Technology: A Crucial Success Factor in Manufacturing?
Some Insights from the Research Project: World Class Manufacturing

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ABSTRACT

Continuous technological change is often cited as a prerequisite for competitiveness and survivability of companies and whole economies alike. Although technology influences all activities in a company's value chain, technology particularly affects a company's competitiveness in the area of manufacturing. This paper falls within the scope of the international research project "World Class Manufacturing". The project's aims are to investigate the critical success factors in manufacturing, mainly on the basis of statistical analysis. A large subset of the project, and the main focus of this paper, is the field of technology. In a first step, the collected data are used to test hypotheses, about the effect of technology on several measures of performance. This part shows the typical approach of empirical analysis. However, this statistical analysis is insufficient to investigate the highly dynamic area of technology, and to show and explain the influences of technology on competitiveness. Therefore, in the second step some basic feedback structures of a System Dynamics model are presented. This structure is verified on the basis of data collected within the empirical survey. The model then can be used to investigate whether there are specific conditions under which technology strategies lead to a competitive advantage or are condemned to failure from the start. Additionally, it will be shown how system dynamics based modeling and empirical research can complement each other and aid the process of theory building.

IMPORTANCE OF TECHNOLOGY FOR MANUFACTURING S COMPETITIVENESS

Continuous technological change is often cited as a prerequisite for competitiveness and survivability of companies and whole economies. Although technology influences all activities in a company's value chain, in particular technology may affect a company's competitiveness in the field of manufacturing. Products manufactured and sold to the customer, processes used to make the products, and information systems used to integrate the various areas of a company are each a part of the technology in use and are expected to show an impact on the performance of the

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manufacturing system. Hence, effective implementation and use of technology is commonly to be seen as a strategic weapon in the battles of a company against competition (Porter 1985).

Since there has been no broad empirical research done about the impact of technology use in the manufacturing sector on manufacturing performance, the question arises whether outstanding technological performance really is a critical factor for the success of manufacturing. If the hypothesis that technology is an important success factor can not be falsified[1], are there specific general conditions and structures that cause the use of technology to be effective? Moreover, can technology be seen as independent to other areas of the company, e.g. the human resource sector or the manufacturing strategy? What are the linkages and are there any reinforcing or limiting feedback structures which automatically lead to competitive advantages or hinder the successful implementation and use? These and related questions will be investigated in this paper.

AIMS AND RESEARCH METHOD OF THE PROJECT WORLD CLASS MANUFACTURING

This paper is based within the scope of the international research project “World Class Manufacturing“. The aims of the project are to identify the management practices pursued by plants which are commonly seen as being at the leading edge in their industry with respect to performance. In literature e.g., quality management practices, human resources management, information technology, product and process technology, Just-in-Time, management support, employee commitment, and among others, implementation of a manufacturing strategy, are seen to be critical success factors. The original aim of the project is to investigate success factors of manufacturing on the basis of statistical analysis of the international empirical research data base.

Industry	Country					Total
	GER	ITL	JPN	UK	USA	
Automotive suppliers	13	10	8	7	10	48
Electronics	9	11	15	7	10	52
Machinery	11	13	14	7	10	55
Total	33	34	37	21	30	155

Table 1: Composition of the data base

The data base comprises qualitative and quantitative information collected in 155 manufacturing plants from USA, Japan, Italy, United Kingdom, and Germany. Data have been collected in the automotive and automotive supply industry, the electronics industry and the machinery industry. In order to be able to identify the management practices of World Class Manufacturers, the sample consists of two groups. The first group represents plants with strong

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[1] Note that in the tradition of Popper in socio-economic systems hypotheses only can be falsified, and never be finally verified. Verification is only possible in the case of logically determined sentences (Popper 1958, see also Chmielewicz, 1979)

evidence of being ‘World Class’. The second group comprises randomly selected ‘traditional’ plants. Table 1 shows the actual composition of the data base.

