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Conference paper

Management of process innovation—the case of FMS: a systems approach†

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The objective of our research is the development of management methods for the effective introduction of new production processes into companies. To support this a descriptive model of process innovation has to be developed. In this paper we will present the framework of such a model and discuss the theoretical and practical implications in the light of data collected in case-studies of the introduction of Flexible Manufacturing Systems into Dutch and British firms.

1. Introduction

1.1. *Backgrounds*

The development of micro-electronics allows production organizations to meet changing market demands with respect to flexibility and quality, while maintaining efficiency. The introduction of micro-electronics based technologies, however, is a radical and complex intra-firm innovation process, calling for (Bolwijn *et al.* 1986) and causing (Krabbendam and Willenborg 1986, Willenborg 1987) fundamental changes in the production organization.

We have restricted our research to the introduction of Flexible Manufacturing Systems (FMS). An FMS is a group of NC machines or other automated workstations which are interconnected by a materials handling system. All of the machines and the work handling system are controlled by computer (Groover and Zimmers 1984). FMSs are designed to fill the gap between high-production transfer lines and low-production stand-alone NC machines. Their main advantage is that demands for flexibility, quality and efficiency can be met simultaneously (Groover and Zimmers 1984, Hartley 1984).

1.2. *Problem*

The introduction of FMS is a protracted process full of uncertainties. FMSs are expensive and advanced systems. Some of the benefits and costs to be expected are readily quantifiable, others are very difficult, using conventional investment selection methods. Insufficient technological knowledge causes a lot of problems. The uncertainties are enlarged by the duration of the innovation process. Most problems however are caused by lack of insight into the organizational conditions for and consequences of FMS (Krabbendam and Willenborg 1986, Willenborg 1987). Due to these factors companies appear to have difficulties in the effective introduction of FMS. Our research relates to this latter problem.

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In the literature, indeed, general guidelines for the management of process innovation can be found (Gerwin 1982, Hayes and Wheelwright 1984, Bolwijn *et al.* 1986), but for the day-to-day innovation management more detailed insight is needed into the true nature of process innovation. Yet, most innovation process models are based on product innovations. Only a few literature sources describe process innovation models. Moreover, most available models describe process innovation as a sequence of activity-stages. This kind of model does not contribute enough to our understanding of the innovation process as will be shown later. Management methods used with innovations like office automation and Manufacturing Resource Planning, equally show little promise. A considerable number of literature sources report failures during or after the implementation of such innovations.

1.3. *Objective*

As theory and practice provide little insight into the nature and manageability of process innovations, a general model has to be developed which not only accurately describes the innovation process but also lays the foundation for the development of innovation management methods, the final objective of our research. In this paper we will present the framework of such a model and discuss some of its implications in the light of data collected in eight case-studies of the introduction of FMS into six Dutch and British firms. For the development of innovation management methods our data need more detailed analysis. Probably more cases need to be studied as well.

2. Research design and method

Our study is part of a broader programme of research into the effective introduction and operation of flexibly automated production processes. As stated above, the objective of our research is the development of methods to manage process innovation effectively. An important step is the development of a descriptive model of the innovation process. In doing so we assume that the systems approach offers a fruitful framework for the description and analysis of empirical reality (De Leeuw 1974). Further we think that, analogous to the management of production systems, at least some insight is needed into specific features of the innovation process to be able to manage it effectively (During 1984).

First, we will present the theoretical framework of our process innovation model, suggesting that the structure of the innovation process is determined by contingency variables, characteristics of the innovative activities, and choices exercised by those organizational members who are dominant in deciding on new processes.

Next, we will present data collected in eight longitudinal case-studies of the introduction of FMS into three Dutch and three British firms. The objectives of these case-studies were:

(*a*) to find out whether our model describes empirical reality well;
(*b*) to determine bottlenecks encountered during process innovation; and
(*c*) to lay the foundations of innovation management methods.

The main tool we used in our research was semi-structured interviews with several employees (managing director, process planners and other staff members, and (future) FMS operators). Among the main topics covered in the interviews were:

(*a*) information about markets, number of employees, structure, etc;
(*b*) company policies towards competition and market environment, organization and technology;

(*c*) manufacturing information about products, resources, etc;
(*d*) consequences of the FMS for work, structure and personnel; and
(*e*) the innovation process: innovation goals, project team, decision-making, stages, bottlenecks, etc.

