are all inputs used in manufacturing process. The better utilisation is the higher is productivity and rate of use. Formula for quantifying the rate of use of human labour, material, machinery or working place is as follows:

\[
U = \frac{\text{actual capacity}}{\text{potential capacity}} = \frac{\text{actual performance}}{\text{potential performance}}
\]  

(5)

In industrial organisations we can meet mainly three basic types of capacities:

- **Potential capacity (maximum capacity)** - quantifies maximum output or through output achievable in ideal conditions.
- **Effective capacity** - represent achievable output in real for defined set of products, schedule, effective time fund, planned service, quality standards, breaks, unsynchronised operations, etc.
- **Actual capacity** - cannot exceed effective capacity levels and is generally lower due to machinery failures, mix-ups, organizational problems, etc. [14]

**Performance rate**

This rate measures a speed of production process. The faster is something produced or activity carried out the higher productivity is achieved. Machinery and labour performance plays a major role in this case. [10] Performance linked to management is difficult to mark as outperforming, standard or underperforming without comparing it to predefined standard value. This standard value may be an achievement from the past, it may be budgeted level or standard set in some objective way such as time or progress study, information about
industry, technical calculation or benchmarking with performance levels achieved by other business units of the same company. [12]

Quality rate

Work not delivered in precision and quality required will be refused with negative effect on productivity. Therefore a balance between fast delivery and quality is important. Quality rate is evaluated through various measures included in Quality Management where different stages of production and final products are controlled and compared with predefined quality standards. [12]

Methods level

The fourth factor described is methods and procedures, work organisation and working environment. Even if we use our time well, our work performance is high and products of high quality, but we do not follow best production methods and procedures, total productivity is much lower than potential productivity level. [12]

Listed factors with direct influence on total productivity are all included in one of the basic formulas - **Overall Equipment Effectiveness (OEE)**.

\[
\text{OEE} = \text{rate of use} \times \text{performance rate} \times \text{quality rate} \times \text{method level} 
\]

OEE is calculated as product of rate of use, performance rate and quality rate. Maximum value equals to 1 (100 % respectively). This parameter describes not only the fact, how much is machinery and technology used to its capacities and capabilities with quality took into consideration. It indicates other important factors such as correct following of working procedures and methods. Parameter „Machinery usage“ indicates a percentage of time planned for production over which the machine operates in real. Calculation of the parameter is fraction with down time when a machine did not operate due to failure or other reasons deducted from total time when machine was available and had planned production as numerator divided by total time when machine was available and had planned production. Parameter “Machine performance” is highly influenced by production rate losses. Means difference between real production rate (measured by number of products produced over time unit) and planned or projected production rate. Another loss is caused by production deviation or interruption which cause, that machine does not operate in a constant rate as we would expect. [15] The last parameter needed to calculate OEE ratio is a parameter, which would record a quality level of products delivered over manufacturing process. From rate of use perspective it is important to notice that in case we do not produce product of desired quality right from the beginning the time we had available and used it to produce waste is lost. Quality rate is then calculated by proportion of quality products on total products finished outspread to certain product sort. Factual calculations are shown in following formulas:
Calculation parameter – **rate of use machine**

\[
rate \ of \ use = \frac{\text{time available} - \text{idle time}}{\text{time available}}
\]  
(7)

Calculation parameter – **performance rate**

\[
performance = \frac{\text{unit produced} \times T_p}{\text{time available} - \text{idle time}}
\]  
(8)

Calculation parameter – **quality rate**

\[
quality = \frac{\text{units produced} - \text{substandard unit}}{\text{units produced}}
\]  
(9)

### 2.2. VALUE ADDED AND TIME

Among valuable tools to calculate an efficiency of individual production units can be included measurement of time, means evaluation of time consumption of different processes of overall production system. Time related is also value added issue, where we try to evaluate efficiency of particular process based on value it adds to final product and time consumed to finish the process.