In each plant, 26 employees—from the plant manager to the direct labor employees—had to fill out questionnaires asking for a plenty of subjective and objective data. Qualitative information was collected on the basis of statements to which the respondents had to indicate—based on a five point Likert scale—to what extent they agree with the statement. Table 2 shows, as an example, the statements to measure the scale of how effective new process technology is implemented in the plant. The statements of this scale were spread unordered over the questionnaires and mixed with the items of other scales in order to hide the intended subject of measurement. After the data collection had been finished, the data from the individual respondents level were aggregated to the plant level, and then scales were calculated as the mean of the connected items. Factor analysis and Cronbach’s Alpha were calculated to judge construct validity and reliability (see Nunnally 1978, for a brief description see also e.g. Sakakibara/Flynn/Schroeder 1993, see also Flynn/Schroeder/Sakakibara 1996).

Subject of measurement: **Effectiveness of implementation of new manufacturing process technology**		
Item name	**Statement**	**Factor loading**
TSEIR01	We often fail to achieve the potential of new process technology.	0.604
TSEIR02	Once a new process is working, we leave it well enough alone.	0.631
TSEIN03	We pay particular attention to the necessary organizational and skill changes needed for new processes.	0.737
TSEIN04	We are a leader in the effective use of new process technology.	0.721
TSEIN05	We search for continuing learning and improvement after installation of the equipment.	0.764
Reliability of constructed scale measured by Cronbach s Alpha:		0.727
Respondents to items: Plant Manager, Plant Superintendent, Process Engineer		

Table 2: Example of measurement of qualitative information

Scales similar to the one shown above have been constructed to measure to what extent management practices in the areas of quality management, Just-in-Time manufacturing, manufacturing strategy, information technology, and among others human resource management are used. E.g. several scales from the human resource practices measure the degree of commitment, the use of problem solving teams, the pride in work, and the shop floor contact of management. The quantitative information collected covers a broad variety of data such as, sales volume, manufacturing cost, value of inventory, number of employees, percentage of products introduced in the last five year, age of equipment, year of first use of CAD or CAM, percentage of scrap and rework, cycle time, lead time, etc. To collect quantitative information, we concentrated on the person who should have the data most easily available, e.g., the account manager was asked about sales and cost figures and other accounting information, and the human resource manager was asked about the number of employees or the total hours of training. Both, qualitative and quantitative data were then used to investigate hypotheses about the use of management practices, and their effects on plant performance using various statistical methods such as regression analysis, structural equation modeling, canonical correlation analysis, as well as cluster and factor analysis.

WHAT EMPIRICAL ANALYSIS TELLS US ABOUT TECHNOLOGY AND COMPETITIVENESS

An area of particular interest in this project, and also the main focus of this paper, is the field of technology. In the following, it will be exemplary shown how hypotheses about the influences of technology on the different measures of plant performance are proven. Since technology is a sparkling term with different facets and which can potentially impact every part of a company it must be clarified first.

Technology a sparkling term

Traditionally, technology comprises the aspects of a plant's products—product technology—and production—process technology or manufacturing technology. However, nowadays technology also includes information systems and thus, information technology. The different aspects of technology are closely interrelated. For example, Computer Integrated Manufacturing (CIM) as a part of the manufacturing system is unthinkable without information technology. Product design and product technology strongly influence the producibility in manufacturing and define the manufacturing technology required. Computer Aided Design (CAD) is also a means from the field of information technology speeding up the process of development of new products (Steele 1989). As a result it seems that technology becomes a competitive weapon only if all technology dimensions are linked together in the manufacturing system of a plant. All three dimensions are assumed to be core factors with direct and indirect impact on the competitiveness and the performance of a plant.

