Chapter 5

Time Factor in Operation Research Tasks for Smart Manufacturing

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Additional information is available at the end of the chapter

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Abstract

The shift to the concepts Industry 4.0 and IIoT helps collect a vast amount of objective data about processes that take place in a production system, and thus, it creates background for taking advantage of theoretical results in practice; it is a trend towards synchronizing production system processes and external (market) processes in practice. In order for the target to be achieved, we use the methods that formalize management tasks in the form of predictive models, consider the cases with the computational solution of management models and decision making in production system tasks which are set based on time factor and are solved by approximate methods. We also take a look at the problems of probabilistic nature of gained decisions and address the cases, when by computational solution of tasks we need to take into account restrictions and select time step in order to obtain the decision in a table form of the function of time. The problems that we investigate help obtain and solve management tasks of production systems with help of forecasting data for a group of indices that are involved in decision making – this all helps enhance the sufficiency and quality of management decisions.

Keywords: production system, smart manufacturing, Industry 4.0, management, operation research, scheduling

1. Introduction

Presently, the information support of production systems management is mainly focused on the control and management of production systems (SCADA), the support of sales and production process (ERP, MRP, Just in Time), organizing production for known customers (CSRP), and product life cycle management (CALS). However, the aspects of tactical and strategical management get information support only on the stage of data preparation for decision making, yet on the stage when potential solutions are to be identified based on data we observe lack of information support. The integration of automatization and control systems, the trend towards Industry 4.0 and IIoT leads to an exponential growth of collected data. Hence, on the one hand, it can be expected that the use of big data might help obtain fundamentally new solutions due to their immense nature, but on the other hand, the issues of decision support automation become more acute as we face the trend of an ongoing automation expansion of production systems, and hereafter, can assume a concept of a virtual factory.

The use of the concepts Industry 4.0 outlines possibilities for the automation of production systems management taking into account the interaction of subsystems and the synchronization of their interaction with external factors. In the age of cutting edge innovation products we cannot talk about the stability of production processes since life cycle of such products is short, the number of modifications and parts is high, and power intensity and resources consumption is much higher. This proves the necessity of collecting reliable information with help of IIoT. The presence of such data helps build predictive models and use preventive control actions as production system is an inertial management object that is not able to adjust the ongoing processes instantaneously. Besides, the change of processes requires additional time resources, financial resources, labor competence, and organization resources.

The implementation of the concepts Industry 4.0 and Industrial Internet of Things [that deals with collecting information about each production unit and provides operation management over production processes in PS] [1] opens new possibilities for developing industrial engineering methods [2].

Taking into account long decades, when production systems were examined only on the basis of general data, data engineers had limited data to develop methods for decision making and took advantage of expert evaluations, i.e. the methods of utility theory (considering customer preferences as maximization of expected utility, probability models (see the works of O. Morgenstern), axiomatic theory of D. Savage that enables measure the utility and subjective probability simultaneously; decision tree approach that partitions the tasks into certain subtasks (look the works of H. Reif); multiple-criteria utility theory (developed in the works of R. Keeney); prospect theory methods, Electre methods (worked out by the French School on MCDA headed by B. Roy), hierarchy analysis method proposed by Saaty [3], heuristic methods (for instance, the method of the weighed sum of its evaluation ratings, compensation methods etc.), the models of bounded rationality by A. Rubinstein, the technic for order of preference by similarity to ideal solution (TOPSIS) [4].

The appearance of a big amount of statistical data encouraged the development of the methods of mathematical formalization used to solve tasks for the management of materials, parts, operations, and choice of suppliers [5] with the consideration of stochastic factors, probability approaches to measure risks taking into account different nature of examined events (joint, correlative, inconsistent and interdependent) used to solve planning tasks taking into account the dynamics of examined processes.

The consideration of random factors and the use of probability approaches help measure risks with help of models. There are planning risks (the risks related to decision making based on models [6] that depend on the current state of market (change in price, sales volumes etc.)) and production risks (the risks related to equipment mortality, failures in the delivery of necessary materials or parts etc.).

The use of probability models is based on the use of risk metrics [7], Bayes' Theorem [8] or Monte-Carlo Method [9].

2. Methodology aspect of management task setting in production systems

Production system is regarded as management object that is placed in a state space. The coordinates on this n is the dimensional space are represented by the management parameters that are considered significant for achieving the targets, and their values describe the current state and remoteness from the selected targets.

If we mark target goal indexes by the vector P_p, and the current state by the vector P_a, we will receive a mathematically measurable metric (P_p, P_a) that shows how the current position deviates from the goal position that is deemed a sign of progress for project implementation (the end of implementation, $P_p = P_a$). However, to know the metrics (P_p, P_a) is not enough for management, we also need to know the vector of the parameters Y that greatly affect the state of project and consist of the values that describe project, production system and the environments in which project is implemented as well as dynamics of change and prognostic values of all these parameters. It should be noted, that the achievement of the goal values $P_p = P_a$ does not always mean the achievement of the vector values Y expected for this state.

In management tasks values and parameters can be classified in four groups [10]: parameters and values that describe a current state $P_p^{(i)}$, values and parameters that describe the action (external factors and control action – $Y = A \cup \Theta$, the A is the set of control actions, Θ is the set of environment values), values and parameters that describe a goal state $P_a^{(i)}$, values and parameters that describe the output of system operation by shifting from the state $P_p^{(i)}$ into $P_a^{(i)}$ - R and time $T^{(0)}$.

Therefore, management has to use an automaton where the consecutive state is defined by experts based on the current state and the state that was planned to be achieved on the previous stage and the time when it has to be done – $\left(P_p^{(0)}, P_a^{(0)}, T^{(0)}\right)$, $\left(P_p^{(1)}, P_a^{(1)}, T^{(1)}\right)$, …, $\left(P_p^{(n)}, P_a^{(n)},\ T^{(n)}\right)$. In order for a new state to come, action $A^{(i)}$ has to be defined. We can determine such action with help of the production system model that implements innovation projects $\varphi_j = \{U, S\}$, where U is the vector of management parameter, S is the set of project resource needs, j is project number.

This approach helps work out hierarchically coordinated managerial decisions by taking into consideration system-interrelated external and internal factors that interact. Management process is considered then as a holistic undetermined process.

In general, the model can be presented in a form of a tuple:

$$\psi = \{Y, P_p, P_a, T, R, \varphi\} \tag{1}$$

where $\varphi = \{\varphi_1, \varphi_2, \ldots, \varphi_n\}$ is the projects' vector, Y is the action vector on each step, R is the outcome vector on each step, P_p is the vector of system states, P_a is the vector of system goal states, T is the vector of decision points.

The use of the model (1) is described by an undetermined algorithm [11] see **Figure 1**.

As a result, management task becomes more transparent. However, it opens new sub-tasks, i.e. to determine decision points, to define the set of indexes and their values for each stage of project implementation, to build a model of production system by implementing the projects (φ) in order to define the vector of control actions Y.

At the same time, the more formalized is the description of tuple parts (1) (less ambiguity), the higher is the quality of management [according to system properties].

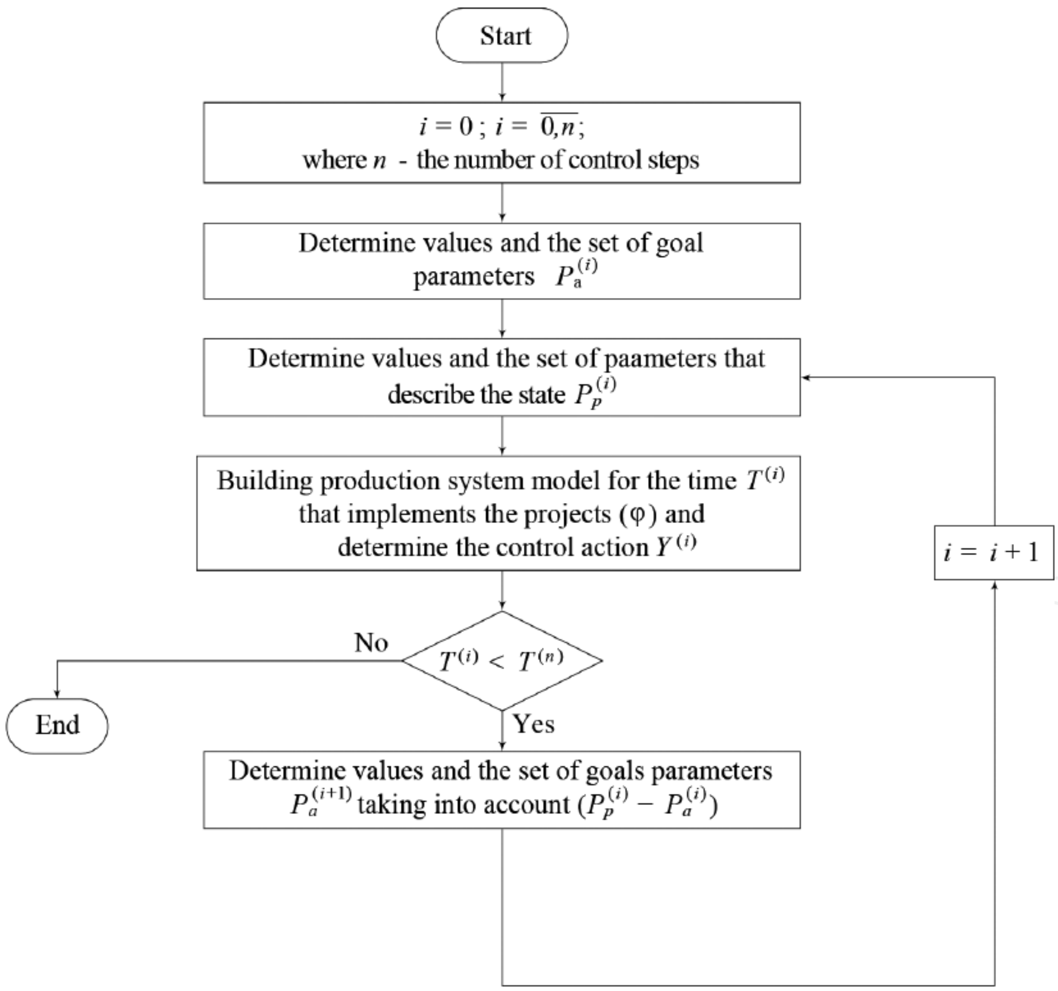

Figure 1. The algorithm to manage a production system that implements projects φ.

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Decision points can be defined in case if we know the set of controlled parameters [12], and have additional information that characterizes the production system that we manage (equipment maintenance periods, internal technological cycles etc.) [13].

The setting of management tasks taking into account time factor $T^{(i)}$ leads to formalizing the models $Y^{(i)} \to M^{(i)}\left(A; \Theta; \overline{T^{(i-1)}, T^{(i)}}\right)$. The structure of the model sets formal interrelations between its parameters, and on each step the type of the model will depend on the managerial task that we consider (whether we forecast properties and behavior of the investigated management project; or when dealing with object management we select best actions by testing them on the model, investigate the object and look for the ways to improve management object).

The model itself can use both non-causal (component-oriented) and causal (block-oriented) modeling, and model components can set requirements to their development tool (for example, the possibility to 1) work with big data volumes set by time series 2) use the methods that are applied for incomplete data 3) solve tasks set in a form of mathematical programming 4) employ methods to work with probabilistic models etc.).

The specialization of models $Y^{(i)}$ brings the problem of choosing approaches and ways for formalization based on the set of already known approaches, ways, methods and models [14] that will be collected as a composition (the compatibility of input and output areas).

For the implementation of each project in the considered production system, the model formation that is presented in a general form is as follows $\{R, \varphi, A, \Theta\} \to M^{(i)}\left(A, \Theta, \overline{T^{(i-1)}, T^{(i)}}\right) \to \left\{m_j^{(i)}(U, \mathfrak{P}, \Pi)\right\}$, where $\mathfrak{P}$ is the vector of external parameters that exert impact on the system, Π is the vector of system parameters, $m_j^{(i)}$ is the components or blocks of the model for time $T^{(i)}$).

Despite the apparent simplicity of the approach, underlying this approach is a necessity to work out managerial decisions taking into account different levels (institutional, managerial, technical) and management types (finance management, production management, goods management, launch management, sales management, R&D management, institutional management), and subsystems of production system – all of that generates a whole group of managerial tasks that have to be solved together for each time period $T^{(i)}$; the interrelation of the tasks is demonstrated in **Figure 2**.

Work with a model structure means that we need to consider several subtasks related to forecasting parameters of the considered project [15] and to formalizing an optimization task in a form of mathematical programming [16].

The examples of tasks that are considered in decision points can encompass the tasks of production and client analytics taking into account time factor, such as demand forecast and sales planning, volume planning, stock and procurement planning (including working life), equipment selection taking into account maintenance costs; these can be the tasks of optimizing stock work and minimizing the volumes of working assets, and obtaining optimal machine utilization and work force.

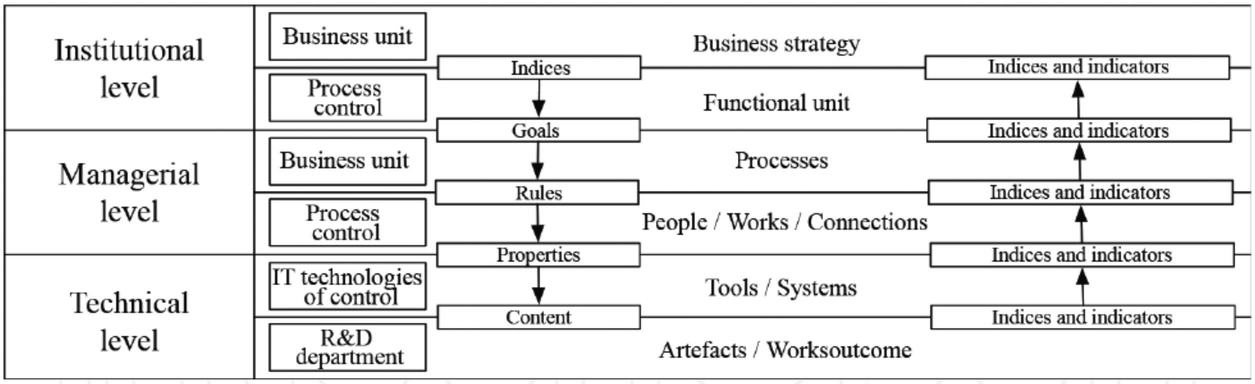

Figure 2. The interrelation of management levels and management tasks to be solved by using parameters and indicators for developing decision support models.

In this case, each of tasks can be described by a separate criterion; the use of a reflexive approach enables their joint solution as a set of optimization tasks that have common parameters and use forecast-based data.

3. Solving management tasks with help of predictive models

Let us now consider a general task of formalizing management processes for project implementation in PS. This task can be handled as a task of defining decision points and a cyclic solution of prognostic models that are represented by optimized formalizations based on forecast data and elaboration done on each step of processing data in order to make consecutive iterations with new data, and calculation results.

In order for the tasks to be formalized as tasks of optimal control, we have to input a set of indices, variables and parameters of management [9], for instance, like: i is the supplier's index; j is the index of production system/stock (PS); m is the part index or the demand in materials; n is the index of end item; k is the index of production operation; g is the index of machine or instrument; p is the index of operation; t is the time; x_{ijm} is the number of parts m received from the supplier i for PS j; y_{jn} is the number of parts n produced in PS j; r_n is the number of returned items n for utilization; o_m is the number of reused parts or materials m; d_m is the number of items or materials m sent to utilization; ref_{jm} is the number of reused items or materials m in PS j; bd_n is the binary variable that possesses the value equal to 1 in case if it can be repeatedly used for the item n and 0 if not; Δt is the time step; $sell_n$ is the item's market price n; $cost_{jn}$ is the item's production cost n in PS j; $price_{im}$ is the price of the part m received from the supplier i; $ship_{m/nij}$ is the delivery cost of the part/ item m/n from the station i to the station j; inv_j is the storage cost in PS j; $setdis_n$ is the preparation cost to get the parts out of the item n; $disa_m$ is the preparation cost to get the part m out for reuse; $disp_m$ is the utilization cost for the part m; $refcost_{jm}$ is the preparation/recovery cost of the part m for reuse in PS j; $dem_{(j)n}$ is the need/demand in the item n, if there is the index j the consumer get then j; req_{mn} is the number of requested parts m required for the production of the item n; $costeq_{pgj}$ is the cost of the operation p on the equipment g in PS j; $timeeq_{pgj}$ is the time of operation performance p on the equipment g in PS j; $part_{mpgj}$ is the demand in parts/materials m in order to perform the operation p on the equipment g in PS j; eq_{pgj} is the demand in the equipment g in order to perform the operation p in PS j; $supmax_{im}$ is the maximum size of the batch of the parts m that can be delivered from the supplier i; $supmin_{im}$ is the minimal size of the batch of the parts m that can be delivered from the supplier i; $supmaxpart_{jm}$ is the maximum potential number of parts and components m that can be delivered for production in PS j; $supmaxeq_{jp}$ is the maximum potential number of equipment units for the operation p in PS j; $reuse_m$ is the maximum percentage of the parts m that can be reused.