Value is defined by cost and customer perceived value ratio [12]:

\[
value = \frac{\text{usage attributes of product}}{\text{costs}}
\]  
(10)

According to value chain mapping a value is “the most effective way how to reliably achieve utility attributes which will fulfil expectations of the customer“. [16] From abovementioned definitions and according to value chain mapping we can derive a new definition of value (VA-index formula), which includes a parameter of time as a basic component for calculation of efficiency of processes proposed or changed within the whole manufacturing system layout.

\[
VA-index = \frac{\text{time, over which value is added to product}}{\text{total time of manufacturing the product}}
\]  
(11)

Time over which a value is added can be from process perspective understood as a time over which activities changing a product are realised or a time of delivering a product to
customer. “Efficiency” of process described in this manner is percentage of time period, over which a value was added to product on total time of product creation and delivery to the customer (i.e. since raw material is stored until time of product acceptance by a customer). This ratio is called „Value Percentage of Time“, „Value Added Ratio“ or VA-index (Value added index) and is labelled by value added. Objective of any layout change is an improvement of VA-index, means shortening of total production time.

Analysis of time over which is value added through production operations is closely correlated with analysis of course of all processes related to transformation of inputs (production factors) into output (products or services). Realised analysis will help us to separate particular process activities into effective activities (increasing a value of product), ineffective activities (activities necessary for product completion but without effect on its value) and wastage. Results from mentioned analysis are base for evaluation of time demandingness (effectiveness) of process layouts proposed.

3. EVALUATION OF BENEFITS AND COSTS OF NEWLY DESIGNED OR CHANGED LAYOUTS

The previous chapter was dedicated to basic methods and measures of performance evaluation. We aimed to conceive a generic list of measures useful for evaluation of effectiveness and performance of production system or their parts. Proposed measures will help us figure out if planed AMT investments will provide us with expected benefits and effectiveness improvements of production system. Findings from assessment provide information about positive or negative impacts of new AMT investment on all important aspects and activities of manufacturing process.

Proposed measures will help us assess the benefits of investments into newly designed technologies. Potential benefits and positive effects of AMTs and their impact on production system effectiveness:

a) Area of improvement of rate of use of sources

- Improvement of rate of use of work labour - new AMT may effectively reduce number of workers needed in production what affects labour costs;
- Improvement of rate of use of machinery and technology - decrease of time intensity of machinery and reduction of down times has direct impact on efficiency and their rate of use;
- Improvement of rate of use of workspace - usage of AMT may reduce non-effective workstations and reduce distances with positive impact on efficiency of total workspace usage;
- Improvement of rate of use of raw and other material - new AMT may improve quality of material storage and waste during transportation or processing causing increase in total output from same volume of material input.
b) Area of improvement of performance rate

- Increase of labour performance rate: new AMT or manufacturing process may shorten time to finish one specific operation therefore number of semi finished goods produced over certain period of time will increase or required number of semi finished products will be available in shorten time for further processing;

- Increase of machinery performance rate: better technologies and modern machineries may improve their usage rate with direct impact on performance rate.

c) Area of quality rate enhancement: with well implemented AMT the total number of defects may be reduced and increase quality level of total production.

d) Area of time intensity reduction

- Reduction of processing time: focus on shortening of processing time of each individual process or activity (especially those lined in main value chain of transformation of factors of production into desired products or services);

- Reduction of maintained production time: change of sequence of processes or activities and reduction of ballast time has positive effect on total production time;

- Reduction of duration of service activities within production process: shortening of service activities especially those lined between value creation activities in value chain reduces operation costs and improves productivity; Reduction of time intensity of processes in general leads to speedup and cost reduction of those processes.

e) Improvement of VA-index: changes in Technology Park is proceeded mainly due to need for elimination of waste activities (processes) or cut off of non-effective activities with no added value. This indicator may help us to identify potential for efficiency improvement in mentioned areas and provides important feedback on proposed changes and their capability to grow value of final product.

f) Other areas of possible benefits or improvements of introduced AMTs:

- Reduction of work-in-progress stock level: effective line-up of production line or workplace leads to reduction of stock of work-in-progress;