High standard **product technology** is seen as the prerequisite for sustaining competition. The better the products of a company are, the higher the competitive advantage is. High performance plants use practices which increase their ability to introduce new products more frequently and faster than the competitors. These practices serve as a means to increase customer's benefits and finally to improve or sustain the competitive advantage. However, product technology should not be seen as isolated from production. Quality, number of different part, and manufacturability defined by product development have a strong influence on manufacturing, the necessary process technology, and the ability of marketing to promote sales. Hence, World Class Manufacturers regard these aspects as interrelated. They consider both, customer needs as well as supplier's and manufacturing's capabilities during the early stages of product development.

With the increasing capabilities of computers and information systems, the impact of **information technology** is at least growing. Information technology is becoming the dominate influence in the manufacturing field (Steele 1989). Information technology is the basis for a plenty of concepts directly related to manufacturing at the plant level. Computer integrated manufacturing (CIM) with its components of CA-components such as CAE, CAD, CAM, CAP, or CAQ are tools that would never exist without computers and information technology. Furthermore, information technology influences all activities in a plant, not only manufacturing. Communication processes can be accelerated, planning systems can be improved, through e.g., improved availability of and access to data.

Effective use of **manufacturing technology** is a means for the achievement of flexibility to changes in production volume, to changes in the job shop schedule, and to changes in the type of product to be manufactured. High quality products are not solely a result of the application of comprehensive systems of quality management. Rather quality is also influenced by the technology used in manufacturing, which e.g., emphasis on smoothly running machines with low deviation of tolerances, scrap, and rework, as well as the use of machines with automated inspections. Low costs are influenced by the manufacturing technology as well, e.g., through economies of scale as well as economies of scope, low down time of equipment caused by production stoppages, short set up time, and a low percentage of rework and scrap. Manufacturing technology also has the role of ensuring a plant’s ability to meet customers’ demands regarding on-time delivery and short delivery time.

Results of the Statistical Analysis

As manufacturing technology is supposed to show the strongest direct influence on plant performance, the following a statistical analysis concentrates on the aspects of manufacturing technology rather than product and information technology. To measure the manufacturing technology performance of a plant, an aggregate indicator is formulated based on subjective and objective data. Table 3 shows the components of the manufacturing performance and the measures of reliability and construct validity.

The questionnaires asked how the plant compares to its competition on a global basis in the areas of manufacturing innovativeness, use of computers and use of process technology. In addition to this subjective information, data regarding the age of the plant equipment was collected. The responses have been standardized by industry and aggregated to the measure of the manufacturing technology performance.

Subject of measurement: Manufacturing technology performance		
Standardized item name	**Statement:**	**Factor loading**
	Please indicate your opinion about how your plant compares to its competition, on a global basis (5 = superior or better than average, ..., 1 = poor or low end of the industry)	
ZPCC1_G	Innovative manufacturing	0.833
ZPPC2_G	Use of computer in manufacturing	0.871
ZPCC3_G	Process technology	0.870
Objective information about the newness of equipment		
ZNEW_EQG	Calculated based on the percentages of equipment that fall into the following categories: Less than 2 years old, between 3-5 years old, 6-10 years old, 11-20 years old, over 20 years old	0.436*
Reliability of constructed scale measured by Cronbach s Alpha:		0.7574
Respondents to items: Plant Manager, Plant Superintendent, Process Engineer, Plant Research Coordinator * Following statistical tradition this item should not be included due to a factor loading being below 0.5.		

Table 3: Indicator of the manufacturing performance of a plant

The measure of manufacturing technology performance should have an impact on several measures of plant performance. Several hypotheses can be formulated and investigated using regression analysis. As examples serve the postulated relationships between manufacturing technology standards on the one hand and the ability to change the mix of products to be manufactured on the shop floor and to adjust the production volume on the other.

H_1: A plants quality of manufacturing technology is related its flexibility to change the mix of products to be manufactured.

H_2: A plants goodness of manufacturing technology is related its flexibility to change productions volume.