Further, we used document studies (company reports and handbooks, organization charts), participant observation (membership of project teams), individual data feedback to the interviewees, and conferences to confront the sample firms with each other.

We will conclude this paper with a discussion of our model and derive some preliminary recommendations for the management of process innovation. A main conclusion will be that our approach might be a powerful instrument for further research into process innovations.

3. Towards a contingency model of the innovation process

3.1. *Introduction*

Innovation is the realization of a new product-market-technology-combination (During 1984). Innovation management consists of goal formulation, structuring the innovation process, monitoring the process and, if necessary, readjusting the structure and/or the innovation goals.

Child (1984) argues that a considerable amount of management control is inherent in the structure of organizations. We think this applies to innovation management as well, so we will restrict ourselves to the structuring of the innovation process as an important means of control. In this section we will describe the innovation process and innovation management from a systems point of view, adopting an approach which has earlier been proposed by Kickert (1979).

First, we will define what we see as the structure of the innovation process and argue that most innovation process models found in the literature describe only a part of this structure. Secondly, we will indicate the influence of contingencies, specific features of innovative activities and managerial choices on the structure of the innovation process and suggest that an appropriate model should take these factors into account. Finally, we will show that a model, developed by During (1984), is more complete with respect to both structure and the influences mentioned, though some adaptations must be made.

3.2. *Innovation: a control perspective*

According to De Leeuw (1974) any interesting phenomenon can be modelled as a control configuration, which consists of a controller, a controlled system and an environment. Control is any form of directed influence of the controller on the controlled system.

Controlling or managing innovation is different from carrying out innovative activities. During the innovation process actions are taken that influence the organization: the innovation process is a control process itself. This kind of control is called *object control*. Innovation management involves the control of the innovation process. This mode of 'controlling the controller' is called *metacontrol* (Fig. 1).

This configuration suggests that the individuals who carry out the innovative activities do not control the innovation process. In practice most innovation processes are intrinsically controlled by (a group of) people who not only perform but also

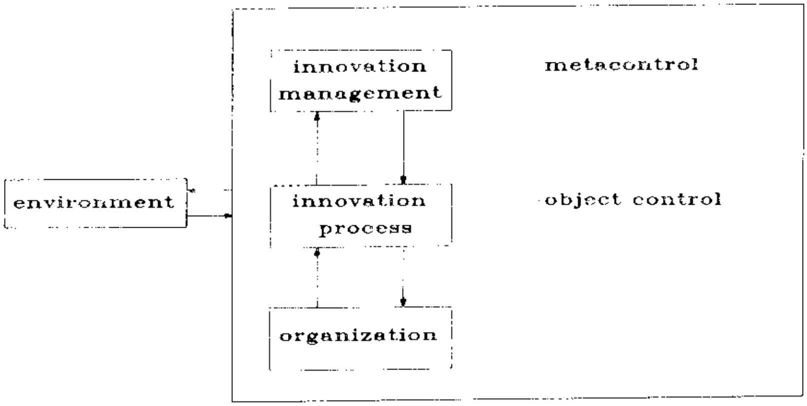

Figure 1. Innovation management: a control configuration.

manage the innovation process and often even perform operational tasks in the standing organization.

According to De Leeuw (1982) an effective controller must have: (*a*) a goal; (*b*) a model of the controlled system; (*c*) information about the environment and state of the controlled system; (*d*) adequate control actions; and (*e*) sufficient information processing capacity. These conditions for effective control have different meanings on the distinct levels of control: an effective innovation manager has another goal and model, and needs other information, control actions and information processing capacity than an effective innovator. The Table provides some samples.

Condition	Metalevel innovation manager	Object level innovator
Goal	structure, effectivity and efficiency of the innovation process	innovation goals: lower costs —product differentiation
Model	innovation process	organization
Information	production, regulatory and maintenance processes; other innovation processes	intra-organizational environment of the new technology
Control actions	project organization, setting innovation goals, making money and time available, implementation of roles	restructuring the organization and adjusting a potential FMS to the organizational structure
Information processing capacity	incorporated in metacontroller (e.g. top management) and available through the object controller	incorporated in project team, certain roles, external expertise; simulation programmes

Examples of the conditions for effective control on the object level and metalevel of control.

Whether the conditions for effective control will be sufficient depends, in the case of process innovations, on:

(*a*) the manageability of the innovation process and the organization the innovation is implemented into; and
(*b*) the capabilities of the innovation manager and the innovator.