The approach described above helps state a set of optimization tasks that can be considered both, as joint and separate tasks. Let us give the examples of feasible task formalizations:

- Profit maximization (production planning for demand), $\left(sell_n(t) - \sum_j cost_{jn}(t)\right) \sum_j y_{jn}(t) \rightarrow \max, \forall n$;
- Production cost minimization, $\sum_p \left(costeq_{pgj}(t) + \sum_m part_{mpgj}(t) price_{mi}(t) + \sum_m part_{mpgj}(t) ship_{mij}(t)\right) \rightarrow \min, \forall g, j$;
- The minimization of costs for goods' storage, $cost_{jn} y_{jn}(t) + inv_j(t) y_{1jn}(t) + ship_{nij}(t) y_{2jn}(t) \rightarrow \min$, $y_{jn}(t) = y_{1jn}(t) + y_{2jn}(t)$, $y_{2jn}(t) \leq dem_{jn}(t)$, where y_{1jn}-the number of items stored in stock, y_{2jn} is the number of items sent to consumer;
- The selection of suppliers taking into account that certain components can be reused, $\sum_j \sum_n (sell_n - cost_{jn}) y_{in} - \sum_i \sum_j \sum_m \left(price_{im} + ship_{ij} + inv_j\right) x_{ijm} - \sum_n setdis_n bd_n \sum_p \left(costeq_{pgj} - \sum_m (disa_m\, o_m + disp_m d_m) - \sum_j \sum_m refcost_{jm} ref_{jm} \rightarrow \max\right.$.

The tasks can be subject to different restrictions:

- Production capacity restriction, $\sum_g eq_{pgj}(t) \leq supmaxeq_{jp}(t), \forall j, p, t$;
- The restriction related to delivery options of components and materials, $\sum_g part_{mpgj}(t) \leq supmaxpart_{jm}(t), \forall j, p, m, t$;
- Non-negativity restriction on the volumes of goods, orders etc., $y_{jn}(t), x_{ijm}(t), r_n(t), o_m(t), d_m(t), ref_{jm}(t) \geq 0, \forall j, n, i, m, t$;
- Demand volume restriction, $\sum_j y_{jn}(t) \leq dem_n(t), \forall n, t$;
- The description of technological process, $\sum_n req_{mn} y_{jn}(t) = \sum_i x_{ijm}(t) + ref_{jm}(t), \forall j, m, t$, $\sum_j ref_{jm}(t) + d_m(t) = o_m, \forall m, t$, $o_m(t) = \sum_n req_{mn}(t) r_n(t), \forall m$,t;
- The restriction on the volume of orders, $\sum_j x_{ijm}(t) \leq supmax_{im}(t) s_i(t), \forall i, m, t$, $\sum_j x_{ijm}(t) \geq supmin_{im}(t) s_i(t), \forall i, m, t$;

- The restriction on the volume of reused parts, $\sum_j ref_{jm}(t) \le reuse_m(t) o_m(t), \forall m, t$, $d_m(t) \le (1 - reuse_m(t)) o_m(t), \forall m$,t;
- etc.

The obtained tasks in their general form refer to a class of multi-parameter tasks with non-linear restrictions. In such tasks a part of parameters is set by time functions. The outcome of the solution of such tasks will be the function of time as well (by numerical solution in a table form). Since today we lack analytical methods to solve such tasks, we will build then the solution of this task on multiple cyclic determination of numerical solutions of a multi-parameter optimization task with the time period $\Delta t \le \min\limits_{i=\overline{1,n}} T^{(i+1)} - T^{(i)}$ that determines the accuracy of the description of the required function (see **Figure 3**).

Taking gradient calculation for finding solution was one of the first approaches to develop solution methods (gradient search method with the split of the step метод градиентного поиска с дроблением шага, steepest descent method, conjugate direction method, the Fletcher-Reeves method, the Davidon-Fletcher-Powell method). By these the goal function has to be differentiated two times and convex. The Newton's method and his modification the Newton–Raphson method is widespread. These methods also set the requirements to the goal function to be differentiated two times and be convex. Besides, these methods are sensitive to the selection of initial value. Moreover, in obtained optimization tasks we the cases can appear that are related with multiextremality, non-convex restrictions, multicoupling of the area of feasible solutions etc., and these methods cannot handle that appropriately. Modern methods can in general be split into three groups [17]: cluster methods, the methods of restrictions' distribution, metaheuristic methods. By choosing the solution method it is important to consider that the most significant feature of combinatoric optimization methods is their completeness and comprehension. A complete method ensures the finding of the task solution if it exists. However, the application of these methods can bring difficulties by a big dimension of search space, and we might not have sufficient amount of time that will be required for

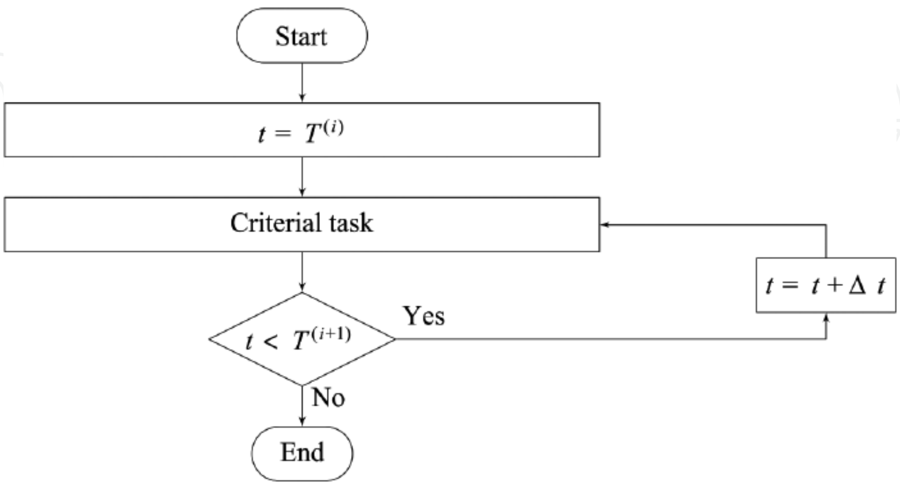

Figure 3. The scheme that clarifies the principle of defining calculation points (special states) by implementing projects in PS.

search in this case (for instance, due to time restrictions for decision making). If we use heuristic methods in task solutions, and heuristic elements complement combinatoric methods, it is getting more complicated to prove that the applied method is comprehensive. The methods of heuristic search are, in general, incomplete.

In practice hybrid algorithms are often used. Besides, the outcome of any algorithm work can be improved by building a joint solver. Due to the lack of specialized solution methods, for the obtained formalization we assume that we can use a developmental approach – the method of stochastic search. The drawback of developmental approaches is that in some cases the results and optimization time are dependent on the selection of initial approximation. This drawback can be eliminated by using as an initial approximation the solution that was worked out by experts. That is why, as a universal solution we suggest to use the method of stochastic search taking into consideration expert knowledge and indistinct preferences. However, in this case we need to direct attention to the fact that for some tasks we can obtain formalizations that already have methods of their solution. Hence, the decision about what method to apply should be taken dependent on the targets, i.e. how accurate the solution is expected to be and whether we have time restrictions for solution search (the methods of stochastic search can be limited in time required for solution search, which is crucial in integrated systems and IIoT that operate in real time).

In heuristic methods of random search we can distinguish two big groups: the methods of random search with learning and developmental programming [18]. In practical use the methods differ in convergence speed and the number of iterations required for search of a feasible solution (several methods, for example, genetic methods, ensure finding an extremal value, but not obligatorily an optimal one). The complexity of selection task is that the efficiency performance of certain methods of stochastic search (in particular, genetic algorithm) is determined by their parameters. As an example let us examine the application of the method of random search with inhibits (Pareto simulated annealing) [19]; along that, we take into account the set values, that were obtained by forecasting during the modification of task for work with restrictions. Before we start perform numerical calculation we need to determine the area for feasible solutions. The algorithm will consist in five steps and an additional sixth step; the latter step allows solve tasks with the restrictions set by functions and forecast values with the set accuracy and the criterion that can also use the values obtained by forecasting.

Let us now consider the search option of parameter values x_i, $i = \overline{1, N}$ as points in space B_i Let us assign Λ^{**} to the set of all points x_i, that comply with the task restrictions: $\Lambda^{**} = \left\{ x_i^{(j)} \in B_i^{(j)}, j = \overline{1, N^{**}} \right\}$ (that are included in the area of feasible values), where N^{**} is the capacity of the finite set $B^{(N)}$, N is the number of components in the vector of unknown quantities. Consequently, the algorithm has the following sequence of steps:

1. Set N^{**} is the requested number of points from the set Λ^{**} (N^{**} is the parameter of algorithm). Depending on the certain task, the value N^{**} can alter.

2. Find N^{**} points for each parameter $x_i \in \Lambda^{**}$, scattered in the spaces $B_i^{(N)}$ randomly or by the use of expert knowledge, and use these points as an initial approximation.

3. For finding the solutions $x_i \in \Lambda_{D_i}$ (Λ_{D_i} is the set of feasible points) apply one of the heuristic methods of stochastic search. For this purpose, the point $x_i \in \Lambda^{**}$ is taken as a base point, and based on this point we build new points belonging to Λ^{**} where the criterion values are better than in a base point. Even if one such point is found, its base is used then for finding new values etc., and next search is done. All the points found this way $x_i \in \Lambda^{**}$ make the set Λ_{D_i}.

4. All points $x_i \in \Lambda_{D_i}$ are studied for optimal factor, after that they are used to form an optimal set of solutions Λ_P. The required sets are easily recovered from the labels of criteria in spaces.

5. The selection of the singular variant $\widehat{X}$, where X is the vector $\widehat{X} = (x_1, x_2, \ldots, x_N)$, from the Pareto-set is submitted to an expert, that has additional information that has not been formalized and neither taken into account in the model.

6. For an operational reaction to altering external factors we should perform several iterations for task solution (by modeling the deviations of forecasting values within the confidence interval) and do that cyclically with the time period Δt.

As a result, we receive altering in time span (corridor) of potential solutions for each time period. At the same time, as several functions describe the parameters that are set by forecasts, where accuracy depends on the planning horizon, we can encounter the case, when the obtained values can fluctuate either towards the increase or the decrease. Such behavior will bring additional organization expenses for PS; however, it is possible to manage such behavior (smoothly adjust the altered values) by changing the dimension within the obtained corridors and the time step Δt (as a rule, such deviation is described by a stochastic variable that obeys normal distribution law).

In the result of the solution we can determine the diapasons and the values of the values that can be presented in a suitable way to the decision-maker (for instance, in a form of the Gantt chart that is so widespread in management) [20].

4. The generation of the area of feasible solutions by solving the tasks for optimal control of projects and production systems

By the implementation of management tasks as dynamic management tasks, where the solution is the function of time, it should be noted that the restrictions can also change in time. It happens as the characteristics of production system can alter in time, the changes can affect the schedule of supplies, the volume of resources allocated for the implementation of a certain project etc. The restrictions can be shown as follows:

$$m_1(t) </\leq M </\leq m_2(t), m_1(t) </\leq M, M </\leq m_2(t), M \in m_3(t),$$

where M is the parameter or an expression with imposed restrictions, $m_1(t)$ and $m_2(t)$ is the restrictions set by the functions of time, $m_3(t)$ is the area of feasible values can also alter in time.

The use of several criteria and a big number of restrictions often leads to the situation that we obtain an empty area of feasible values or the solution shows some deviations. In any case, in PS management tasks the final decision is taken by the expert. That is why, the restrictions can be presented by the functions $F(m_1(t), m_2(t), t)$ that can be represented in a form of additional criteria and used by performing the operation of criteria compression.

In case of discrete set values or if restrictions are set as an area of feasible values, the function $F(m_1(t), m_2(t), t)$ or $F(m_3(t), t)$ becomes piecewise-set. Hence, the values that belong to a feasible interval are maximum high by considering a maximization task, and the others become maximum low and vice versa by considering a minimization task. In general, for the consideration of all types of restrictions in one record the function can be written as $F(m_1(t), m_2(t), m_3(t), t)$. The membership with the area of feasible values can be validated then by calculating the value:

$$\sum_{i=1}^{n} F_i(m_1(t), m_2(t), m_3(t), t) \tag{2}$$

where n is the number of restrictions.

If this value is equal to the sum of minimal or maximal values $\sum_{i=1}^{n} \min/\max F_i(m_1(t), m_2(t), m_3(t), t)$ dependent on the type of the considered task (minimization or maximization), then it will belong to the area of feasible values. In practice, the restrictions can be considered not as stiff and we can determine the feasible deviation of values ($\mp \Delta$).

Such approach helps add restrictions to a criterial function as additive components that allows get rid of restrictions and apply for solution the methods that do not work with restrictions. Since restrictions can be destroyed in this case, so the obtained functions are to be ranged with help of weight coefficients K. As a result, we receive a final setting of the task for extremum in the following form:

$$J + \sum_{i=1}^{n} K_i F_i(m_1(t), m_2(t), m_3(t), t) \to opt, \tag{3}$$

where J is the criterial function.

5. The problems of obtaining solutions as functions of time

By solving tasks of optimal control taking into account time factor and some discrete time step Δt the solution will be a set function presented in a table form. In this case, the system interacts with the external environment and the found solution can be not achievable due to the changes of external or internal factors. According to Bayes' theorem [21] the probability of a successful transfer to another state (to a new solution) will depend on the previous state (the state that we are placed now). Hence, for selecting the path for project development it is useful to consider

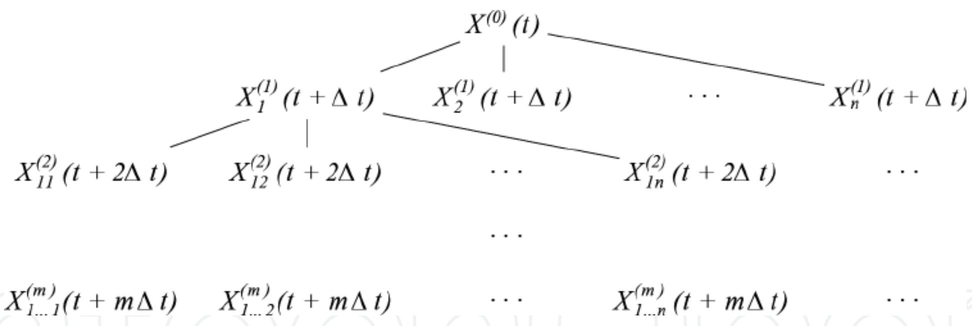

Figure 4. The tree of management task solutions taking into account time factor X is the vector of variable values received in the solution of an optimization task, $m\Delta t$ is the planning horizon, m is the number of task solutions, n is the number of solutions found on each step.

not just one solution, but a set of solutions that are Pareto optimal. So, the task solution will be a set of development paths that technically can be shown as a tree for each of the required parameter values (see **Figure 4**) that can be considered as Bayesian network.

The selection of a singular solution will be based on the choice of a path and on the potential of its implementation. The potential of each solution will be defined by chain rule [21]:

$$P\left(X^{(0)}, \ldots, X^{(m)}\right) = \prod_{j=1}^{m} P\left(X^{(j)} | X^{(j-1)}, \ldots, X^{(1)}\right). \tag{4}$$

Therefore, by the planning horizon in $m\Delta t$ and n solutions on each step we will obtain $\prod_{j=1}^{m} n$ probabilities for leaf nodes in the built tree that should satisfy the following conditions $\sum_{i=1}^{n} P\left(X_i^{(1)}\right) = 1$, $\sum_{i=1}^{n} \sum_{j=1}^{n} P\left(X_{ij}^{(2)}\right) = 1$, etc. for each solution step.

If we assume that all X are unique, then the implementation potential for each solution will be equal. However, in practice solutions can repeat. It is connected with the fact that we use the method of random search for solving a task; more than that, for modeling deviations we need a multiple solution of a considered task. In this case, the probability of a transfer from the state $X^{(0)}$ into the state $X^{(m)}$ will be determined by the sum of probabilities of repeated values, and this value will determine the probability of a transfer from one decision point to another one.

This probability will not be a random value since multiple calculations are performed, as parameters that are obtained based on forecast data can have random walk described by the functions of probability density; the latter ones are necessary to be used for generating new forecast values by multiple calculations.

$$\mu(x_1) = \frac{1}{\sigma_1\sqrt{2\pi}} e^{-\frac{(x-x_1)^2}{2\sigma_1^2}} \tag{5}$$

where σ_1 is the standard deviation, x_1 is the value obtained by forecasting. By a transfer to the consequent value the function will alter:

$$\mu(x_2) = \frac{1}{(\sigma_1 + \sigma_2)\sqrt{2\pi}} e^{-\frac{(x-x_2)^2}{2\left(\sigma_1^2+\sigma_2^2\right)}} \tag{6}$$

in a new formula we add σ_2^2 is the Gaussian perturbation of constant dispersion that is calculated by the formula [22]:

$$\sigma_2^2 = D[x] = M\left[x^2\right] = \sum_{j=1}^{m} x_{1j}^2 \mu(x_1) \tag{7}$$

where $D[x]$ is the dispersion, $M\left[x^2\right]$ is the mathematical expectation, x_{1j} is the possible values for x_1 (belonging to the interval σ in order to perform the validation for adequacy).

As a result, it is possible to define the probabilities of obtaining solutions and select the most probable ones.

The use of the probability density functions for modeling deviation helps measure the achievement probabilities of a series of consecutive states $s_1, s_2, \cdots, s_n$. If the probability $p_1^{(0)}$ indicates that we are placed in the state s_i and the state fully complies with the expected state (determined on the basis of previous stages), p_{ij} shows the probability of the transfer from the state s_i into the state s_j, and $p_i^{(1)}$ indicates the probability that the state s_i will be achieved. Then:

$$\left(p_1^{(1)}, p_2^{(1)}, \dots, p_n^{(1)}\right) = \left(p_1^{(0)}, p_2^{(0)}, \dots, p_n^{(0)}\right) \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{12} & p_{22} & \cdots & p_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{pmatrix} \tag{8}$$

and the management task adds up to the selection of a desired state from the set of possible states and the determination of a path (the set of delta states) to achieve this desired state. Therefore, it is possible to define the probabilities for obtaining decisions that will be taken into account for further selection of the most probabilistic ones based on the method of dynamic programming (Bellman method) (see **Figure 5**).