Figure 1 gives an overview on the hypothesized relationships as well as the results of the regression analysis. Starting on the left with the indicator of manufacturing technology each arrow reflects a hypothesized relationship to the variable it is connected to. Hence, in addition to H_1 and H_2 which are represented through the connecting arrows between manufacturing performance and the first two rectangles, it was expected that manufacturing performance decreases a plants time horizon from which on the production schedule is frozen and has to be followed, increases the on time delivery rate, and improves its ability to deliver the products manufactured fast. The rational behind these hypotheses is that state of the art manufacturing equipment is more flexible due to lower set-up time, and can cost efficiently produce small lot sizes. It is also expected that the reliability of modern manufacturing equipment is higher and many times offers automated quality control and thus less products are returned from the customer with defects. All these postulated relationships could not be falsified and consequently the hypotheses are accepted. Although, the proportion of variance explained as indicated by the R^2 is very low. This indicates that there are additional factors explaining the performance measures and shows that additional research is necessary. For example, flexibility could partly be explained by well trained employees in the production line and the production management.

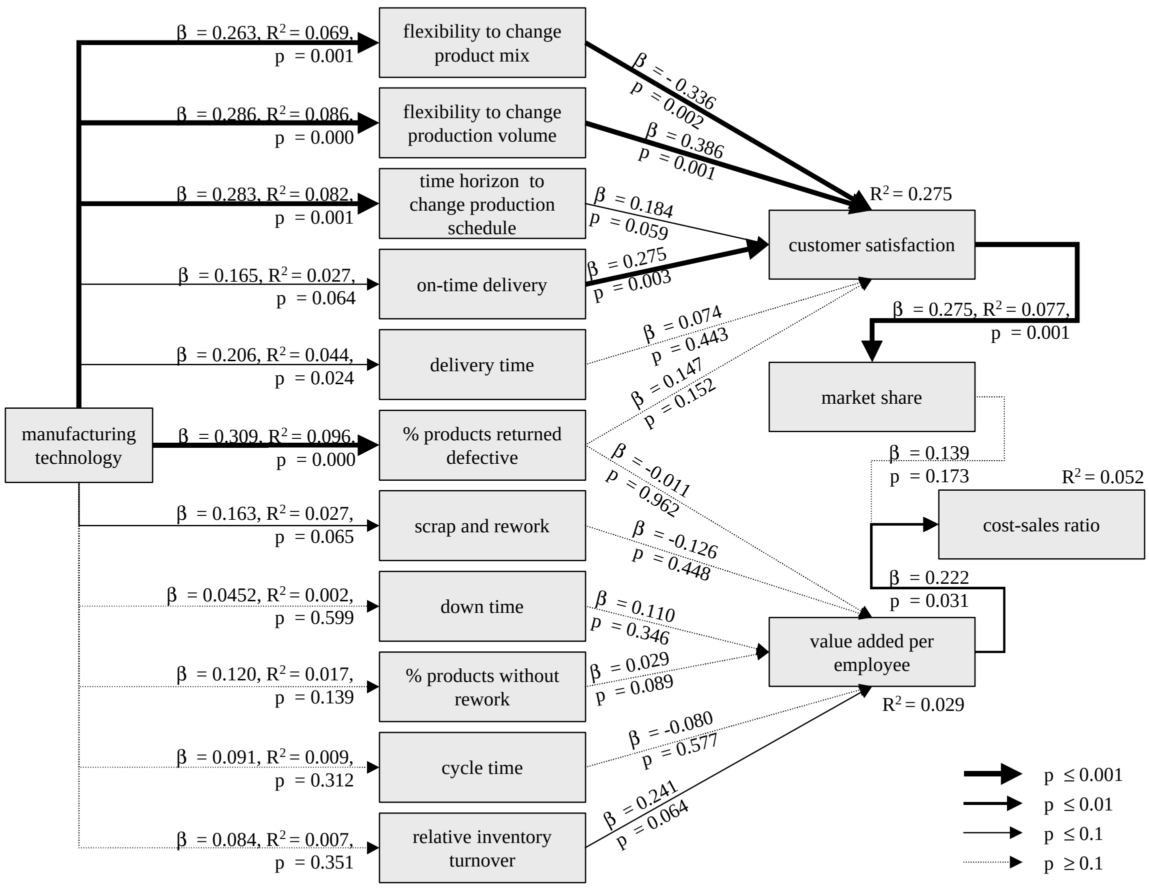

Figure 1: Hypothesized relationships between manufacturing technology and performance