In this paper we restrict ourselves to the structuring of the innovation process as an important means of control. For that purpose we consider the innovation process as a system. A system is defined as a set of objects, a set of relations between all these objects and an environment, consisting of objects that have relations with the system. A subsystem is a subset of the objects with all the original relations between these objects. An aspect-system is the original set of objects with only a subset of the relations. A phase-system is identical to the original system only during a certain time interval. The part systems of the innovation process can be understood as follows (c.f. Kickert 1979):

(*a*) subsystems: which groups, departments are involved?
(*b*) aspect-systems: which activities can be discerned?
(*c*) phase-systems: which phases can be distinguished?

The structure of the innovation process is the set of relations between:

(*a*) subsystems: interactions, communication
(*b*) aspect-systems: independent and related activities
(*c*) phase-systems: what is the sequence of phases?
(*d*) aspect- and subsystems: who does what?
(*e*) phase- and subsystems: who acts when?
(*f*) phase- and aspect-systems: what is dealt with when?

Structuring the innovation process involves defining the part systems and the relations between these systems. An appropriate model of the innovation process should thus describe which people (should) perform which activities during which phases: 'who' is doing 'what' and 'when' (Kickert 1979).

Using a classification of models of the intra-firm innovation process (Saren 1984), it becomes clear that most models describe only a part of the structure. Activity-stage and decision-stage models describe the relations between the aspect- and phase-systems of the innovation process. Departmental-stage models describe the relations between sub- and phase-systems. Conversion process and response models consider the innovation process as a blackbox and provide little insight into the structure of the innovation process. So, most innovation process models are inadequate in the light of the above mentioned conditions for controlling the innovation process.

A useful model should not only give insight into the structure of the innovation process, but also enlighten how this structure is formed or changed. The structure of an innovation process is a result of *strategic choices* exercised by management. Different responses of management to similar problems (efficiency, quality and/or flexibility need to be improved) cause different innovation goals and differences in the perception of the innovation (Bessant and Grunt 1986): is the new technology and it's organizational impact regarded as complex or simple, radical or incremental, decomposable or not, strategic or tactical? The actual choices depend on the way managers assess (the influence of) *contingency variables*. Main contingencies are the technical applicability and compatibility, the profitability and relative advantage of the new technology, organizational size and structure, availability of and access to financial, information and specialist resources, and market and competitive environment (Nabseth and Ray 1974). The design space for management is further restricted by *intermediate variables* like the complexity, diversity, interdependency and predictability of innovative activities. These characteristics may change over time, asking for different kinds of organization in the course of the innovation process. E.g.: idea generation requires an organic structure, adoption and implementation demand a more mechanistic structure (Daft 1978).

These theoretical considerations show that a suitable model of the innovation process should describe the relations between contingency variables, intermediate variables and strategic choices on the one hand, and structural variables on the other.

3.3. *A contingency model of innovation processes*

Starting from the hypothesis that the specific features of the innovation process will for a great deal determine the possibilities of control, During (1984) has developed a model of the (product) innovation process in small industrial firms. According to this model the innovation process consists of three part processes: problem solving, internal diffusion and organizational change (see Fig. 2).

Problem solving is a cyclical process consisting of the creation, selection, design and application of a solution(s) to the problems that 'forced' the organization to innovate. These phases may be passed through several times. *Internal diffusion* consists of