- Reduction of operation space: effectively used AMT may result in reduction of space necessary to accommodate all workstations and manipulation spaces.
When evaluating investment opportunities investor has to assess both benefits and costs of planned change and make a decision to go for a change or abandon it. Cost analysis consists of following stages:

a) **Identification of labour costs and other personnel expenses**
   - When planning AMT investment change in other personnel expenses such as overtime, brigade-work costs, night or weekend premium pays or project team expenses have to be considered.

b) **Identification of material costs** - we need to analyse all material costs linked to AMT such as:
   - material consumed to establish new workstations for controlling, in-process store or master offices,
   - purchase of furniture and technical equipment of new offices,
   - costs of increased stock required with project,
   - other small material costs.

c) **Sum of financial investment costs** – all financial expenses resulting from investment project:
   - purchase costs related to a project,
   - expenses of external subjects (university, private company) taking part in investment decision process.

4. **IDENTIFICATION OF IMPACT OF INVESTMENT ON COMPANY COMPETITIVENESS**

Through evaluation of effectiveness of newly implemented AMT into the production system we can measure their positive effects on company. Question arises what impact on competitiveness of company those effects have. We are interested in fact how potential investments into AMT influence increase and sustaining of competitiveness and performance of the company. Useful tool to identify mentioned affects is strategic concept of Balanced Scorecard (BSC).

Company management through BSC may measure how individual business units create value to their current and future customers and how quality of personnel, systems and operations necessary for growth of performance in future is growing. [17] BSC clearly shows value-creating drivers which lead to sustainable growth of financial performance and competitiveness. BSC measures company performance within 4 main perspectives - financial, customer, internal processes and perspective of learning and growth [18].

Logic of Balanced Scorecard allows us an identification of impact of investments into AMT on company competitiveness. With cause-and-effect relationship and four perspectives
of BSC we can follow the chain of impacts of AMT up to financial performance and competitiveness of company. [18] Scheme of investment influences on competitiveness is described on Figure 2. Partial impact within four perspectives of BSC is explained in following articles (number 1, 2, 3, 4), where we will show real effects of AMT on competitiveness and performance of the company.

1) **Learning and growth perspective**
   - AMT undermine increase of qualification and competencies of personnel,
   - AMT may improve working environment with increasing effect on personnel satisfaction and motivation,
   - financial sources saved through AMT operations may be used to increase wages or bonuses with another positive effect on personnel satisfaction and motivation.

2) **Internal business processes**
   - new AMT may affect following indicators - higher rate of use of machinery, material saves, reduction of stock, speedup of production cycle, enhancement of process quality;
   - motivated and satisfied employees are another positive effect useful for improvement of individual processes quality,
   - qualified personnel may influence a speedup of production cycle,
   - material saves have positive effect on stock and its optimization.

3) **Customer perspective**
   - main goal of AMT is an increase of manufacturing process flexibility what has direct impact on customer satisfaction,
   - also enhancement of quality of individual processes through whole value chain may have positive effect on customer satisfaction.

4) **Financial perspective**
   - cost aspect of BSC financial perspective is improved by speedup of manufacturing process, reduction of stock as well as increased rate of use of machinery, therefore AMT in general may reduce costs of individual processes within whole manufacturing system of the company,
   - satisfied customers drive company sales,
   - reduction of costs and increased sales may secure increased profitability for long term what is one of main goals of any company, which strive for sustainable competitiveness on the market.
Figure 2: Potential strategy map for AMT investment and its effects (hypothesis)
5. CONCLUSION

The paper works with different methods of evaluation of effectiveness of AMTs. The attention is given specially to the evaluation of effectiveness and competitiveness through BSC. The aim of study is to create overall list of criterions, measures and criteria which could be used in process of evaluation of new AMT. We specially pointed out the possible benefits (effects) of new investments and its expenditures. Important step was the identification and definition of possible impacts of new AMT on competitive strength of company.

Acknowledgement

Authors are thankful to the Grant Agency in the Czech Republic (GA CR) No. 402/07/1495 for financial support to carry out this investigation.

6. REFERENCES