A further hypothesis is that these performance measures can be externally perceived and thus honored by the customers. Hence the customer satisfaction should increase as the performance measures improve. However, as shown in Figure 1, delivery time and the percentage of products returned defective have a low correlation and an insufficient significance level. Consequently, in a mainly statistical research the related hypotheses would have been falsified. The remaining linkages between the externally perceivable performance measures and the customer satisfaction explain 27.5 % of its variance. Note that customer satisfaction is a subjective measure determined as shown in Table 2. It reflects the opinion of the employees within the plant about the customer satisfaction and does not measure the customers opinion.

Beyond the externally perceivable performance measures it is hypothesized that state of the art manufacturing technology shows an impact on internal performance measures. Besides a lower percentage of products returned by the customers, it is postulated that the percentage of cost for scrap and rework, the down time of equipment due to machine break downs, the percentage of products which pass final inspection without necessary rework, and the cycle time decreases, while the inventory turnover increases. However, only the cost of scrap and rework and the percentage of products returned defective are influenced significantly by manufacturing technology performance as Figure 1 shows. Since this is to some extent surprising it indicates that more detailed research is necessary. Also, the hypotheses reflected through the arrows between the internal performance measures and the variable “value added per employee”—from a statistical point of view—have to be rejected.

Following the causal map from Figure 1 further to the right it is additionally hypothesized that customer satisfaction is related to the market share and market share as well as the value added per employee, influence the final performance measure represented by the cost sales ratio. Cost sales ratio can be interpreted as profitability. However, only the value added per employee has a significant, but still weak impact on the profitability. Surprisingly, the market share is not statistically related to the cost sales ratio.

Based on strong statistical criteria, from the above described analysis one could conclude that manufacturing technology does nothing for the profitability. On one hand, manufacturing technology influences several performance measures which themselves are related to customer satisfaction and market share, but not to the value added per employee. At the other hand, value added influences the cost sales ratio but market share does not. The linkages from manufacturing technology to profitability are broken. However, such a conclusion is contradictory to any logical analysis. Measurement problems as well as an inadequate sampling could be the reason.

Moreover, if the hypotheses could have been proven more significantly, could one then conclude that management just has to invest in technology and it will show immediate effects on profitability? This question has to be answered in the negative. As it will be shown in the following, the static analysis is very restrictive to such a dynamic and interrelated subject as technology is. Or to put it in other words: a system dynamicist would ask “Where is the feedback?”.

THE DYNAMIC VIEW

Feedback Loops Driving Competitiveness

Porter characterizes technological change „... as a great equalizer, eroding the competitive advantage of even well-entrenched firms and propelling others to the forefront...“ (Porter 1985) and therefore influences the structure of whole industries. On the face of it, this description shows the importance of technology; even more important it shows implicitly that the effects of technology on competitiveness have to be seen from a dynamic point of view. “Eroding” and “propelling” indicate that there is a dynamic process and no discrete shift in the competitive position of a company through the introduction of, e.g., new manufacturing technology by a single competitor. Neither, the competitors' decisions are uninfluenced from each other—actions of one company causes the other to react—, nor the markets and the customers show immediate response to changes in competitiveness resulting from, e.g., improved delivery performance of one company caused by improved and more reliable new manufacturing equipment. There are long delays in the interactions between the competing companies, as well as between companies and customers; and there are feedback loops which may strongly limit or accelerate the outcome of the actions taken.