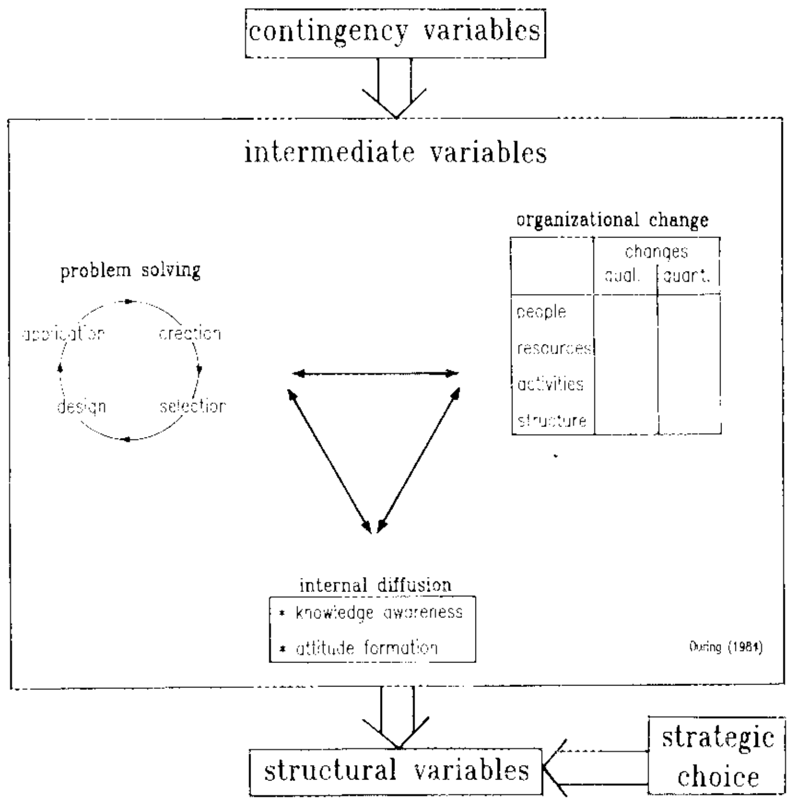

Figure 2. A contingency model of the innovation process.

knowledge awareness and attitude formation. *Organizational change* relates to qualitative and/or quantitative changes in people, resources, activities and structure.

According to this model bottlenecks may be expected if:

(*a*) The part processes are not adjusted to each other and to organizational characteristics: if members of a project team have a negative attitude towards a potential innovation, problem solving might interrupt; the innovation must fit the organization, else organizational changes must be carried through.

(*b*) Certain roles are not fulfilled: besides a number of roles well-known from the literature, During (1984, 1986) designates:

1. the (re)organizer, who plays a role in initiating, realizing and consolidating organizational changes; this role relates to the management of the innovation process as well as to organizational changes needed as a consequence of the innovation;
2. the integrator who has to achieve a balanced attention for different innovation problems (if several innovation problems are being solved simultaneously) and can play a role in mutually adjusting the part processes of the innovation process; this role refers to the management of the innovation process; and
3. the scout, whose mission it is to survey a specified, yet insufficiently known region by gathering specific information.

(*c*) In shifting from one stage of the problem solving process to another, internal diffusion, problem solving activities to be performed, and organizational characteristics are not mutually adjusted.

(*d*) The working style of the organization is not innovative.

This model is important for a number of reasons:

(*a*) It provides detailed insight into the activities (to be) performed during the innovation process, and the relations between (clusters of) activities, (clusters of) people and, though less explicitly, phases (clusters in time): who is doing what and when during the innovation process.

(*b*) It is a contingency model of the innovation process: characteristics of the organization and of the three part processes influence the kind of bottlenecks the organization will meet in the course of the innovation process.

(*c*) It pays explicit attention to the part process of organizational change, not only as a prerequisite for the innovation process to be successful (metalevel), but also for the innovation to be effective and efficient (object level).

In summary (see Fig. 2), we think that a considerable amount of innovation management consists of the structuring of the innovation process. The design space for managers however is constrained: if there is lack of consistency among the contingency variables, characteristics of the innovative activities and the structural variables, bottlenecks will occur in the progress of the innovation process. To be able to structure effectively, at least a model of and information about the innovation process and its environment are required. For the innovation to be effective, other conditions must be fulfilled (see Table). The model developed by During (1984) is more appropriate than other innovation process models. It pays attention to the influence of the specific features of innovative activities and of organizational characteristics on the structure of the innovation process on both levels of control: which people (roles) should perform which activities (problem solving, internal diffusion, organizational change) in the course of the innovation process (adjustment of the part processes). Other literature (Bessant and Grunt 1986, Nabseth and Ray 1974) shows that besides organizational dimensions other contingency variables (e.g. characteristics of the innovation, environmental dimensions) are supposed to influence the structure of the innovation process.

4. Case-studies: some results

In this paper we can only describe the most common similarities of the eight innovations we studied. Successively the progress of the innovation process, the influence of contingency variables, and the main bottlenecks are treated.

4.1. *The innovation process*

The problem solving process consists of two main cycles. The *first cycle* starts with the formulation of the motives for innovation, in all cases the need to replace present machining tools because of technical or economic aging and/or the introduction of a new range of products. Constraints (in the form of operational goals) are set to eventual solutions to the innovation problem and ideas are generated to solve the problem (*creative phase*). The main operational goals appear to be: reduction of manufacturing lead time, delivery time and in-process inventory by increasing production flexibility, and reduction of direct labour. Next, potential solutions are selected (*selection phase*), elaborated (*design phase*) and evaluated by simulation or otherwise (*application phase*).