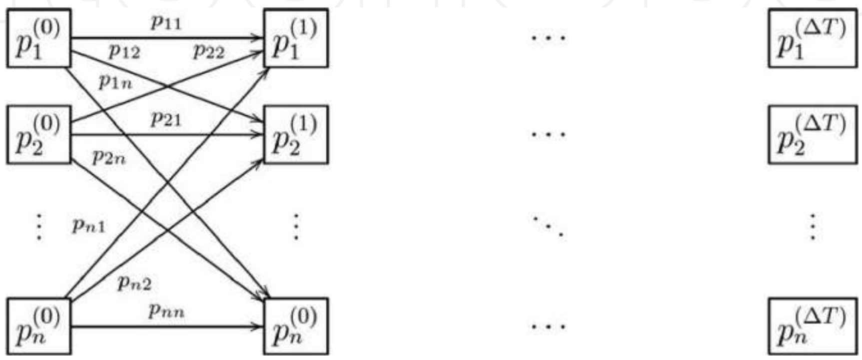

Figure 5. Decision tree for PS path selection task or project implementation.

Each state is determined by a risk metric (a value that is calculated on the base of the probability p_{ij} depending on the path that we have taken to land at the examined state) and the dynamics of the change in the criterion value by the transfer from one special state into another one (see **Figure 5**).

By obtaining the solutions as the functions of time on each step of calculations the time step Δt becomes an important algorithm parameter. On the one hand, as a step we can choose the time between the decision points $T^{(i+1)} - T^{(i)}$, from the other hand, by such approach the sensitivity of the system to altering external factors is decreasing (it becomes inertial). That is why, the selection of time step will be a trade-off between sensitivity and persistence of system. At the same time, time step can be an altering dimension ($\Delta t = f(t)$) but it should be placed in the diapason $\tau \leq \Delta t \leq T^{(i+1)} - T^{(i)}$, where τ is the minimal time required for changing production capacity, reset of technological cycle etc. (system characteristic), $T^{(i+1)} - T^{(i)}$ is the time for the next decision point. There can be any number of solutions between decision points.

Underlying a new calculation is the output of values of a forecast parameter outside the bounder of the confidence interval $\pm\sigma$. On the other hand, works related to changing production capacity, production and procurement scheduling etc., bring additional expenses for enterprise (in general, we encounter the situations, when production capacity is to be increased first and decreased afterwards, that in some cases can be balanced, particularly, by stocks. Therefore, we should consider this task as a separate management task and use the algorithm shown in **Figure 6**.

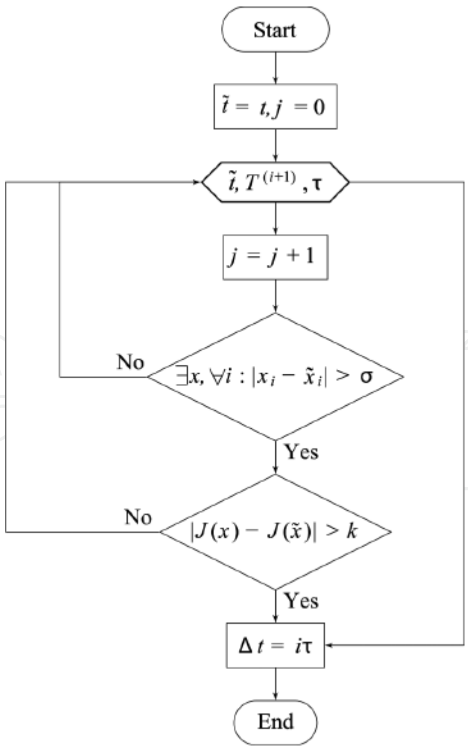

Figure 6. The algorithm for defining the step Δt for time moment $\tilde{t}$, where J is the criterion value, k is the amount of work expenses for changing production cycle taking into account economic criteria.

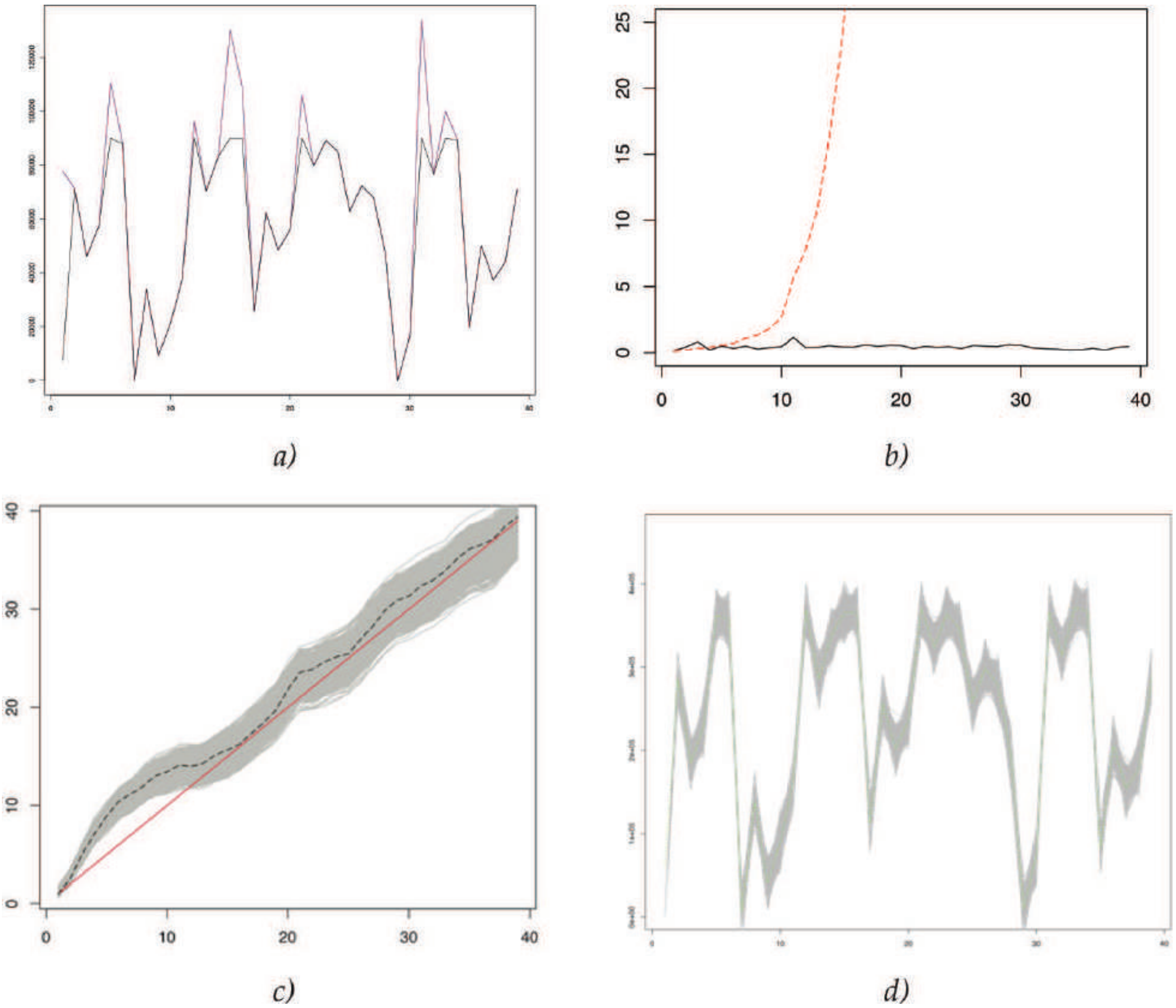

Figure 7. The solution results of volume planning and procurement management tasks based on the collected data about production system for a discrete production: (*a*) an example of production output volume for one of the products by the use of different forecasting methods, (*b*) the values of risk metrics (solid line) and progressive risk metrics (dotted line) connected with the use of planning data, (*c*) adjusted criterion value by the use of best forecast results and the corridor of possible deviations by the use of normal distribution for their modeling and its correlation with the retrospective data-based criterion value, (*d*) the need in one type of parts taking into account possible deviations in production plan.

The solution for the examined diapason $T^{(i+1)} - T^{(i)}$ by, for instance, joint consideration of the tasks of volume planning and procurement management will be production plan, the value of the given criterion (with a potential deviation diapason of decisions), the value of risk metrics and the volumes of changes in required parts and components taking into account possible deviations from target production volumes (**Figure 7**).

6. Conclusion

The present chapter describes the approaches that thanks to the use of the concepts Industry 4.0 enable the formalization of the processes that are connected with the reasoning and preparation of managerial decisions which are based on real statistical data that take into consideration the interaction of subsystems in production system. Therefore, together with the use of predictive models IIoT helps not only enhance the level of automation and reduce a certain part of personnel production expenses but also consider such factors as increasing power intensity and resources consumption of productions, inertness of integration and management processes in production systems, and the situations that are connected with repair actions, equipment mortality, procurement failures, change in demand and prices etc.

We have investigated the question how to use and apply under existing conditions the approaches that search feasible and optimal solutions in the tasks of efficient management and planning (taking into account time factor). The changes that affect the setting and solution of tasks can be explained by the shift to automated and automatic enterprises, by the shift from mass production to single-part production. In this connection, the current situation requires operational rearrangement of ongoing production processes; we need to increase global economics mobility, i.e. the variability of external environment where production systems operate.

The approach that is described in the chapter is relevant as it tackles management tasks given as optimization tasks; besides, it helps deal with the phenomenon of *NP* is the completeness of obtained tasks.

The obtained results are sensitive to the quality of forecasts and lack time lags; more than that, we can observe a change in production volume that creates additional increased capacities for production system (related to the change in production schedule).

That is why, the shift to the concepts Industry 4.0 gives not only evident momentary advantages, but also outlines new areas for studies, i.e. the solution of tasks that take into consideration the inertness of production system and expenses that arise due to changes in production volume and risk metrics, that appear upon interaction with external systems (for example, delayed delivery, the delivery of faulty parts, return of goods etc.).

The development of mathematical formalization of these areas of studies can lead to additional effects in future and underlie the appearance of industrial concepts of next generations.

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Chapter 6

Influence of Strategic Technology Management on Smart Manufacturing: The Concept of 'Smart Manufacturing Management'

Arif Sikander

Additional information is available at the end of the chapter

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Abstract

As technology advances, organisations are moving towards adapting the best options so as to enjoy a competitive edge. The performance of firms, besides other factors, relies on effective management of these technologies. Strategic management of these technologies is of interest to firms, but studies on this have been restricted to studies in the West. A study carried out by the author helped to analyse which of the technology strategy (TS) and technology management (TM) factors are related to performance of firms. Additionally, it was explored if any of these factors are related to nature and size of the firm. The research focused on high-technology manufacturing industries; some of which employed advanced manufacturing. This chapter will introduce the concepts of strategic technology management and smart manufacturing, provide a critical analysis of literature on the work done in these areas, discuss results of a study done on the application of STM in a high-technology manufacturing sector and extend the results of research to smart manufacturing. It is concluded that a good STM can guide smart manufacturing in enhancing firm productivity and achieving a competitive advantage.

Keywords: technology management, strategic, smart manufacturing, performance

1. Introduction

Technology management has come to be accepted as a vital activity and considered by many to be the basis of competition amongst organisations. On the other hand, Pandza et al. (2004) posit that 'Advances in technology have moved manufacturing organisations toward a new competitive landscape. Managers in manufacturing organisations are experiencing the emergence of new manufacturing concepts or even a new paradigm' (p. 402). Smart manufacturing is one of these emerging concepts. There has been considerable interest by researchers to peep inside manufacturing firms and explore the elements contributing to their performance. 'Over the last decade there have been many attempts to set out the elements of manufacturing systems and to understand their effects' [1]. Concepts such as virtual organisations, concurrent engineering, advanced manufacturing, flexible manufacturing systems and computer-integrated manufacturing have been applied at the company level. However, Hayes and Jaikumar [2] are of the opinion that 'investment based on these technologies frequently proved disappointing, not because of any fundamental weakness in these technologies, but because the links between these technologies and the needs of business were not well understood'. The repercussion of this has been, according to Womack et al. [3], a move by companies to lay more emphasis on soft issues like operations, quality, financial control, production control, change management and supply chain networks. It would be worthwhile to deduce that advanced manufacturing or smart manufacturing alone might not relate to performance of firms. The application of advanced technologies needs to align with the strategy of the firm, hence the need to consider technology strategy and technology management as the main drivers of smart manufacturing.

It is almost impossible for firms to keep away from technology. Continuous development in various industries has relied heavily on technology. The manufacturing sector has also moved leaps and bounds in technology applications. The concept of smart manufacturing also relies on utilising state-of-the-art technologies to monitor and improve productive effectiveness. 'The primary fact about technology in the twentieth and twenty-first centuries is that it has a momentum of its own. Although the technological stream can to some extent be directed, it is impossible to dam it; the stream flows on endlessly' [4]. The development of the Internet and modern sensor technology has benefited most. These technologies can be 'directed' to able to monitor and control the production processes more effectively than is done by current systems which are a mix of manual and automatic parameters. The trend in the development of fast Internet and control systems has provided unique opportunities to introduce smart manufacturing. However, technology alone cannot provide a competitive advantage. The way these technologies need to be applied (technology strategy) and implemented (technology management) needs to be understood by both the academics and the practitioners. This concept of integrating the areas of engineering and management is a concept which this chapter looks into and is introduced by the author for the first time here as 'smart manufacturing management' and resembles with 'engineering management' and 'technology management'. It provides useful results based on a study undertaken in a high-technology manufacturing sector.

Business strategy can be apprehended through its content or its processes [5]. Content research mainly focuses and investigates strategic typologies. Process research puts more emphasis on how the strategy is formulated and implemented ([6], p. 193). 'Strategic technology management' (STM) encompasses both the 'content' of technology strategy and the 'process' of technology management. Technological advances and the timing of their implementation have a considerable influence on the competitive standing of firms. Technology strategies could thus be regarded as important elements which could provide a competitive edge to organisations and also help in the development of their business strategies. Badawy ([7], p. 359) observed that White and Bruton use a similar definition for the management of technology, that is, 'the linking of engineering, science and management disciplines to plan, develop and implement technological capabilities to shape and accomplish the strategic and operational goals of an organisation'.

2. Technology management

Technology management, according to Corey [8], is an integration between business and technical disciplines to develop technology capabilities in order to achieve operational objectives. He further elaborates that R&D is also an essential ingredient for incorporating technology into the products and processes of a firm. Jones, Green and Coombs [9] have defined technology management as the 'identification, development and application of relevant technical knowledge and expertise to achieve organisational goals'. This definition goes beyond the usual domain of R&D and is more strategic in nature.

The effect of employing such strategies has resulted in enhanced productivity of many firms where technology was once treated as a relatively low priority [10]. The importance of technological competencies is evident from the fact that NEC outperformed GTE simply because 'it conceived itself in terms of core competencies' [11]. Therefore, it can be concluded that for the advanced manufacturing industry, technological competencies are always going to be significant as effective *management* of technology is dependent on them (on this, see also [12–16]).

2.1. Missing links in technology management

In order to determine the missing links in technology management, Gregory [1] conducted a critical literature review on this subject and concluded that 'all authors identify the need for a set of instruments, for a methodology to facilitate technology oriented decision making and none of the current approaches relates to general management concepts i.e. they do not lend themselves to integration in a unified concept of firm management'. Traditional approaches to technology strategy tend to focus on the identification of critical technologies and the allocation of R&D effort to the most important of these. Manufacturing firms tend to become multinationals, and technologies employed in the parent firm are similar to those employed by other countries, but it is unclear as to whether or not R&D is similar in the home and host countries. The firm exists to create value-added products. Wahab [17] reiterates that the 'performance of firms depends very much on innovation and R&D environment'. However, despite their similarities there are striking differences in the ways that different firms and organisations approach their technology management—the university system in the USA, for example, plays a different role from the one in Southeast Asia. Thus, technology management strategies applied in advanced manufacturing firms in the host country might be different than those applied in the home country—this is a missing link (gap), and this chapter in part has tried to address this gap.

2.2. Overemphasis on technologies in smart manufacturing

If as Gregory [1] maintains that 'a strategy is only of value if mechanisms for its implementation and renewal are in place', it is surprising that no comprehensive framework for technology management has emerged. Many authors, including Hayes and Jaikumar [2], have highlighted that an overemphasis on technology, rather than on products and services, has led some companies to develop or acquire inappropriate technologies. 'There is a need, then, for a "language" which can represent and link the important dimensions of a business, including technology, in the context of customer requirements' [1]. However, if such a language of technology is developed, it should be common across all functions in the organisation. It should be noted as an example that 'accounting language tends to be the only common language of the firm while technological language fragments at lower operational levels, that is, in production engineering and R&D' [5]. The failure to *measure* technological capabilities is also a missing link in technology management; though the technology contribution factor (TCF) has been applied in research conducted by various researchers, it does not provide the necessary link between the various dimensions of technology management. Therefore, studies which can provide measures to establish this link should contribute to the existing knowledge. The concept of strategic technology management introduced in this chapter—a combination of technology strategy (TS) and technology management(TM)—attempts to address this issue in the sense that it measures the performance of firms in relation to various technology strategy and management dimensions. Acquiring smart manufacturing capability is a moderator in the performance of the firm, and strategic technology management is the driver.

2.3. The strategic content in technology management

The rapid change in technology over the last two decades has raised concern on two major issues. These have been defined by Mitchell [18] as (1) poor linkage between technology and strategy planning and (2) over-reliance on short-term measures, both of which masks the more strategic plans. Strategic importance of technology has been recognised as helping to provide competitive advantage. However, Mitchell [18] states that strategic management of technology has certain practical problems, which are:

1. There is no generally accepted language for defining the critical technologies.
2. There is no way to manage these technologies.
3. There is no appropriate financial framework for allocating resources for strategic positioning.