In the following, a more comprehensive view will be discussed based on a feedback-oriented view of the problem. Basis for the conceptualization of the model, is the information and data collected within the project. Causal links between variables are postulated as usual in system dynamics studies. Though, whenever possible, causal linkages have been investigated on the basis of the database with regression analysis[2]. The reason for this approach to model the effects of technology on performance, has to be seen in the intention of the analysis: the formulation of a widely proven theory of success factors in manufacturing—to the extent it is at all possible in social sciences (see footnote 1).

Starting point of the feedback structure shown in Figure 2, is the performance of manufacturing technology as defined in the statistical analysis before. Three similar reinforcing loops R1a-c (marked red and with bold lines) have been identified causing a process of exponential growth or decay. Increasing manufacturing technology performance is supposed to increase flexibility, on time delivery rate, shortens the delivery delay, and improves the percentage of products delivered to the customer without defects[3]. The three measures increase customer satisfaction and cause the market share, as well as the sales volume to be rising. Since return on sales is increasing, the investment budgets available and—assuming there is no competition among areas requiring these resources—the investments in manufacturing technology are increasing as well. This causes the newness of equipment to improve, and finally the manufacturing technology performance grows because newer equipment is supposed to be more sophisticated than older equipment. However, these "investments in manufacturing technology"-loops have long time delays, since investment decisions have to be made, new equipment have to be ordered and built up in the plant. Undoubtedly they will not show unlimited growth since there are additional loops, not shown here like, e.g., the reactions of competitors to the loss of market share. Hence, the loops R1a-c are not seen as being effective in the short run.

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[2] Correlation between two variables does not necessarily mean that there is also causality. Two variables can be highly correlated, although there is no logical explanation for that. E.g., a correlation between variables A and B can be identified, because both variables are influenced by a third variable C. (Richardson and Pugh 1981; Norušis 1997, Bortz 1993) A famous example of this is, that in some regions of the world, a high correlation between the sighting of storks and birth rate can be found (see Norušis 1997).

[3] Note, that the variables of the indicators of flexibility and the measures of scrap and rework, down time and products delivered defective as shown in Figure 1 have been aggregated into two separate variables only for the sake of simplicity of the Figure 2.

Although, they improve the manufacturing performance, they are not effective in day-to-day operations (see Repenning and Sterman 1997, Sterman/Repenning 1997, Repenning 1996 for a discussion of improvement programs and models explaining their failure).

Two additional reinforcing loops (R1d, and R2) have been identified, which also cause—ceteris paribus—continuos improvement of a plants manufacturing capabilities. As the percentage of products delivered with hidden defects to the customer decreases, the customer satisfaction increases (loop R1d), and, as scarp and rework, down time and products with defects decrease, the cost situation of a plant will improve. Hence, the return on sales, investment budgets allocated to manufacturing technology, and manufacturing technology will improve, which then leads to further improvements of scrap and rework and down time. However, this reinforcing processes are strongly balanced by the feedback loops of equipment aging B2a-d. As investment increases, in fact the amount of recently ordered equipment and hence the newness of equipment rises, but, the investment decision also puts more equipment into the aging process andequipment becomes older.

Additionally, these long run reinforcing loops will be limited through the balancing loops B1a-d created by the turquoise linkages shown in Figure 2, which add to the structures already described. As through a logical analysis postulated, and by a statistical analysis supported, product technology and manufacturing technology have to fit together. If product technology has a high standard, the manufacturing equipment also needs to be more sophisticated. This makes the importance of a balanced improvement of a plants products and processes explicit. Concentrating of one aspect or the other decreases the adequacy of manufacturing technology and product technology performance. In consequence, the manufacturing processes run less smoothly, flexibility as well as on time delivery rate decreases. Delivery time, scrap and rework, and down time increases, and more products with hidden defects will be delivered to the customers. These balancing loops are able to stabilize to some extent the effects of the reinforcing loops R1a-d. It seems plausible, that it is easier to manufacture less sophisticated products with highly modern manufacturing technology than vice versa. The inadequacy of product and manufacturing technology can get worse if the positive feedback loop R4 is dominating the system. Since improved product technology leads to a higher customer satisfaction, market share, sales, return on sales and therefore is strengthening the investments in product technology. This then leads to a further improvement of the product technology performance. Beyond that, the disproportion of product and manufacturing technology rises and the reinforcing loops R3a-d come into play. However, these feedback processes show considerable lower delays than the “investment in manufacturing technology”-loops described before and are assumed to be dominating the behavior of the system.