The *second cycle* starts with the choice of the technology to be applied, in all cases FMS. The FMS is specified and potential suppliers are chosen (*creative phase*). After the evaluation of their offers the ultimate supplier is selected (*selection phase*) and ordered to develop the system according to specifications (*design phase*). Finally the developed system is built up, tested and debugged at the supplier's site, and transported to and installed at the purchaser's site (*application phase*).

So far it seems that the innovation process does not differ much from the description of activity-stage models found in the literature. There are some main differences.

First, the distinct phases in the problem solving process are cycles themselves. The definition of the specifications, e.g. is a problem itself, which is solved by the creation of ideas about the design of specific parts of the FMS, the selection of possibilities which need further elaboration, and finally the evaluation and choice among the elaborated ideas.

Secondly, during problem solving an internal diffusion process of knowledge awareness and attitude formation can be observed resulting in a positive attitude towards the FMS with all employees we interviewed.

Thirdly, and most important, during the innovation process important organizational changes are carried through. Two kinds of changes are worth mentioning here. In all firms top management installed a project team. The task of the teams was to solve the innovation problem felt within the organization: the introduction of new machines, by which throughput and delivery times, work-in-progress and direct labour could be reduced. In all project teams technicians dominated, the project leader always being a process planner. For the development of the FMS (second problem solving cycle) often a joint project team of purchaser and supplier was formed. In order to operate the FMS effectively and efficiently, i.e. meeting the goals with respect to costs and flexibility, major organizational changes were carried through. We will not describe these changes exhaustively, but refer to

Krabbendam and Willenborg (1986) and Willenborg (1987). Their conclusions (based on the same empirical data) indicate that, to achieve the advantages of FMS, a flexible organization is required: low degree of specialization, formalization and centralization, use of liaison devices, and well trained personnel. In all cases this last kind of organizational change actually took place *after* the installation of the system.

4.2. *Contingency variables*

Our data do not show the influence of contingency factors on the structure of the innovation process unambiguously. Managerial choices, which will be dealt with later, seem to be more important. In the cases we studied, the main contingencies were:

(*a*) Legislation: the British trade unions are more involved in decision-making on process innovation than the Dutch.
(*b*) The company's structure: FMS demands a product based manufacturing organization; those firms which have a process based structure must carry through a relatively more complex reorganization in order to fit the organization to the technological demands.

4.3. *Bottlenecks*

All firms encountered insufficient technological knowledge, mainly with respect to fixturing methods, (system) software and system control, both within the firm and with the supplier. Considering the sophistication of this new technology this was not surprising. It however caused inadequate specifications and feedback loops during problem solving, close co-operation of supplier and purchaser from system development through installation, and considerable delay of the innovation process. Another problem is the justification of the system. Qualitative advantages such as shorter lead times and improved quality are hardly quantifiable, as are reorganization and training costs. Most firms needed considerable government grants to meet demands with respect to pay-back-period and net-cash-flow.

The main bottleneck however seems to be the integration of the new technology into the organization. This is mainly due to management's perception of the innovation problem. In most cases the introduction of FMS was perceived as a technical problem only: management did not recognize the radical implications of such a complex and expensive system for the people, resources, activities and structure of operating and regulatory processes (Krabbendam and Willenborg 1986, Willenborg 1987). As a consequence:

(*a*) Certain roles, such as the reorganizer, were not implemented; only one firm, which installed three FMSs, supported the introduction of the new technology indirectly by a strategy towards improvement of the quality of working life (operators' job enrichment, higher level of education).
(*b*) Although the reduction of throughput time and work-in-progress were main operational goals, in none of the cases was the logistics function represented in the project team, nor were other key functions, like the maintenance and personnel functions, involved in preparing for and deciding on flexible manufacturing.
(*c*) The project teams only had a narrow understanding of the organizational conditions for and consequences of the FMS; organizational change really was ill-structured.

(*d*) Most organizational changes took place after the installation of the system, when the organization discovered the need for changes, not only in resources, but in people, processes and structure as well, in order to gain full profit of the advantages of FMS (see Krabbendam and Willenborg 1986, Willenborg 1987).