Hence, there are opportunities to explore how technology strategies are formulated by firms, how they are subsequently implemented and how they contribute towards the firm's growth, especially those which employ advanced manufacturing.

The need to create and use new technology to provide a competitive advantage has been ever increasing and has been a source of growth for many firms. This requires strategic thinking about technology beyond the simple development of new products and services. Hence, 'the task of managing technology is integral to, and essentially synonymous with, strategic management' [19].

Since 1980, the relationship between technology and business strategy has been considered important by companies, but its implementation has not. As highlighted by Chiarmonte [20], 'technology, although very important, was still often not considered in the process of strategy formulation, the essential reason being the trend that technology development takes longer time compared to other functions of the company like marketing'. Thus, more than recognition of this issue is needed to determine what linkage mechanisms need to be established to provide the technology strategy fit.

Contrary to this argument, Thomas and McGee [21] suggest that the strategy literature treats technology as an implementation issue, that is, the technology to be used is defined by strategy.

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Thus, technology does not enter into the strategy formulation process, and there is no clear direction on how to manage it. The authors further suggest that technology should be considered as the central part of a company's thinking. Evan et al. [22] go a step further and suggest that 'technology should be recognised as a strategic resource … to ensure new technologies provide sources of strategic advantage. This has tempted cutting-edge firms [to] increasingly integrate technology management with their management processes'. However, this approach on its own is not sufficient; it may confine firms to an inward-looking approach. There is also a need to explore those technology developments occurring outside the firm so that appropriate technologies can be matched to their management strategy. This emphasis by firms on both internal and external inputs—a key aspect of strategic technology management—is explored in this chapter, and both approaches are included as relevant variables in the survey instrument.

Attaran [23] opines that technology in itself does not guarantee success in increased efficiencies and reduced inventory turnover times. He further states that 'management plays a fundamental role in the implementation of such initiatives which could include flexibility, customer service, employee welfare, quality and training'. Thus, allocation of appropriate resources and provision of capital, both for product (development) and services (welfare, training, etc.), are important for the implementation of technologies—a point which has been borne out by one of the results of the bigger research and does not form part of this chapter.

Wilson [24] analyses the strategic management process of Bank of America and concludes that four major thrusts are included in the technology planning of its strategic management process. They are 'emphasis on focusing on technology to meet customer needs; investing in employees to build a diversity of skills and talent; applying technology to build a competitive advantage; and linking business and technology strategies to build a common value'. These values provide a useful set of strategic technology management strategies for researchers. Wilson's understanding of the subject is supported by Sahlman and Haapasalo [25] who regard strategic technology management as the management of those technology activities which interact with a company's socio-economic and technological environment and help to formulate and implement that company's overall strategy.

According to Thomas and McGee [21], 'the evolutionary theory of the firm also provides an important framework for the strategic management of technology because the strategic capabilities evolved through experience reflect the ability of the organisation to adapt to changing technologies which provides profitability'. Although not exclusively naming the approach as strategic technology management, Corey [4] proposes that 'technology management must accept the responsibility for managing its process with the associated strategic perspective otherwise the results could be catastrophic'.

One of the definitions of technology management which integrates the elements of strategic management comes from the NRC Report (cited in [26]): 'Management of technology is a linking block amongst engineering, science and management disciplines to plan, develop and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organisation'.

One of the key recommendations of the Strategic Management of Technology Conference [27] was that firms needed to create a sustainable competitive position, one which requires strong linkages between the company's business environment and the way that company develops and maintains its technological base. Despite this, the main focus remains on the way of acquiring new technology and how to improve the existing ones to gain competitive advantage. The underlying task remains how to find an answer to match technology to market. This is relevant in the case of smart manufacturing whereby employing only modern technologies in terms of IoT (Internet of Things), and data analytics might not be able to provide the competitive advantage.

3. Smart manufacturing and strategic technology management

Smart manufacturing is nothing new; terminologies like advanced and flexible manufacturing have also been used in the past which focus on utilising modern technologies to improve manufacturing. Smart manufacturing entails availability of data of the entire manufacturing process so that manufacturing organisations can *strategise* the processes to match the market. In this respect smart manufacturing 'influences' and 'aids' technology management decisions. Smart manufacturing provides data and empowers everyone in the organisation including top management, which should help management in developing appropriate technology strategies to maintain a sustainable competitive advantage. It would not be wrong to say that smart manufacturing is in fact a technology management trend.

Ettlie [28] conducted a study of various successful firms in the USA and found that synchronous innovation of both technology and administration made for the best-performing firms. 'If business strategy can be thought of as defining the preferred field of contest and the tactics used in confronting a competitor, a technology strategy defines how these tactics can be created and employed' [29]. Clark et al. [30] use the phrase 'technology management' to refer to 'organizational issues and processes involved in developing and implementing a strategic approach to technology'. *As such in the context of smart manufacturing, only utilisation of advanced technology is one of the aspects of performance of firms; how to employ and administer these technologies (TS/TM) will remain the major driver of performance enhancement.*

According to Dell ([31], smart manufacturing provides immense opportunities for organisations including predictive maintenance, quality control, automated process management and supply chain visibility. To be able to avail these opportunities, organisations will need a robust technology strategy in order to determine what tactics need to be employed to ensure compliance of these.

Andrew Waycott [32] suggests that smart manufacturing is about collecting and crunching data to make more informed decisions. With greater visibility of the real workings, your shift supervisors and operators can make better, more informed decisions, all day long. Thus, smart manufacturing can help in strategic management of technology.

Chand and Davis in a paper written for Rockwell Automation [33] suggest that smart manufacturing is not merely technology rather an integration of information, technology and human ingenuity. This integration could be achieved by application of technology management strategies at the strategic level in the organisation to ensure it aligns with the business strategy and provides a competitive advantage.

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4. Strategic technology management in advanced manufacturing: analysis of a research study

A study was carried out to determine the influence of STM on the performance of firms in technology-intensive advanced manufacturing sector of the economy. This was a mixed-mode study and employed a survey instrument comprising both quantitative and qualitative questions. The respondents were the chief executive officers, technology managers and senior management in 101 high-technology firms who were considered to be part of strategies at the firm level. The responses were analysed using statistical tools. The variables included in the questionnaire were reduced by performing factor analysis. The relationship between the variables of interest was determined using regression analysis. The factors were grouped into TS and TM dimensions. These were then used to determine their influence on performance of firms. Sales revenue growth (SRG) was selected as the performance measure. Two of the factors, namely, *key positioning* and *strategic R&D*, were found to relate with performance, while the other five factors, namely, *technology leadership*, *up-to-date plants and facilities*, *technology consciousness*, *formal planning* and *external technology acquisition*, were not correlated with performance. Multinational corporation and joint venture firms were found to have acquired the factors of key positioning and strategic R&D, whereas foreign and locally owned companies were found less likely to acquire these factors. These results have implications both for management within the firm and the policy planners at the national level.

4.1. Influence of R&D on technology strategies

Investment in R&D contributes to technological innovation, and to manage these innovations requires the development of technology strategies. So, why do firms invest in R&D? Shane [34] highlights five reasons for this:

1. To create new technologies that can serve as the basis for new products and services.
2. To develop products to replace those threatened by substitutes.
3. To differentiate products from those of competitors.
4. To create strong intellectual property positions by making fundamental discoveries on which pioneering patents can be obtained.
5. To create absorptive capacity to recognise and use knowledge from elsewhere.

Competition amongst firms lays the foundations of business strategy and is a driving force in the establishment of R&D strategy. 'R&D strategy' is often used interchangeably with 'technology strategy' in the literature. As such R&D management has dominated in technology-intensive and advanced manufacturing industries. This R&D emphasis is quite common in the US industries; this is in contrast to the European model which stresses acquisition, diffusion and transfer of knowledge [20]. R&D strategy needs to be integrated with the other strategies of the firm. And, indeed in recent times, there has been a 'shift from an R&D management focused attitude, towards a wider perspective of the issues facing innovation management, and, more recently, towards a combination of innovation, technology and strategy' [20].

In this study R&D is considered as an integral part of a firm's strategy and is employed as a background variable to determine its relationship with the performance of firms. Technology helps in the formulation of a company's technology strategy, and its implementation provides the success. This is the rationale to define strategic technology management as a combination of technology strategy and technology management.

'R&D has to live in continuous symbiosis with other functions in the company and should be absorbed into the technology function' [27]. This Strategic Management Conference [27] also recommended that firms need to 'measure the technological assets' so as to decide on how to use technology in making strategic choices.

According to Van der Meer et al. [35], 'Companies which operate in technology intensive environments are compelled to invest heavily in R&D in order to maintain a competitive advantage'. This study, besides exploring the effect of technology strategy factors on success of firms, also explored if R&D investments in terms of the number of people employed in the R&D department related to the performance of the firms.

'The promise that R&D holds is not the reality for many firms as competitors often appropriate and commercialise new technologies more nimbly than the firms that paid to develop them' [36]. Firms need to find a fit between their R&D and their company strategy. Evan et al. [22] suggest that technology strategy improves communication between R&D and the rest of the firm and seeks to answer questions like:

1. What is the fit between technology projects and the company strategy?

2. How do technology efforts compare with those of competitors?

3. Are external sources (universities, laboratories) used effectively?

4.2. Methodology

4.2.1. Sample

The definition of a high-technology industry has not been agreed upon. The Department of Commerce (USA) [36] defines a high-technology industry on the basis of the percentage of its investment in R&D relative to its sales revenue. Although MNCs in the manufacturing sector outnumbered other types, this study chose to include all types of firms within this subsector: multinational corporations (MNCs), joint ventures (JVs), foreign-owned (FO) and locally owned (LO). The further classification of firms was inspired by Thomas and McGee [21] who define firms in terms of modes of innovation: 'mode 1 as small high technology firms, mode 2 as large multi-product, multi-market, and multi-divisional corporations and mode 3 as huge multinational enterprises that usually involve public and private sector collaboration on mission-oriented programs' (p. 266).

There were a total of 380 E&E firms listed in the Federation of Manufacturing Directory. However, about 80 of these were incorporated after the date this research was carried out, so they were excluded, leaving about 300 high-technology manufacturing firms for the survey.

This sample was considered as a probable one, and it was thus possible to 'extrapolate beyond the sample to establish findings for the wider population of interest' ([37], p. 184).

Because of their familiarity with technology management and strategy issues in their firm, the CEO, technology managers or senior management of each firm was expected to complete the questionnaire.

4.2.2. Research design

In order to address the research question, a mixed method design was used to collect data. Zahra [38] has indicated a 'need to refine the conceptual and operational definitions of technology strategy and … that field studies and surveys can help to identify additional components of technology strategy' (p. 214). The data-gathering phase had three objectives:

1. To gather data on key technology strategy and management elements from senior executives of firms in the manufacturing sector.

2. To gather data about the level of technology awareness of the respondents and about their understanding of the role of technology and the competitive environment.

3. To gather data about the performance of the firms.

The research was designed in three phases. The first phase involved the development of a survey instrument. The survey instrument was developed in line with the objectives of the research and so as to maximise information extraction from the respondents ([39], p. 29). Advantage was taken of prior surveys in selecting the variables chosen for the study, especially Herman [40]. The response rate was initially 18%; this increased to 26.5% (useful rate being 20.7%) after two follow-up letters were sent. The second phase involved the pilot testing of the survey instrument. The pilot study involved 10 firms and sought to assess the clarity and usefulness of the questionnaire items. Phase three of the study involved the administration of the survey.

4.2.3. Measures

According to Jones et al. [9], 'Successful technology strategy management must go beyond content, implementation is as important' (p. 158). There are 10 elements of strategic technology management that were selected for this study. Each element is measured through inductively developed items in order to develop a richer description of the element and to triangulate on the element value. A four-point modified Likert scale was chosen due to its inherent advantages over the original odd-numbered Likert scale.

4.2.4. Firm's performance dimensions

In this study firm performance was measured using sales revenue growth (SRG), that is, by considering the annual sales revenue at the start and end of the period of this study. SRG reflects the effects of technology strategy decisions. Although SRG is not a perfect measure, various researchers have found it adequate for performance, especially for developing countries [41].

4.3. Data analysis

4.3.1. Factors underlying strategic technology management

Factor analysis was used to reduce the original number of items (32 items, 16 strategy and 16 management) in the survey. The literature review identified several variables which could be used to measure two dimensions which define strategic technology management. These two dimensions are referred to as technology management (TM) and technology strategy (TS). A thorough analysis of the environment in which the survey was carried out revealed that 32 items could be used to measure these dimensions. According to the respondents to the pilot study, these items were deemed suitable for use in the main questionnaire.

Principal component analysis (PCA) was selected for extracting the factors. In order to determine the appropriateness of the factor analytic framework, a number of methods were employed. These included Bartlett's test of sphericity and Kaiser-Meyer-Olsen's (KMO) test. The 16 strategy items were factor analysed using the PCA method.

Kaiser's criterion with an eigenvalue of greater than 1.0 was used to determine the number of factors to be extracted. The extraction using PCA for the 'technology strategy' variables revealed that three components accounted for 71.3% of the total variance. The extraction using PCA for the 'technology management' variables revealed that four components accounted for 83.2% of the total variance. The rotated factor loadings are presented in Appendix A.

Strategic technology management in this research has been understood in terms of the technology strategies formulated by firms and the processes for implementing or managing these strategies. Seven new factors have been identified by this research, and these all apply at the company level (Appendix A). These seven factors can be seen as falling into two dimensions: the technology strategy (TS) dimension and the technology management (TM) dimension.

The TS dimension, which refers to the *content* of strategies, is in this study and can be conceptualised in terms of three factors:

1. The first is *technology positioning*, in which a firm introduces high-risk or breakthrough technologies in order to build a reputation for technical innovation that it can be used as a competitive advantage. A firm that uses *technology positioning* also emphasises the sophistication of the technology they apply, with an emphasis on state-of-the-art tools and equipment and a focus on hiring highly trained R&D personnel. Such a firm strives to not only increase its range of products but also to reduce product development time. Thus, this factor could be summarised as referring to a firm's utilisation of technology to achieve competitive advantage. It does so by using even more sophisticated technology and by increasing the number and rate of development of new products.
2. The second factor developed from the data is that of *leading in the discovery of new technologies and introducing innovative products*. This factor relates to the efforts a firm puts into the *discovery* of new technologies and to introducing new products before other firms. Thus, it is about the willingness to lead in technology discovery and in the introduction of new products.

3. This third factor relates to the extent to which *technology is embedded in plants and processes*. This construct relates to a firm's exploitation of technology to manufacture unique products, to reduce manufacturing costs and to increase the flexibility of production processes. This measure also reflects the maximisation of the inclusion of technology in a firm's plant and processes in order to gain an advantage in relation to competitors.

The TM dimension, which relates to a firm's handling of the process side of technology, can be conceived in terms of four unique factors:

1. The first is *R&D linked to business*. This refers to the degree to which a firm links its R&D activities with its other business operations, that is, the degree to which it elevates R&D to a strategic level. It also relates to the existence of mechanisms—mechanisms for recognising and rewarding R&D and mechanisms for evaluating the costs and benefits of specific R&D projects.

2. The second factor is called *keeping abreast with emerging technologies*. This is about the processes that firms employ to ensure that they are aware of innovative and competing emerging technologies. This basically refers to the processes it has in place for scanning for new technologies employed by firms.

3. The third factor is *formal process for planning*. This reflects the emphasis that firms place on using formal processes for planning and selecting technologies, as compared to *ad hoc* decision-making.

4. The fourth factor is *in-country external acquisition of technology*. This is about the processes that firms use to acquire technology by conducting R&D in collaboration with universities, research labs and other companies within a country, that is, technology acquisition that does not rely on internal R&D at the firm level.

The seven strategic technology management factors highlighted above were evident in firms investigated. However, not all factors were found to contribute to a firm's success. The next section describes in detail the relationship between these factors and SRG.

4.3.2. Factors influencing performance of firms

For this study, sales revenue growth (SRG) was used as a measure of firm performance and was averaged over a 10-year period.

The results revealed that there was a statistically significant correlation between *strategic R&D* and SRG, as well as between *technology positioning* and SRG. These two factors represent technology management and technology strategy dimensions of strategic technology management; thus, it could be stated that application of strategic technology management factors contributed to the positive performance of the advanced manufacturing firms during the 10-year period under review. The summary of the factors that correlated with success is provided in **Table 1**.

Factors	Correlation with SRG	Result
Strategic R&D (TM)	Yes ($r = 0.34$, $p < 0.01$)	The firms that are extremely focused in placing emphasis on R&D and linking it with other business operations have a positive significant correlation with the growth rate
Key positioning (TS)	Yes ($r = 0.33$, $p < 0.01$)	The firms that are extremely focused in using technology as a key positioning factor in their strategy have a positive significant correlation with the growth rate

Table 1. Strategic technology management factors contributing to success.

5. Implications

This study has contributed to the discipline of STM and SM by investigating the nature of technology strategies applied in advanced manufacturing firms in an Eastern environment.

The study has offered an approach to quantify the cumulative effect of STM application in SM and performance.

The results could be extremely useful to provide an insight to the national technology planners of the influence of STM in smart manufacturing and the performance of firms.

This study indicated that not all factors of strategic technology management applied in smart manufacturing would produce sales revenue growth. This has implications for the managers of firms and especially for those who are responsible for technology management.