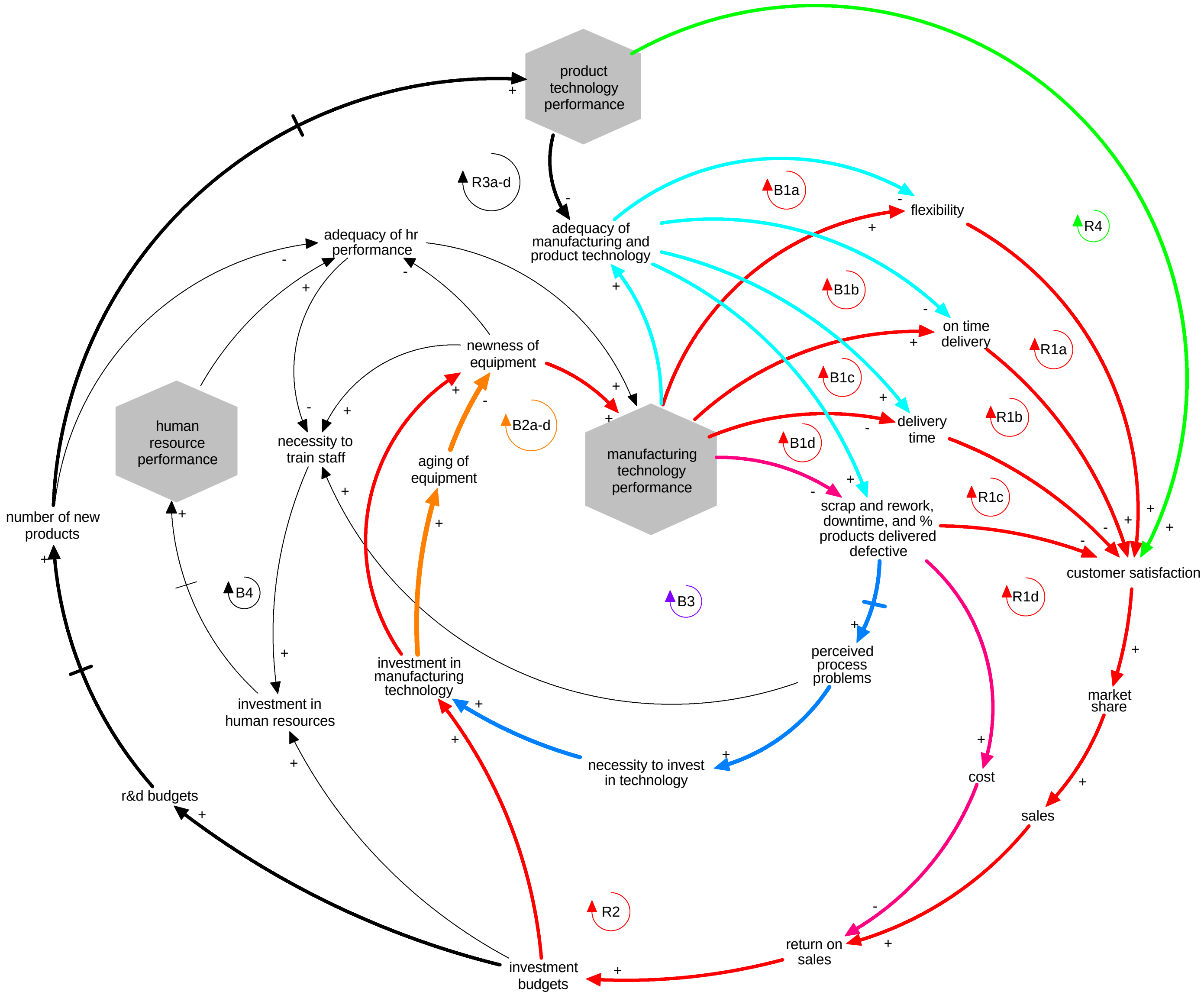

Figure 2: Feedback around manufacturing technology

This solely feedback-oriented analysis of driving and regulating forces in a plant's technological system strongly indicate the importance of the necessary next step: the development of a simulation model to generate the time behavior of the system and to really understand the dynamics of technological strategies and limiting and driving forces. Nevertheless, already this—in comparison to the statistical analysis—more comprehensive view, shows that technology in World Class Manufacturing has no end in itself. Beyond that, additional effects such as the performance and adequacy of human resources and the technology area are assumed to be important and also show statistical evidence. Products, manufacturing processes, and supporting information technology as well as the performance of human resources have to „fit" together. Without skilled employees, growth processes initiated by the technology strategies are most likely to fail from the very beginning.

CAN WE LEARN FROM EACH OTHER?

As shown before, the two approaches to investigate whether technology is a critical success factor in the manufacturing area, are different to a large extent. However, in retrospective the question arises, whether both approaches can contribute from each other. This question will be answered in the following.

Since the aim of the project is formulating a theory of world class management practices, it has to be as general as possible. Otherwise there is the risk of inductive reasoning based from a single or only a few cases to a general sentence. (see Popper 1966, who is claiming that logically acceptable inductive reasoning is not possible). From this point of view, it is necessary to formulate the theory on the basis of a representative sample and not only single cases. This is to some extent a different approach than traditional system dynamics modeling, starting with a client's problem and trying to solve it through the process of modeling and simulation. However, to formulate a theory of world class manufacturing one has to go far beyond static statistical analysis since it is a highly dynamic phenomenon. Considering this, it is only consequent to use system dynamics to support the formulation of a dynamic theory of world class manufacturing.