In all cases the installation and evaluation of the system lasted longer than expected, the production volumes being lower than anticipated. Whether the operational goals will be achieved in the long run is not clear yet.

5. Discussion

As we expected, the introduction of FMS is a rather cyclical than linear process of problem solving attended with organizational changes (to enable the innovation process to proceed and the FMS to be integrated into the organization) and an internal diffusion process of knowledge awareness and attitude formation.

The structure of the innovation process ('who' is doing 'what' and 'when') mainly seems to depend on management's perception of characteristics of the FMS and it's impact on the organization. In all cases management underestimated the organizational conditions for and consequences of the effective introduction and operation of FMS. Due to this:

(*a*) problem solving was well-structured but not consciously adjusted to organizational characteristics; the members of the project teams were chosen because of their knowledge and abilities with respect to production technology; other key functions (logistics, maintenance, personnel) were not involved in preparing for and deciding on flexible manufacturing. Additionally,
(*b*) organizational change, needed to adjust the FMS and the existing organization, was hardly structured; the role of the reorganizer was not implemented; the changes mainly depended on 'coincidence'.

Internal diffusion does not seem to cause problems. We did not find any worker opposition towards the FMS. We are not sure what would have happened if more FMSs had been installed or if the FMSs would have had more impact on, for example, employment.

Our model not only forms a suitable framework for the description of process innovations. It also provides insight into the bottlenecks to be expected during the innovation process: if management does not make the right choices with respect to the structure of the innovation process *on both levels of control*, problems in the progress of the innovation process and the achievability of innovation goals may be encountered. During an effectively structured innovation process the part processes are continuously adjusted to each other and to contingency variables. To be able to structure effectively, (top)management should have a model of and information about the state and environment (contingency variables) of the innovation process (metalevel) and the organization (object level) the innovation is implemented into. As most organizations do not have such models and information readily available, they should take more time preparing *for* instead of problem solving and reorganizing *after* implementation. Most important is that *management should not underestimate the organizational conditions for and consequences of the effective and efficient operation of FMS*. A flexible organization is a prerequisite for the achievement of lower costs and increased production flexibility. This means that the introduction of FMS should not be perceived as tactical decision-making, to be handled at a lower point in the organization by production engineers or supervisors (Bessant and Grunt 1986). It is an organizational problem, and object of strategic and integrated decision-making in which all production functions should be involved, managed by top management itself.

6. Conclusion

We performed only eight case-studies, so our conclusions are only preliminary. A lot more needs to be done before we will be able to exactly determine how process innovation should be managed and structured in order to achieve effective and efficient new processes. The process innovations we studied were first of all meant to replace present machining tools. All innovations were successful in that sense. Only after implementation did the firms discover the need for radical organizational changes to gain full benefit of the new system. The question remains whether these firms, if eventually innovating other processes, will appear to have learnt from this first project and be more successful in terms of quicker, more efficient, more integrated and better managed innovation processes which result sooner in effective and efficient innovations.

With Bessant and Grunt (1986) we think that, to fill the gaps in our knowledge of such complex topics, the case-study approach, despite the disadvantages that go with it, is highly valuable. More research, using multiple tools as we did, should be specifically aimed at what really happens within firms during process innovations. Our results show that, despite the small number of cases, it thus indeed is possible to better understand the innovation process.

Acknowledgements

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Notre étude a pour objectif la mise au point de méthodes de gestion destinées à une introduction efficace de nouveaux processus de production dans les entreprises. Il convient pour cela de réaliser un modèle descriptif d'innovation de processus. Nous présenterons dans cet article le cadre d'un tel modèle et nous examinerons les implications théoriques et pratiques à la lumière des données rassemblées dans des études de cas portant sur l'introdution de systèmes de fabrication flexible au niveau d'entreprises des Pays-Bas et de la Grande-Bretagne.

Das Ziel dieser Untersuchung ist die Entwicklung von Methoden, mit denen die Unternehmensleitungen neue Produktionsverfahren in ihre Firmen einführen können. Als Hilfsmittel für die Untersuchung wurde ein Modell entwickelt, das den Verfahrens-Innovationsvorgang beschreibt. In der vorliegenden Arbeit stellen wir das Rahmenwerk eines solchen Modells vor und besprechen die theoretischen und praktischen Auswirkungen auf Grund der Daten, die in Fallstudien der Einführung flexibler Fertigungssysteme in holländischen und britischen Firmen gesammelt wurden.