6. Conclusion

Smart manufacturing alone will not be able to provide success in the performance of firms. It has been demonstrated based on the literature review, and an exclusive study carried to explore if strategic technology management factors rather technology alone (as is smart manufacturing) influence performance of advanced manufacturing firm. Although several factors were drawn up from this study, but only two factors contributed to the performance of such firms, and they were strategic R&D and key positioning. The strategic R&D factor demonstrates that the innovative use of technologies and new product designs can contribute to performance of firms. The key positioning factor accounts for good decision-making in terms of market positioning. The study also supports the viewpoint of Chand and Davis (in Rockwell Automation Report) [33] that smart manufacturing is not merely technology rather an integration of information, technology and human ingenuity. Since two factors in strategic technology management contributed to the growth of firms, it could be concluded that integration of both

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technology (R&D) and human ingenuity (key positioning/decision-making) can provide success to firms. Thus, smart manufacturing is the engine, and strategic technology management the driver for performance of firms.

A. Appendix A: factor analysis

A.1. Technology strategy

Total variance explained							
Component	**Initial eigenvalues**			**Extraction sums of squared loadings**			**Rotation sums of squared loadings[a]**
	Total	**Percentage of variance**	**Cumulative (%)**	**Total**	**Percentage of variance**	**Cumulative (%)**	**Total**
1	8.261	51.632	51.632	8.261	51.632	51.632	7.383
2	1.755	10.968	62.600	1.755	10.968	62.600	3.750
3	1.388	8.677	71.277	1.388	8.677	71.277	4.769
4	.987	6.167	77.444				
5	.784	4.903	82.347				
6	.672	4.203	86.549				
7	.457	2.853	89.403				
8	.428	2.678	92.080				
9	.324	2.025	94.105				
10	.256	1.598	95.703				
11	.192	1.199	96.902				
12	.187	1.167	98.069				
13	.113	.704	98.773				
14	.089	.558	99.332				
15	.071	.446	99.777				
16	.036	.223	100.000				

Extraction method: principal component analysis.

	Component matrix[a]		
	Component		
	1	2	3
Pursuing high technical risk	.757		
Having reputation for technology innovation	.775		
Dominance in key technologies	.774		−.411
Importance of advanced qualifications	.652		
Striving for technology development	.755		
Employing pacing technologies	.795	−.425	
Using state-of-the-art tools	.796	−.420	
Reducing product development time	.769		
Increasing the number of products	.582		
Continuously improving products	.708		
First in discovering technologies	.704	.638	
First in introducing new products	.683	.628	
First in introducing low-cost products	.498	.626	
Unique product manufacturing capabilities	.725		.579
Low manufacturing cost	.661		.606
Improving production flexibility	.790		.478
Extraction method: principal component analysis			

[a]Three components extracted.

A.2. Technology management

Total variance explained							
Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings[a]
	Total	Percentage of variance	Cumulative (%)	Total	Percentage of variance	Cumulative (%)	Total
1	7.804	48.772	48.772	7.804	48.772	48.772	6.961
2	2.927	18.296	67.069	2.927	18.296	67.069	4.941
3	1.387	8.668	75.737	1.387	8.668	75.737	2.117
4	1.190	7.440	83.177	1.190	7.440	83.177	2.548

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Total variance explained							
Component	**Initial eigenvalues**			**Extraction sums of squared loadings**			**Rotation sums of squared loadings[a]**
	Total	**Percentage of variance**	**Cumulative (%)**	**Total**	**Percentage of variance**	**Cumulative (%)**	**Total**
5	.642	4.012	87.189				
6	.505	3.155	90.344				
7	.358	2.237	92.582				
8	.320	1.998	94.580				
9	.259	1.619	96.199				
10	.167	1.046	97.246				
11	.150	.939	98.184				
12	.116	.725	98.909				
13	.060	.374	99.283				
14	.052	.327	99.610				
15	.033	.203	99.814				
16	.030	.186	100.000				

Extraction method: principal component analysis.

Component matrix[a]				
	Component			
	1	**2**	**3**	**4**
Awareness of existing technologies	.665	.658		
Awareness of emerging technologies	.650	.670		
Awareness of innovative technologies	.619	.689		
Awareness of competing technologies	.520	.746		
Technology acquisition within the firm	.786			
Technology acquisition from laboratories & universities	.570			.528
Technology acquisition from outside firms within the country				.738
Market-driven programmes	.692			
Product-driven programmes			.776	
Formal planning processes	.454		.455	
R&D integrated programmes	.867			
R&D researchers empowered	.905			

Component matrix[a]

	Component			
	1	2	3	4
R&D success rewarded	.895			
High R&D investment	.858			
Ensuring high returns on R&D investment	.894			
External R&D funding	.753			

Extraction method: principal component analysis.
[a]Four components extracted.

B. Appendix B: regression analysis

Variables entered/removed[b]

Model	Variables entered	Variables removed	Method
1	Capital Investment, employees[a]	.	Enter
2	Strategic R&D[a]	.	Enter
3	Technology positioning[a]	.	Enter

[a]All requested variables entered.
[b]Dependent variable: sales revenue growth.

Model summary

Model	R	R square	Adjusted R square	Std. error of the estimate
1	.732[a]	.536	.520	342.24750
2	.733[b]	.538	.514	344.47139
3	.740[c]	.547	.516	343.85691

[a]Predictors: (constant), capital investment, employees.
[b]Predictors: (constant), capital investment, employees, strategic R&D.
[c]Predictors: (constant), capital investment, employees, strategic R&D, technology positioning.

ANOVA[d]

Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	7979285.248	2	3989642.624	34.061	.000[a]
	Residual	6910867.880	59	117133.354		
	Total	1.489E7	61			
2	Regression	8007841.708	3	2669280.569	22.495	.000[b]
	Residual	6882311.420	58	118660.542		
	Total	1.489E7	61			

ANOVA[d]

Model		Sum of squares	df	Mean square	F	Sig.
3	Regression	8150611.362	4	2037652.841	17.234	.000[c]
	Residual	6739541.766	57	118237.575		
	Total	1.489E7	61			

[a]Predictors: (constant), capital investment, employees.
[b]Predictors: (constant), capital investment, employees, strategic R&D.
[c]Predictors: (constant), capital investment, employees, strategic R&D, technology positioning.
[d]Dependent variable: sales revenue growth.

Coefficients[a]

	Model	Unstandardised coefficients		Standardised coefficients	t	Sig.
		B	Std. error	Beta		
1	(Constant)	−440.577	125.548		−3.509	.001
	Employees	40.917	53.711	.094	.762	.449
	Capital investment	342.801	63.427	.664	5.405	.000
2	(Constant)	−416.552	135.523		−3.074	.003
	Employees	47.858	55.881	.109	.856	.395
	Capital investment	350.486	65.733	.679	5.332	.000
	Strategic R&D	−27.306	55.663	−.052	−.491	.626
3	(Constant)	−640.907	244.923		−2.617	.011
	Employees	44.717	55.855	.102	.801	.427
	Capital investment	351.309	65.620	.681	5.354	.000
	Strategic R&D	−79.027	72.820	−.151	−1.085	.282
	Technology positioning	123.035	111.967	.141	1.099	.276

[a]Dependent variable: sales revenue growth.

Excluded variables[c]

	Model	Beta In	t	Sig.	Partial correlation	Collinearity statistics tolerance
1	Strategic R&D	−.052[a]	−.491	.626	−.064	.705
	Technology positioning	.051[a]	.520	.605	.068	.826
2	Technology positioning	.141[b]	1.099	.276	.144	.481

[a]Predictors in the model: (constant), capital investment, employees.
[b]Predictors in the model: (constant), capital investment, employees, strategic R&D.
[c]Dependent variable: sales revenue growth.

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Chapter 8

Renewing a University to Support Smart Manufacturing Within a Region

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Additional information is available at the end of the chapter

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Abstract

This chapter focuses on the topic of renewing a university in order to be able to support the adaptation of smart manufacturing and Industry 4.0 within a region. The chapter introduces Industry 4.0 as a framework for regional development. Factors related to Industry 4.0 related renewal in the region are identified and discussed further. An idea of how to apply Industry 4.0 as a framework for renewal of a multidisciplinary university's structure and curricula is introduced. Also, a case study for applying Industry 4.0 as a framework for increasing competitiveness in the region is introduced.

Keywords: Industry 4.0, smart manufacturing, regional development, university

1. Introduction

The chapter is closely linked to Industry 4.0 framework. The geographic focus, while developing this chapter further, is the region of Häme in the southern part of Finland. The various activities within the region are evaluated from the perspective of smartness and their ability to support Industry 4.0 framework, as well as the renewal of operations in the region.

The development of competitiveness of the region, while maintaining and developing it as an attractive location for companies requires, co-operation between various stakeholders. Industry 4.0 can be applied as a framework for regional development. Universities have a major task to support competence development of relevant topics in various fields. In the field of manufacturing industry, the Industry 4.0 is increasingly relevant topic and the universities should identify their role to support local industry in its adaptation.

2. Industry 4.0 as a framework for regional development

The term “Industrie 4.0” was initially originated in Germany [1]. Industry 4.0 is a policy framework that defines and describes how new technologies should be adopted to renew manufacturing. The renewal is expected to bring major boost in competitiveness. It provides the framework for different kinds of policy initiatives. From the regional development perspective it can also be used as a guideline for steering research and development activities [2].

Industry 4.0 describes how machines, and other technologies adapted in manufacturing communicate with each other. The major importance is on a networked perspective, i.e., how different companies within a value chain communicate each other. The intention is such that computerized systems control and monitor physical processes. Industry 4.0 takes manufacturing-related industries to the next level in adapting and utilizing digitization. In networked environment machines and physical objects are linked with each other. This allows decentralized production and real-time adaptation to the changes on the level of demand in the future [2].

The characteristics of Industry 4.0 is that it promotes computerization of manufacturing. Industry 4.0 is closely linked to Cyber-Physical Systems (CPS) [3]. They can be defined as transformative technologies which manage interconnected systems between its physical assets and computational capabilities [4]. We are increasingly using the concepts of the Internet of Things, the Internet of Everything and the Industrial Internet. The widespread adoption of information and communication technology (ICT) is increasingly accelerating and blurring the boundaries between the real physical world and the virtual one. The linkage is becoming increasingly smart [5].

Industry 4.0 is made possible through the development of the industrial Internet of Things [4]. New ICT-related technologies make Industry 4.0 development possible and give opportunities to re-engineer value chains and create new business models. Internet of Things (IoT) is one of the core technologies for Industry 4.0. The growth of connections brings the new possibilities and solutions for business. On the other hand, exponential growth brings also new challenges for education, R&D&I, and regional development activities. The exponential growth of IoT connections indicates the birth of new business models and new kind of business environments. This “smartness” requires greater connection and collaborations. This is where the “explosion” of platforms and ecosystems is occurring. An attempt to connect the Internet of Things, services, data, and people need radical redesigns within industries and the participants to connect up this all. Presently, Industry 4.0 is more industrial driven, but this will change and broaden out [6].

Industry 4.0 is about increasing productivity and competitiveness. One perspective how this increase in productivity takes place is increase in the efficiency and speed of processes within a company or a value network. Basically, utilization of Industrial Internet makes it possible to optimize the activities and resource utilization in entire value network. Also, material and energy efficiency can be improved, which is important from the perspective of sustainable operations. Large sets of accumulated and real-time data can be applied to forecast or process development purposes. In addition, digitization provides opportunities for new start-ups and may create further prosperity [1].

Digitalization will bring new business opportunities and increasing competition. Companies are forced to renew their processes and activities, and at the same time restructure their business processes and models. Regions and areas are forced to plan and redesign services in their business environments as well. In order to see the development needs for attractiveness and welfare, but also to use the development resources in the best possible way, the key research questions related to this paper are:

1. How Industry 4.0 could be used as a framework for regional development?
2. What are issues affecting competitiveness of regions?
3. How structure and curricula of university could be renewed in order to support adaptation of Industry 4.0 in the region?
4. What issues to consider while applying Industry 4.0 to increase competitiveness of a region?

The changes created by Industry 4.0 are not only technological but also organizational [7]. More network-oriented operations are emphasized instead of a perspective of one single economic unit like one factory. The competence development activity, that is required to fully internalize Industry 4.0, is a major task. It should be implemented both on the societal level implemented for example by higher education institutions as well as on private enterprises. It is possible that productivity improvement perspective, which on the short to medium term, may lead to layoffs of workers regarding their current work positions is not necessarily welcomed by representatives of trade unions. However, on longer time frame, the competiveness of European manufacturing-related industries is beneficial for all members of the society [1].

3. Adaption of new technologies supporting Industry 4.0

It is assumed that European manufacturing industry has to radically renew itself. Industry 4.0 provides guidelines on how to make this renewal ambition a reality. The adaptation of new technologies that can be interconnected provides major opportunities. While large-scale utilization of sensors that are connected by wireless networks as well as further adapting robotics provide potential to gain major leaps in productivity. Analytical methods that can be utilized on big data provide further insights on managing a network of producers and suppliers. Mass customization becomes a reality. The overall productivity increase is due to increased speed, improved quality, better utilization of existing resources, and so on. However, the manufacturing firms should be prepared to make required investment on both hardware (equipment and computers) as well as on software (competence development and applications) [8].

Digitization is an increasingly relevant option while companies are trying to renew themselves and their operations to remain competitive. However, digitization is not only a short-term project; it is a long term transformation that should be lead. The leadership perspective is very important in this change management initiative. Such technologies like cloud computing, wireless networks, and big data can be adapted. However, the main question remains,

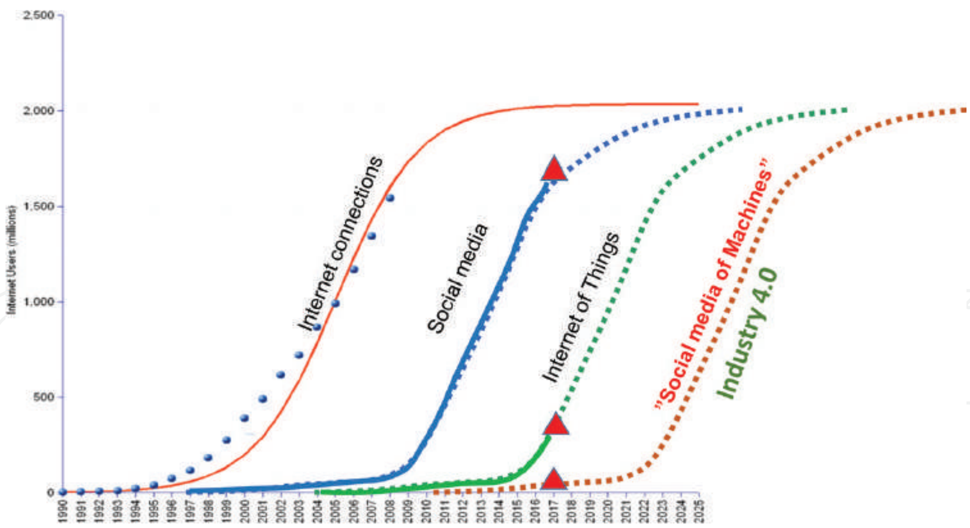

Figure 1. Rapid adaptation of new internet-related technologies.

what changes are about to happen in our industry or value network and how applying digitization makes it possible to remain competitive and even further increase competitiveness.

The development of new technologies not only causes major changes and transformations, but also provides plenty of opportunities for exploitation of sustainable, residential, and residential-oriented urban centers and environments. The subscriptions to the Internet (IoT) alone will rapidly multiply in the years to come. This development affects traffic, travel chains, housing for commerce, welfare, healthcare, tourism, services, industry, etc. This development of new Internet-related technologies described in **Figure 1** places urban development and development principles into a new perspective.

Training, development, innovation, and testing can no longer take place in a separate and closed laboratory environment, but to be able to create sustainable innovations education and development activities must be brought into an operating environment where residents, non-governmental organizations, political decision-making, civil servants, and students meet with regional development and different disciplines. The urban infrastructure is a part of the innovation-based ecosystems of different actors that produce new innovations at their interface.

4. Competitiveness of regions

Private organizations are doing their best to be more profitable and they are open to new ideas. That is why companies are actively starting to use new technologies and trying to find the most suitable business environment for their locations. At the government, region, and town level, the situation is quite different. Their task is not to make business, but to develop good and fruitful business environments for companies. Building infrastructure, providing a skilled labor force, etc., have been their main tasks.

By identifying the key factors for the Industry 4.0 related renewal, we will find different factors, i.e., "levels." These are described in **Figure 2**.

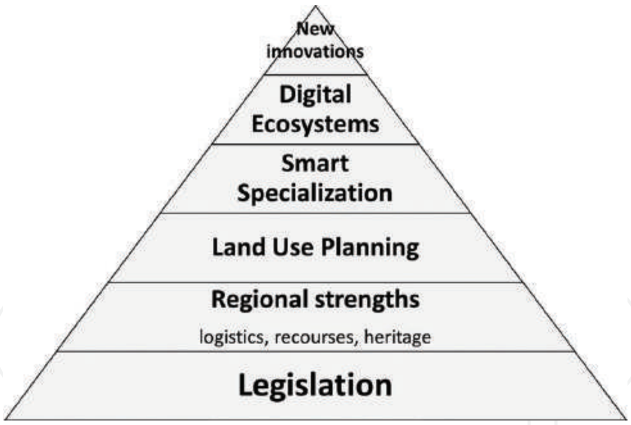

Figure 2. Factors affecting Industry 4.0 related renewal.

4.1. Legislation

Legislation is the very first level that we can see as the driver of development. At this level, we should understand that legislation should not be considered as an actor, which regulates/limits (actions), but legislation makes new kinds of business possible and supports business development. Generally, we can understand that legislation gives “the rules of the game” and this way makes business environments more predictable with less business risks. Legislation also gives the framework for operations like recycling, land use, and new business models, but also taxation decisions might encourage new businesses. EU legislation gives the framework for legislation but still there is national legislation, which steers local business and industry.