In this sense, the data empirical data base can be very helpful for several reasons:

- the data can be used for model parameterization,
- and for investigating hypotheses about causal relationships between variables.

Nevertheless, it has to pointed out, that correlation between variables does not necessarily mean that there also is causality and vice versa (see Richardson and Pugh 1981 for a more detailed discussion and potential pitfalls of interpreting the results of statistical analysis in the context of system dynamics modeling). In addition, the design of the questionnaires made reliable and valid measurement of soft variables like commitment, pride in work, etc. possible. This has to be seen as a strong support for the conceptualization of a general dynamic model of world class manufacturing practices and their importance for the performance of plants.

Since the Industrieseminar of the University of Mannheim joined this project in an advanced stage, this caused some limitations to the study described here and being continued. They will be explained briefly. From the very beginning on, the World-Class-Manufacturing-project was conceptualized as a purely empirical research project, concentrating on cross sectional data collection. Almost no longitudinal data have been collected. This limits the possibilities to analyze the dynamic changes in the plants in the sample. Beyond that, a system dynamicist would have asked other and additional questions. Ideally a general model of the theory should be formulated first, then the questionnaires should be designed and the broad data collection should be done. These data then can be used more effectively to investigate the assumptions about the interrelations. This model-driven data collection is clearly the preferable way. Data-driven analysis often leads to an overload of information. Not rarely, only a limited percentage of these information really is useful, and it sometimes turns out, that really relevant information is not available. This is the major contribution the field of system dynamics can make to empirical research: Using a dynamic model of all the logically and intuitively deduced interrelations between variables, to ask questions that really matter and not collecting data for its own sake.

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