4.2. Land use

We have industrial/logistics areas where companies are located. Usually, the industrial areas have developed and profiled themselves based on the strengths in the local region like logistic connections, population, energy, raw materials, knowhow at universities, skilled labor force, and so on. The question will be: how should we plan land use (business/logistic areas) so that companies would be able to create a fruitful business ecosystem, efficient material use (circular economy), and minimize logistic expenses. This is usually a long process and the steps are not known accurately.

4.3. Regional strengths

We have industrial/logistics areas where companies are located. Usually, the industrial areas have developed and profiled themselves based on the strengths in the local region (like logistic connections, population, energy, raw materials, knowhow at universities, and skilled labor force).

4.4. Enterprise ecosystem

There are clear indicators that short distances will improve co-operation between companies. In the case of material and economic efficiency, short distances give savings in logistic expenses.

4.5. History

Every region and business has its own history and traditions, which makes it challenging to introduce new ideas makes it more difficult to manage change.

5. Renewal of university structure and curricula to support adaptation of Industry 4.0 in the region

One important role for universities is to support enterprises by applied research and creation of research and learning environments for continuous piloting of new technologies and preparation of new business models on Industry 4.0. It is not self-evident that representatives of government, enterprise, and universities collaborate with each other. It would be beneficial to support regional development while building up competence through shared projects and development activities. Digitization provides a large variety of opportunities. The question remains are we competent enough to utilize these opportunities. A close co-operation makes it possible to build a shared vision, which guides the further development work. This is important so that all the existing and available development resources could be aligned.

Quite often, it is expected that public sector organizations take care of the development of infrastructure and business environments. However, it is possible that the public sector organizations are not aligned with each other. Some of them may represent national perspective, while some are have a more local orientation. Also, there may still be other organizations, whose duty is to develop business environment. All the layers and activities should be along the same line, support each other, and be sustainable in order to get the co-operative environment to function efficiently. In a rapidly changing operational environment, a clear and commonly understood vision is required.

Industry 4.0 and Internet of Things are new topics; and both enterprises as well as universities have a little experience on what kind of real benefits they may bring. Co-operation between private enterprises and universities has potential, but still many universities as well as companies are just taking their initial steps on this arena. Various areas of collaboration do exist both on a national as well as on an international level. User-driven innovations show lots of promise, and therefore universities should try to identify the real market or real users for the potential innovations. Companies themselves could serve as field labs. One challenge is the confidentiality of information. This should be respected while promoting co-operational learning on various aspects related to Industry 4.0. To be able to reveal the full potential of enterprise-university partnerships, the interaction should take place on all levels. Being able to help the other partner to achieve their goals is beneficial for all. Longer-term development projects require high quality and in-depth roadmaps that should be developed collaboratively. This increases trust and commitment for long-term co-operation. Concrete co-operation project could emerge on various research projects, thesis work on both undergraduate and graduate studies and so on. Different kinds of experiments and measurements related to them could be started. It is important to succeed in benefiting multidisciplinary competence and sharing information sharing openly.

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The vision and approach are based on the need of regional clusters and the strengths of a region (e.g., logistic, university, natural resources, etc.). Industry 4.0 development can be seen as a smart utilization of digitization, which has European level comparability to European development in all key clusters.

Contents of education and training will be designed so that content will respond the future needs. Learning will take place in "real world" environments (field labs), which gives faster cycle time for development activities and implementation. This is the way, how to ensure the birth of new innovations and the renewing the businesses and organizations. In universities, engineering students among others should be prepared to meet the demands of Industry 4.0 in order to be able to operate in future employment domains [9]. However, Industry 4.0 should not be linked to the competence requirements of only engineering students and thus future engineers. It is probable that Industry 4.0 affects largely the whole society, and therefore all the university students should be somehow involved with various perspectives of Industry 4.0.

Most regions do not have a strategy or analysis on aligning regional development and digitization. Häme region of Finland is designing its new strategy "Smart Häme" to respond the challenges of digitization and to be the part of Digital Single Market (DSM). Based on that, the focus is to increase the know-how on how to successfully apply digitization on Häme region. After a Smart Specialization analysis, five key ecosystems (clusters) were identified. These were expected to be the most critical for the development and attractiveness of Häme region (see **Figure 3**). These are the ecosystems, which also should have special attention and resource allocation, in development: "Smart Agriculture," "Smart City," "Smart Factory," "Smart Wellbeing," and "Smart Defense." The evaluation criteria, which were used to select the ecosystems

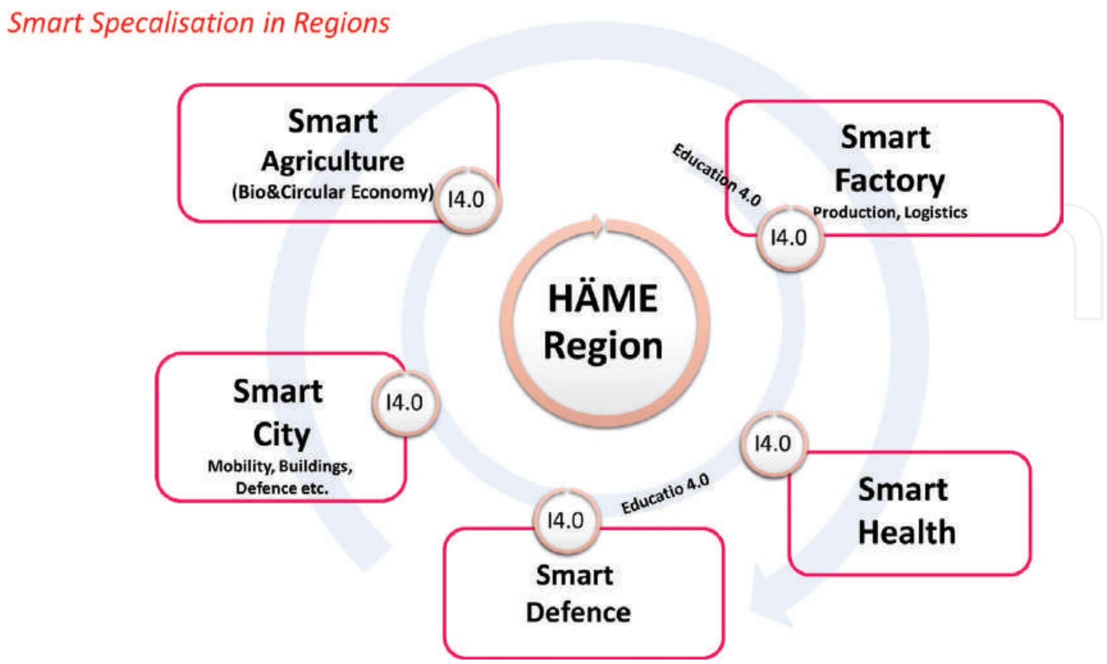

Figure 3. Häme region clusters/"Smarts."

in order to prioritize the development activities and resource allocation, were: size, know-how, importance, and versatility of the identified ecosystems.

“Smart Agriculture” was considered to be the strongest and most advanced, because of food processing industry, agribusiness, large education, and strong R&D activities in the region “Smart Agriculture” includes both BioEconomy and Circular Economy (bio) activities in the region.

“Smart Health” is the biggest expense in the cost structure of public services. Also, the amount of increasing elderly people and demand for better services emphasize a strong need to utilize the various opportunities of digital services. There are also many equipment and service providers in the region.

“Smart City” was also considered to be one of the key elements to improve the competitiveness of the region. There has been a clear understanding that digitization will change the planning of cities and the services in a city. The majority of services are probably in the densely populated urban areas in city centers. In Häme region “Smart City” includes also issues related to tourism, “Smart Mobility,” “Smart Buildings,” and “Smart Security.”

“Smart Factory” has not been traditionally linked with services at all; but when we take a closer look at manufacturing industry, we will notice that lifecycle services might even play a bigger role than the production itself. Also, modern supply chains in the manufacturing industry have a strong and large service component. Regional development point of view is important to see that manufacturing itself creates new innovations and services.

The Smarts in the region and the ecosystemic choice to develop them are based on the region’s own choices and intent. When defining the smarts, at least the following things should be taken into consideration: the strengths of the region, the competence (students and universities), the size, the intent, the development prospects, the history, the inheritance, the logistical position of skilled labor, prospects, and trends.

It is also important to understand the supporting nature of knowledge-intensive services in an increasingly digital world. This would better able the regional authorities and developers in co-operation with other actors to support the emergence of innovative ecosystems. Each smart must create its own “I4.0” renewal program, which creates a common vision, strategic steps forward and integration with the existing network organizations. **Figure 4** illustrates how the selected smarts are linked to university’s faculties (schools) and research units.

Industry 4.0 focuses on the fourth major transition phase in an industrial partnership covering all industries and areas of life. The fourth stage of the transition is digitality and the development of information technology. Industry 4.0 provides a framework for development, development of architecture, and standardization, and hence functional compatibility. The development of Smarts (clusters) is based on a multi-disciplinary know-how, therefore universities must support development work in all the sectors they are implementing academic degree programs. The following topics ought to be taken into account while renewing university’s structure and curricula.

5.1. Transdisciplinary approach

A transdisciplinary approach to research enables multidisciplinary outlook and understanding phenomena from various perspectives. This makes it possible to study complex systems and their interactions.

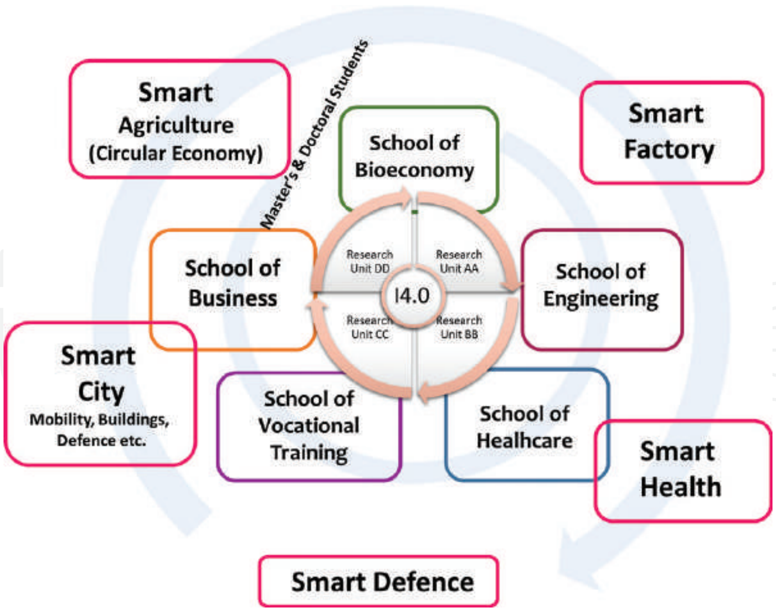

Figure 4. Integrating regional Smarts and university structure.

5.2. System design management

Digitality, multidisciplinarity, and the growing speed of change will result in increasing complexity, which is why the need for knowledge associated with managing complexity needs to be taken into account in education and development.

5.3. Smart specialization

Digitization provides the ability for data collection, rapid transfer, and processing. Various activities create new kinds of networks around them. For this reason, entities should be considered as digital ecosystems, which form efficient value chains and thus support creating new customer-focused products and services.

5.4. Field labs

The real-life learning environment is based on training, research, testing, and piloting environments. Multidisciplinary, complex, and fast changing things need “real-life” environments, where new things can be learned, adapt rapid methods for developing new products and services, and thus enable innovation to emerge.

5.5. Innovations

There are opportunities for new innovations that arise from different disciplines, customer interfaces, digital ecosystems, etc.

5.6. Organizational culture

The introduction of new approaches will also require the systematic development of a new organizational culture and a strong vision of the goals regarding the renewal.

6. Applying Industry 4.0 as a framework for increasing competitiveness in the region

Attractiveness from various perspectives is important so that region would be seen as an interesting and innovative environment. On the other hand, cities and public organizations (for example, hospitals, military bases, elderly houses, schools, parks, etc.) are using tax money for maintaining the welfare and provide services for people and organizations in the region. Based on that background, it would be justified that public organizations would be acting as "platforms" for different actors. This would allow testing their activities and products in "field labs" where education, research, and testing would take place in the same multidisciplinary environment.

We recommend that Industry 4.0 would be used as a transdisciplinary framework supporting a development of local service ecosystem. Since Industry 4.0 is a European concept and part of European platform, it is proposed that best practices will be benchmarked into European approach and experiences.

The key elements to designing the Local Service Ecosystem for Industry 4.0, are:

- "Smart development areas": to recognize the potential "smart" clusters on the region/area
- Vision: create the goal and vision for regional development based on "Smart" clusters
- "Field labs": make public sector organizations, cities, companies and universities to work together and create "real life learning" environment (field labs) in clusters.

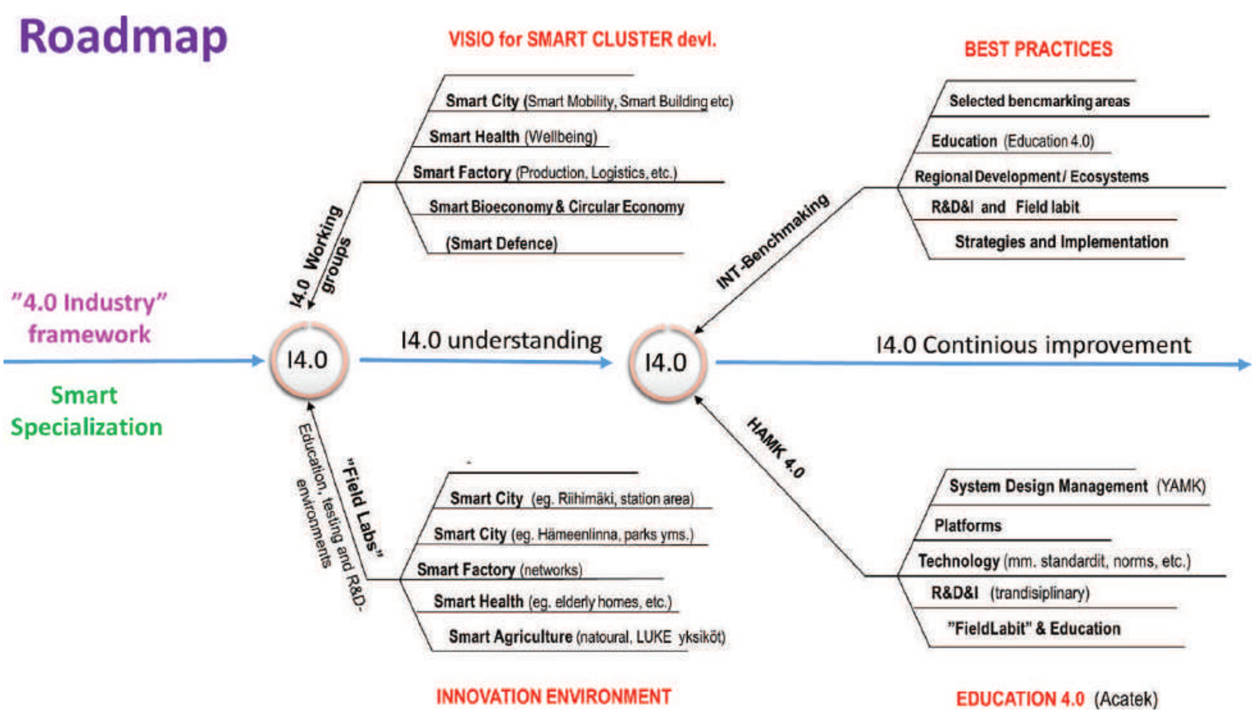

Figure 5. Steps to develop Industry 4.0 related services.

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- Education: renew education content so that it response the new ICT-based technologies that are needed in Industry 4.0 and transdisciplinary approach.
- Benchmarking: make benchmarking for the regions, which are like “Häme” and have already taken the steps to adapt Industry 4.0 and to ensure compatibility.

These elements are further covered in **Figure 5**. The core idea of the figure is that Industry 4.0 framework should be understood in the existing innovation environment so that smart clusters could be established. International benchmarking could be applied to identify best practices, which could be adapted to educational programs and field labs. In order to be able to adapt Industry 4.0 framework to education so that it could be called Education 4.0 the following issues should be considered: system design management course should be introduced as a part of graduate studies. Technology platforms and implementation of transdisciplinary field labs should be introduced.

7. Discussion and conclusions

The principal idea behind this article has been to combine the principles of Industry 4.0 to value network thinking and digitization. Industry 4.0 is about creating significant impact and opportunities where business, technology, services, and innovation intersect. The aim has been to find a transdisciplinary concept supporting higher education, regional development, and business renewal in testing laboratories, while supporting and enabling new growth opportunities in the region.

That requires combining of various approaches. The main challenge is in the utilization of transdisciplinary knowledge and implementation work. The use of new technologies; including digitization and big data can capitalize on new opportunities. According to the experiences of conceptual development work, successful activity in Industry 4.0 is dependent on systematic long-term development on the public sector. The essential topic is preparing of up to date platforms, which enables, controls, and support the operations and creates a business environment to apply approaches. There are several contributing technologies related to Industry 4.0 framework. This implies that there is a major emphasis on competence development, and shared learning to apply these technologies to support transdisciplinary regional development.

The practical implications for renewing a university so that it could better support the adaptation of Industry 4.0 are as follows:

1. Higher education institutions should provide education and support for the adaptation of Industry 4.0

It is important to give a relevant role for the higher education institutions to provide and support a transdisciplinary approach to study services in a proper operating environment.

2. Research and learning environments in universities should be used to pilot new Industry 4.0 related technologies

One of the core roles for universities is to support enterprises by applied research and by creating of research and learning environments for continuous piloting of new technologies and preparation of new business models on Industry 4.0. At the same time, a local higher education institution's future areas of focus, challenges related to digitization, as well as profiling among other higher education institutions are taken into account.

3. Enterprise-university partnerships should be established

To be successful on new challenges of Industry 4.0 development, enterprise-university partnerships have to be intense and main objective should be a shared learning. Long-term co-operation creates a background for new co-innovation and co-evolution.

Adapting Industry 4.0 framework as a basis for development activities is expected to provide not only an opportunity for remarkable competitive advantage for businesses, but also for regions.

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Chapter 7

Digital Smart Jewelry: Next Revolution of Jewelry Industry?

Erno Salmela and Ivary Vimm

Additional information is available at the end of the chapter

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Abstract

The purpose of this article is to examine business potential of digital smart jewelry. When jewelry has tens of thousands of years of history, it is interesting to find out what people think of jewelry that contains technology. The study was conducted as an action research, in which researchers acted as main innovators of smart jewelry. The smart jewelry can be divided into two main product groups: the esthetic light jewelry and the functional jewelry. Six different jewelry prototypes were manufactured–three pieces for both product groups, after which they were tested by potential and nonpotential users. According to study, the smart jewelry seems to have business potential, but as often with radical products and new markets, it will take time. Forty percent of potential users saw the smart jewelry as fun, cool, fantastic, and an inevitable future. On the other hand, 25% kept them as obnoxious. The functional jewelry seems to have much more potential target groups and users than the light jewelry. As wearable technology and the Internet of things become more common, the smart jewelry market will probably grow as well. The healthcare and wellness industry is a particular force for growth.

Keywords: smart jewelry, digital jewelry, wearable technology, prototype, revolution, radical innovation, user-centered innovation, user experience, user-study method, user data

1. Introduction

Wearable technology is one of the megatrends. One of its branches is the digital smart jewelry (later in text 'smart jewelry') that are esthetic and jewel-like smart electronic devices, which provide different kinds of value for their user. The smart jewelry is a new product group without an established market. Therefore, the uncertainty in demand is very high. Smart jewels are already on the market, but the sales volume is still modest. Why do not people buy smart jewelry? What people think the jewelry that contains technology? On the other hand, because of the current movement toward digitalization is everywhere, it may be only a matter of time before digital technology will emerge in jewelry. The aim of this study is to find out whether the smart jewelry has the potential to break through widely and even revolutionize the jewelry industry. In order to reach a holistic view to research problem, the study seeks answers to the following questions:

- What kind of smart jewelry has the most business potential?
- What value people expect to experience from the smart jewelry?
- Who are the most potential users of the smart jewelry?
- How and in what circumstances the smart jewelry would be used?
- What can prevent people from buying and using the smart jewelry?

Therefore, the objective was to create new information on demand and thus reduce uncertainty in demand. It was important to understand what potential and nonpotential users think of smart jewelry. Nonpotential users were defined as a group that does not use even traditional jewelry. Uncertainty of innovation, user-centered innovation, and user-study methods were utilized as theoretical themes. Users were participated in innovation in different ways, and user data was collected with various user-study methods. The smart jewelry was divided into two product groups: the LED technology-based light jewelry and the functional jewelry that can contain different kinds of technologies. Jewels in the light jewelry group do not create functional value for their users, but esthetic, status, emotional, and symbolic value. Three different kinds of smart jewel prototypes were manufactured for both the product groups to obtain user feedback concerning five questions presented above. The light jewelry prototypes included light jewelry for consumers, light jewelry for pets, and effect jewelry for a movie and its fans. The functional jewelry prototypes included bola jewelry, lifesaving jewelry, and access control key jewelry.

Next section presents the methodology of the study, after which Section 3 focuses theoretically on uncertainty of innovation, user-centered innovation, and user-study methods. Section 4 presents the action research and its results, and the article ends with conclusions.

2. Research methodology

The purpose of an action research is to develop new skills or a new approach to a specific matter and to solve problems that have connection to some practical activity. Action researchers have an active role in this. Action research helps to examine reality in order to change it, but also to change reality in order to examine it. Action research is suitable for situations where action is taken to change something and at the same time increase both understanding and knowledge about change. The action study proceeds cyclically. During the new rounds, new efforts are made to increase knowledge or improve something.

The objectives and problems of an action research are formulated together with researchers and practitioners. Often, it is somewhat difficult to determine what a customer needs for results. The customer may also be unknown when the research is executed. The purpose of this research was not to influence a specific company but rather to provide with information on the potential of smart jewelry to inspire and prompt some companies to develop smart jewelry in the future. The research was positioned in the first phase of market design, the mental model design such as market definitions for smart jewelry. The action researchers were in the role of an activist by encouraging companies to move forward.

Reflection is an essential part of action research. It is defined as a conscious, systematic, and critical assessment of events, with the aim to learn something new. It is a matter of distancing oneself from the phenomenon under consideration–by watching it from the outside. Action research proceeds as follows:

1. Definition of problem or setting of goals
2. State of art: what is already known about the problem or solutions
3. Planning of study and interventions
4. Action: Doing interventions
5. Gathering data from interventions; for example by observing
6. Reflection: Assessment of interventions; what was learned [1–4]

The study was conducted as an action research of two researchers. Adapting the above process, this study proceeded as follows:

1. Definition of problem: What is the business potential of the smart jewelry. Research questions were set based on uncertainties – in other words, what information is needed to understand the business potential.
2. State of art: Preliminary understanding about the uncertainty of innovation, user-centered innovation, user-study methods, and smart jewelry was created.
3. Planning: Interventions were recognized and planned to create new knowledge on research questions.
4. Action. Part 1: Hundreds of different smart jewels were brainstormed by potential and nonpotential users, after which the best 30 ideas were conceptualized. Prototypes were designed and manufactured for six different smart jewelry groups. Part 2: Implementation of interventions to get feedback from potential and nonpotential smart jewelry users.
5. Gathering data: Prototypes, surveys, trial runs, design probes, observation, interviews, conceptualizing workshops, and storytelling were used as methods to gather user data.
6. Reflection: The action researchers conducted a critical reflection of the user data and created understanding how people relate to smart jewelry.

3. Preliminary theoretical understanding through literature review

Theoretical themes included uncertainty of innovation, user-centered innovation, and user-study methods. In addition, it was examined what kind of smart jewelry is already on the market. In 2013, there were still very few jewelry for sale, but innovation and development work seemed to be in quite a many places in progress.

3.1. Uncertainty of innovation

Innovations can be parsed with the product-market matrix (**Figure 1**). Uncertainty is greatest when creating a new product for new markets. This is called a suicide quadrant of innovation. In fact, entrepreneurs or innovators do not see this as a suicide quadrant, but as a vital possibility to create new business [5, 6].

Uncertainty can be divided into uncertainty in demand (whether customers buy a solution) and supply/technology (can we build the desired solution). Uncertainty is related to a lack of knowledge. The more unknown things are in customer preferences and behaviors, the greater is the uncertainty in demand. If there are already existing products and market, then forecasting is easier, for example by analyzing competitors' sales and actions. Technological uncertainty is associated with, what new technologies emerge, and when or what kind of new technology the company can itself develop. Experimental innovation with users has been seen as a key tool to reduce uncertainty [7–9].

3.2. User-centered innovation

User-centered innovation means that persons in the company and its value network are included in the innovation. Especially the end users of products and services play an important part in this. Users can also come from outside the current value system, in which case the issue deals with extreme type of open innovation [10, 11].

Users may have different roles during the innovation process, such as idea creator, evaluator, idea refiner, designer, and manufacturer of prototypes. At most, they may participate in

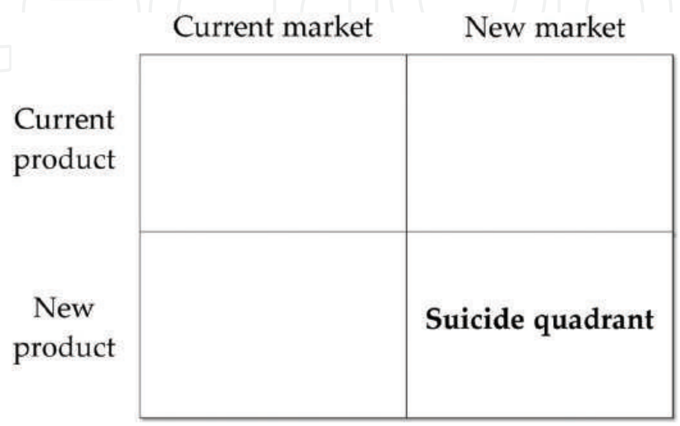

Figure 1. Product-market matrix [5, 6].

innovation throughout the innovation process. On the other hand, users can be grouped to three groups according to how active they are:

- for the user: company creates a solution based on knowledge about users' needs,
- with the user: company and users co-design a solution, and
- by the user: users innovate a solution on their own initiative [12–16].

Innovation is born when a company meets the conscious or unconscious needs of the customers. Majority of the customers cannot say what they need before seeing and even experiencing a solution. Unconscious needs often come up only through product or service experiences. This may take place, for example, by providing a prototype for the customers to test use. Customers can be divided into innovators, early adopters, early majority, late majority, and skeptics. Innovators and early adopters are called lead users. Compared to the designers who are good at solving defined problems, the lead users or fans are need experts who have insider knowledge. They can identify previously unknown customer needs. When they bring their need expertise in order to connect it with a designer’s solution expertise, new solutions can become blockbusters. Lead users often help designers further customize and fit a product into users’ everyday life. The innovators are the kind of lead users who innovate on their own initiative. The early adopters, on the other hand, are more like codesigners. Critical point is between the early adopters and the early majority. Most innovations die in this chasm [9, 12, 15–20].

3.3. User-study methods

The essential thing in creating new products for new markets is to challenge the current market definition and create a new one; in this case, challenge the definition of traditional jewelry and create a new one for smart jewelry. Creating a new market definition is based on an in-depth understanding of the users. For this reason, it is necessary to consider what designers know in advance, and which questions can only be answered through collaboration with customers and other partners. For this, variety of user-study methods can be utilized such as user participation, prototypes, experiments, observation, and interviews (**Figure 2**). On the basis of the user research problem, the most suitable method classes and single methods within them are utilized. The use of different methods may take place simultaneously (e.g. observation and interview) or sequentially, such as making first prototypes and then testing them. Choosing the method and knowing how to use it are essential skills when carrying out user research [17, 21–23].

In the user-centered innovation, qualitative research methods are utilized instead of or in addition to traditional market surveys. The aim is to get caught up on the users' experiential relationship to a product. This approach is a key to getting an idea of a variety of product use cases and finding the core value of product. It is critical to understand user goals and motives through the meanings. User understanding can be structured through user profiles that refer to a variety of ways to use the product, as well as attitudes toward the product. Users can be placed in different categories, such as doubtful, familiar, seeker, etc. Creation of a user profile can start from only one customer by understanding his life profoundly. After this, the profile may reflect a larger crowd [9, 17, 24].

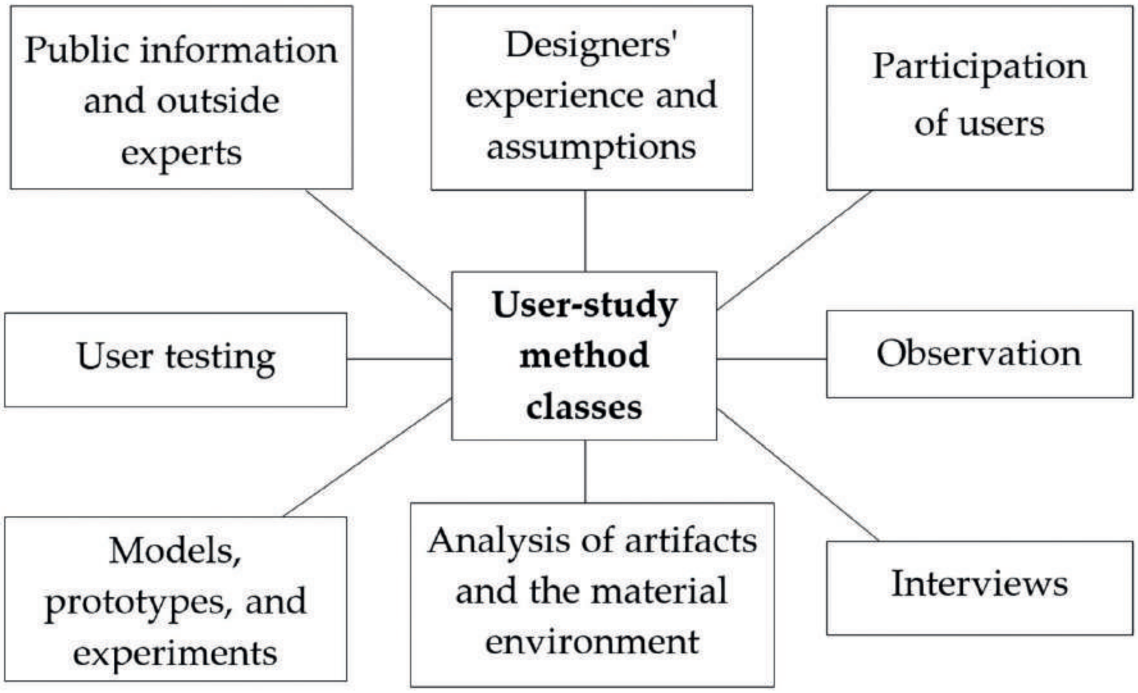

Figure 2. User-study method classes [21].

4. Action research

Smart jewelry is a new product group without an established market. An initial market definition was named concisely "smart and digitalization comes to jewelry." Smart jewelry is a category of wearable technology, and therefore the market definition of wearable technology [25] was applied to the second market definition: *Smart jewelries are esthetic electronic devices (electronic devices with microcontrollers), which provide value for their user through esthetic and different functions and features.*

4.1. Background of smart jewelry innovation

The idea of smart jewelry was conceived in 2012, in a technology company's innovation workshop, where different applications for the company's display technologies were created. One of the ideas related to the smart jewelry. One of the researchers was involved in the workshop, and through this, innovation of smart jewelry started. Initially, seven smart jewelry brainstorming and conceptualizing workshops were held, which produced hundreds of ideas of 30 concepts. The best 100 ideas were described briefly in text format, through which a common understanding of smart jewelry was formed. For example, a reminder necklace was described as follows: *The necklace reminds a person when to take the medicine*. In the brainstorming stage, the smart jewelries were divided into two product groups: the esthetic light jewelry and the functional jewelry.

> Smart light jewelry was defined as follows: *Light jewelry provides users esthetic, symbolic, social, and emotional value, and differs from traditional jewelry by using internal light as additive design element.*

> Smart functional jewelry was defined as follows: *Functional jewelry provides users just only aesthetic, social, symbolic and emotional value but also functional value, in other words concrete benefits.*

The best 30 smart jewelry ideas were conceptualized. **Figure 3** shows pictures from conceptualizing workshop and the first rapid prototypes of smart jewelry. Rapid prototypes were important in making the ideas more concrete as well as in forming a common understanding what smart jewelry means. They also inspired to innovate more.

The best smart jewelry ideas were conceptualized, after which prototypes were manufactured from the best concepts. By utilizing readily available electronics, some of the prototypes became bulky and heavy compared to many traditional jewelries. Solar cells were utilized in some prototypes as renewable energy source.

Action researchers were the main innovators of smart jewelry and potential jewelry users themselves. Numerous other potential and nonpotential users participated in innovation work as innovators, early adopters, and other users of smart jewelry. Less than 5% of them had previous knowledge of smart jewelry and no one had any previous user experience. Sixty-eight percent of users were Finnish and the remaining 32% came from other nationalities, emphasizing on Europeans. Totally 14 different nationalities were presented. The proportion of women to men was 61 vs. 39%, and the age varied from 16 to 62 years, the average age being 25 years. One-fourth of the test group people did not use even traditional jewelry at all. They were chosen to study as the laggards or the late majority groups. It was immediately obvious that the smart jewelry was "high concept," which attracted people's attention and pulled free resources to participate in innovation. To get answers to the five research questions, different kinds of user-study methods were used (**Table 1**). The manufactured prototypes were utilized with all the methods.

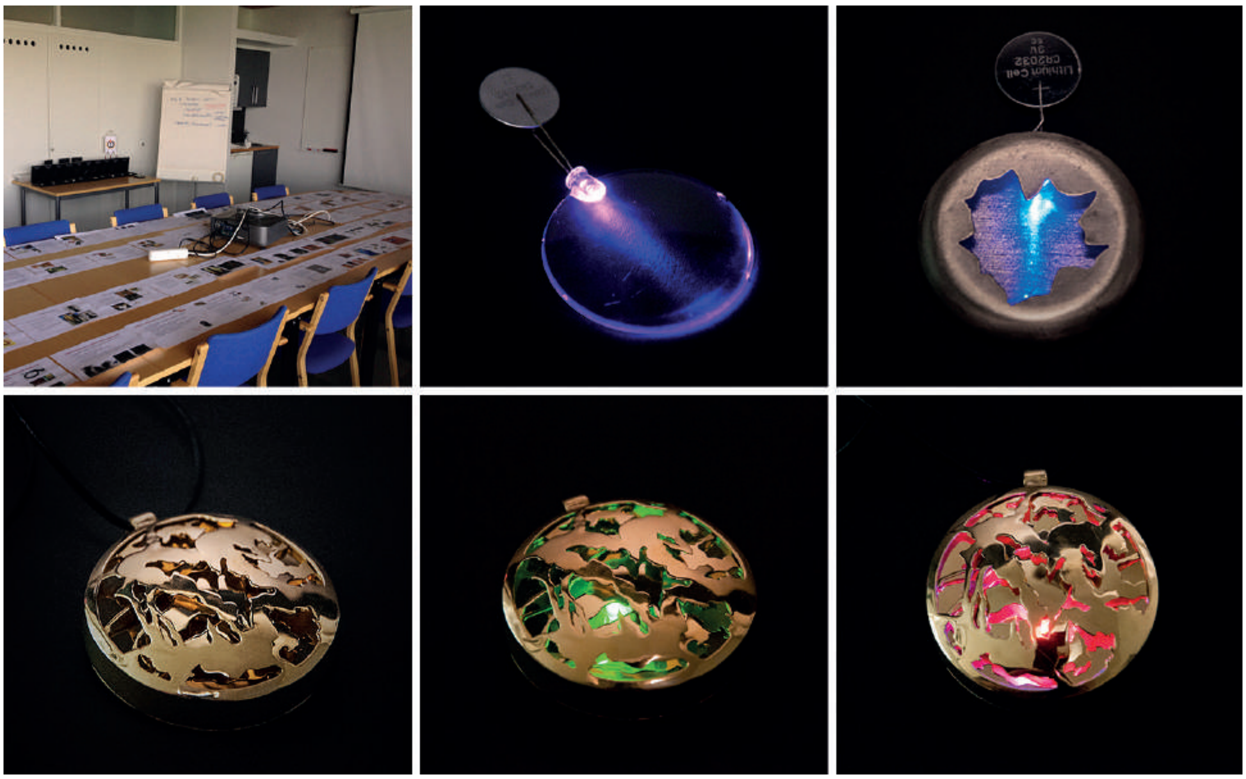

Figure 3. The concepts and first rapid prototypes of smart jewelry.

Research method	Objective
Public information and outside expert	Examine, what kind of smart jewelry is on the market and how much they sell.
Designers´ experience and assumptions and user participation	To create smart jewelry ideas and concepts. Eight designers created hundreds of ideas and 30 concepts in seven brainstorming and conceptualization workshops with Finnish people.
Rapid prototypes and prototypes	To recognize technological challenges, to inspire, and to help obtaining user feedback, two designers (action researchers) designed and manufactured 15 rapid prototypes and after this prototypes for six different kinds of smart jewelry.
Survey	To obtain views from a wide range of people from different nationalities about smart jewelry value, use cases, main target groups, and jewelry design. The surveys were carried out in Finland and Germany in international events. N = 186.
User testing and interviews	To find the emerging experiences and meanings from smart jewelry use in real-life situations. Information was collected through design probes and interviews. The trial use was carried out by Finnish users. N = 21.
Passive observation	To get information about smart jewelry users' preliminary reactions and how other people react the users with jewelry. This observation was carried out in Finland and Germany in international events. N = 85.
Participatory observation and interviews	To get information about smart jewelry user's preliminary reactions and how other people react the users with jewelry. Action researchers put the smart jewelry on themselves. Third of the people were also interviewed. The observation was carried out in Finland in international and domestic events. N = 57.
User stories	To obtain feelings toward smart jewelry. User stories were written by Finnish users. N = 12.

Table 1. User-study methods used in mental model design.

In the following, six different smart jewelry prototypes are presented and how users experienced them. The light jewelry prototypes included jewelry for consumers, jewelry for pets, and effect jewelry for a movie and its fans. The functional jewelry prototypes included life-saving jewelry, access control key jewelry, and bola jewelry.

Taking into account all prototypes, almost all people interested also in traditional jewelry reacted to smart jewelry with a strong or fairly strong emotion – positively or negatively. Forty percent of these people saw smart jewelry as fun, 'cool,' fantastic, and an inevitable future. About half of them loved the smart jewelry. On the other hand, 25% of "traditional jewelry people" could not tolerate the smart jewelry. The remaining 35% were unable to form a clear opinion. One fourth of the participating test users were not "jewelry people." Eighty-five percent of them were not either interested in the smart jewelry. With the functional jewelry, the potential user base is remarkably larger than the light jewelry.

4.2. Prototypes and user tests of light jewelry

4.2.1. Light jewelry for consumers

Three different light jewelry prototypes were manufactured (**Figure 4**) to help people to find the most preferred design for themselves. The jewelry on the left was a favorite for test users

Figure 4. Light jewelry prototypes for consumers.

because of its pleasant design. The light effect worked best in it as an additional design element. For the test users, the light jewelry produced esthetic, emotional, symbolic, and social value. Middle jewelry in the figure was able to charge with solar energy while the other two were charged electrically. From test users′ point of view, this was a good feature that produces ecological value.

The light jewelry was considered most likely to be used in evening parties, parties for young people, and at Christmas or pre-Christmas, but also in everyday use (**Figure 5**). As user studies progressed, it was realized that the original assessment of young adults as the main target group of light jewelry was wrong. Young people quickly began to ask whether the light jewelry incorporated additional features, such as a music player and sensors—in other words, functional value. They wished to challenge jewelry more holistically with regard to design. On the contrary, many 35–50-year-old women born in 1960s and 1970s fell in love with the light jewelry. More precisely defined, they have a positive attitude to life and were extrovert, courage, tolerant, being trendsetters, and 'nutty.' Also men who have same kinds of characteristics were seen as potential target group. Other potential target groups were communities, guides, and tourists. Also, pets were found to be one new potential user group–*"I could also buy a collar with light jewelry for my dog."*

Light jewelry was seen more as a work of art than an electronic device. Silver or other high-quality material was seen as a clear added value. Jewelry design had a significant impact. Test users wanted to find their preferred model from the model options. None of the test users expected personal customization, but the personal product relationship appeared strong.

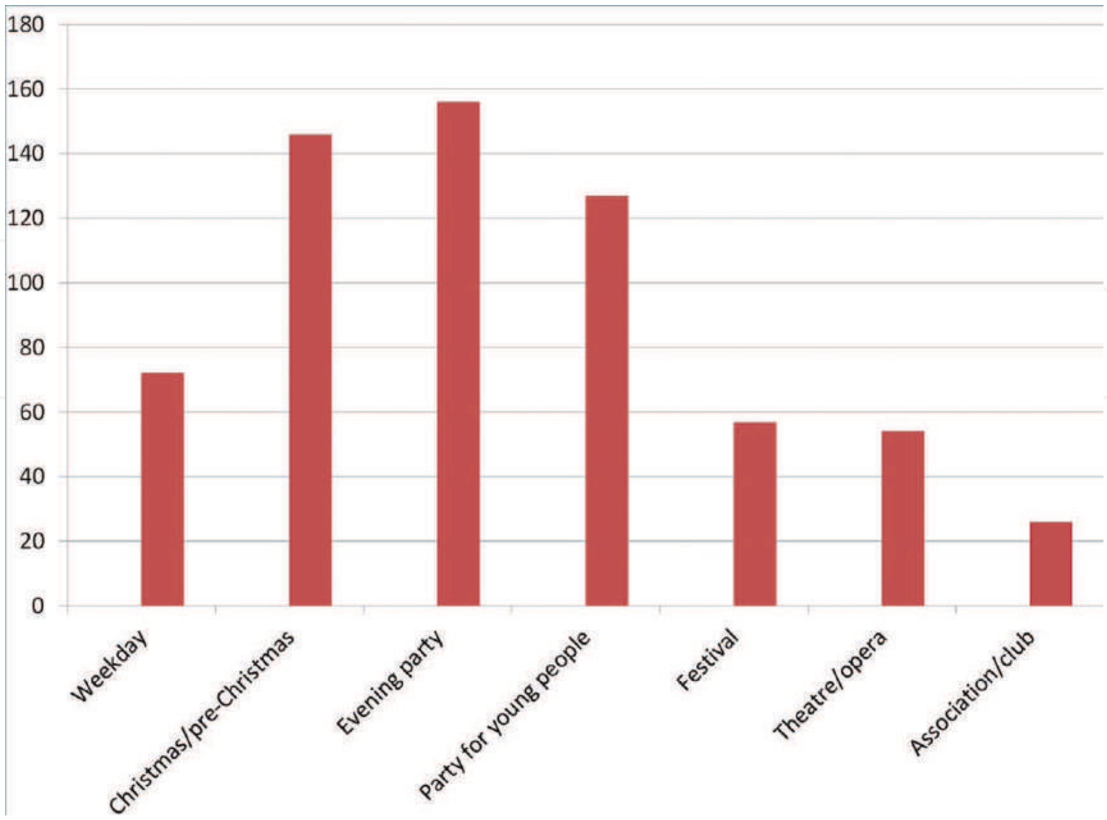

Figure 5. Use cases of light jewelry.

Color options for lights in the same piece of jewelry were important. Most quickly found their favorite color and said they could also change the color depending on the situation and their clothes. Light jewelry aroused curiosity and interest in people. Strangers watched the jewelry cautiously and whispered, *"Is there a light?"*. Users felt it was important that the jewelry was impressive even without light. Jewelry with light is not suitable for all situations; for example, a funeral or when someone else is the center of attention. In everyday use, jewelry also received some disapproving views, such as *"Why are you trying to show off."*

During the test use, it obtained usable bits of story such as *"Light jewelry brings joy to my and others' lives,", "I would proudly wear light jewelry," "Light jewelry looks impressively grand," "I would want one right away,"* and *"I would buy is as a Christmas present for my wife."* People also wanted to give their own names such as *"Twinkle," "Aurora borealis," and "Fairy of Light"* for the jewelry.

Battery life, the need for maintenance, price, and market position raised questions. Most of the respondents estimated the price range as or would be willing to pay 200€ for designed light jewelry. On the other hand, if light jewelry is perceived as bauble, the price should be max 20€. Some did not like the large size of the jewelry, while others appreciated it for that same reason. Quite many, however, thought the jewelry prototypes were too heavy. People wished for more compact and lighter models as well as more details. **Table 2** summarizes contents from stories that test users wrote about the light jewelry.

Why would I buy them?	- They stand out from the crowd, they are different - They are modern and innovative, they have a novelty value - They are wonderful, esthetically pleasing/attractive, fun, interesting, youthful, impressive, playful, intriguing, surprising, and personal - They are striking - They are versatile–they adapt to different situations and clothes
Whom I would buy light jewelry?	- For myself - For family members – for a spouse and/or children - For friends or acquaintances - As gifts or business gifts - My pet
What would I tell about light jewelry to others?	- They are great gifts - They are fun, beautiful, and unique - The color of the jewelry can be changed - They have received recognition on television news and other media - They are jewelry containing electronics/new technology - They make for good costume jewelry and also work for bar nights - They are a different and a thing for pioneers - The jewelry comes in various models that can be adapted - They are unique and handcrafted
What may be troublesome?	- Adequacy of power - Changing the battery–could energy be produced ecologically? - Frost durability - Lifetime/duration of technology - Big size, palette is too colorful - Price

Table 2. Summary of results from user stories.

4.2.2. *Light jewelry for pets*

When it comes to pets, the reactions of the animals to light jewelry were observed. The prototype was tried on cats and dogs (**Figure 6**). When the cord was adjusted appropriately, so that it did not meddle with walking, it did not bother dog at all, seeing as dogs are used to collars to begin with. It was more challenging with cat, but it also got used to the collar in ca. 5 minutes. The cat got used to collar more quickly the next time it used jewelry. A solution that would be lighter than the prototype would be more suitable to smaller animals. The test pets weighted 7 and 4.5 kg. The potential purchasers are naturally pet owners and their animal friendly friends. The pets themselves do not obviously be esthetically pleased with the jewelry. Pet owners saw two crucial values of the pet jewelry: they decorate the pet and act as a substitute to a traditional reflector for safety, later of which is a functional feature. Ca. 30% thought that the idea of jewelry for pets was good, but an equal amount was of a different opinion. Mostly the pet jewelry was interesting to those pet owners, who themselves wanted to own a light jewelry. The idea for further design work was that more user friendly solution would be a design collar with integrated jewelry. The collar would be more practical because it lets the pet move freely, and poses no imminent threat of choking. As an additional functional feature, a locating or tracking system was wished for, in case the pet goes astray.

Figure 6. Light jewelry prototype for pets.

Too high a price can be a hindrance when buying light jewelry for your pet. On the other hand, the jewels are possible to be made more cheaply for pets because of more affordable materials, for example, plastic, rubber/latex, etc. The need for maintenance was also seen as a possible hindrance. However, nowadays there are LED collars, where the change of batteries is made easy. Furthermore, there was a speculation about the jewelry's durability and safety in wet conditions, but the solutions are possible to be made waterproof. The whole idea of pet jewelry is part of the trend of people using more their time and money on their pets.

4.2.3. Effect jewelry for a movie and its fans

A prototype with highlighting the logo of the movie was made, which then could be used as a so-called effect jewelry in the movie—even a central part of the plot. Effect jewelry would then bring esthetic value and possibly functional value (cf. the light sabers in Star Wars). For better visibility, the piece of jewelry was made big, ca. 6 inches in diameter. In **Figure 7**, we can see the effect jewelry prototype in action, while in the lower part of the figure shows the blueprint and electronics of the jewelry. The more pivotal role the jewelry would be in the movie, the more likely also the fans would buy the consumer version of the jewelry. The size of the fan jewelry is about half of the original and it would be available also without the effect feature, that is, a regular piece of jewelry. With alternative versions, fans could have a choice of design and price. The jewelry could be numbered and thus unique.

Fan jewelry could be a subject of crowdfunding along with more traditional ones, like signed Blu-ray or DVD discs or posters. It would be a symbolic icon for fans to have been a part of a

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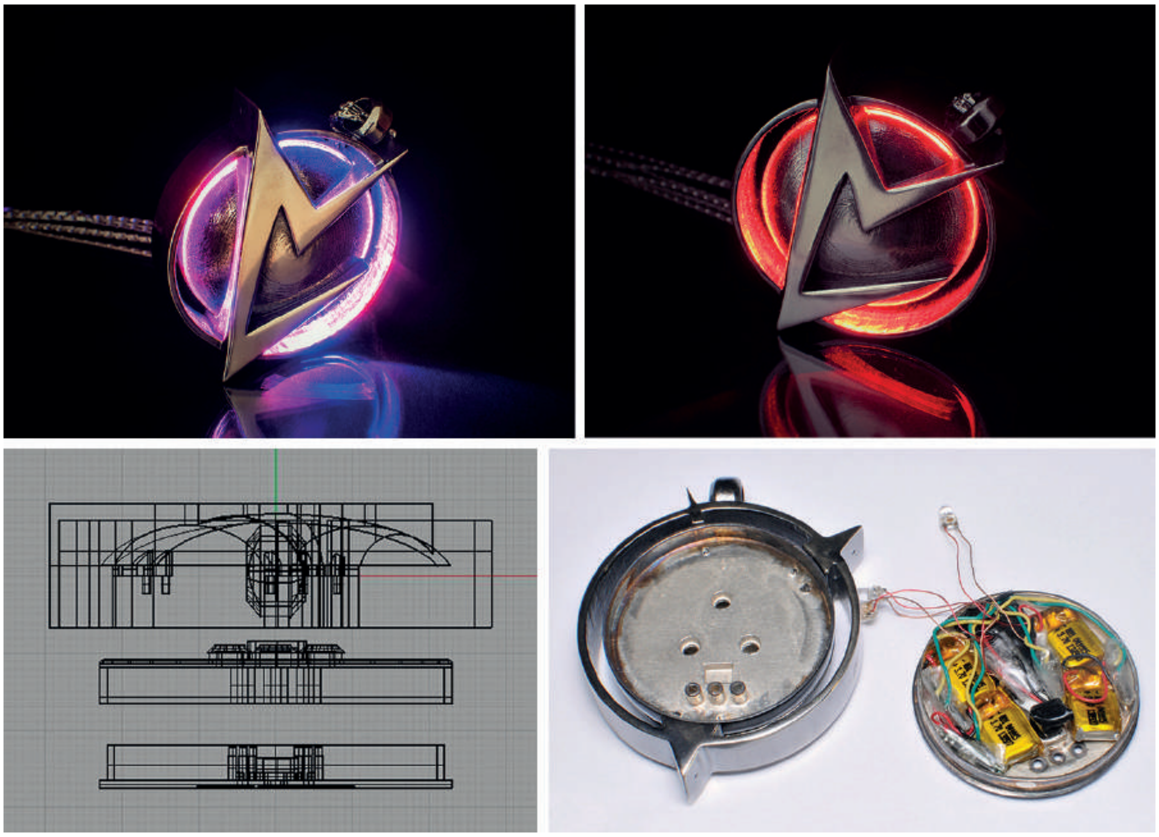

Figure 7. Effect jewelry prototype for a movie and its fans.

group making the movie possible. The jewelry would thus have a clear meaning. Furthermore, it could be a utility article for everyday and party use. Party use could be wearing the jewelry for a premiere or a fan meeting. People could be interested in jewelry of this kind even when they are not usually jewelry oriented. Effect jewelry could be an object in a showcase. The value for the moviemakers would be economical and related to getting the fans hooked; furthermore, the jewelry would have image value and marketing value. This already realized when the media got interested in the effect jewelry.

The insufficient visibility could be a hindrance in using the item in a movie. This already happened when filming the trailer for the movie. As the lights were so strong, the effect jewelry did not shine enough. On the other hand, if jewelry is not an integral part of the plot, it is a mere decoration with no larger significance. The purchase or use of the jewelry can be prevented by the fact that it does not please the fans despite the different choices, the price is too high or the fan is simply not interested.

4.3. Prototypes and user tests of functional jewelry

4.3.1. Lifesaving jewelry

Lifesaving jewelry (**Figure 8**) contains the crucial identity and health data of the person who is wearing it, readily readable in the case of a sudden seizure, which means when the person is not being able to show data or tell about it. Smart jewelry had a near field communication (NFC) tag into which the data had been recorded. In the prototype, the health information

Figure 8. Lifesaving jewelry and its field test.

was readable with mobile phone by putting it close to the jewelry. A field experiment of this was carried out with paramedics. A situation with the person having a seizure was simulated. She acted unconscious and could not communicate at all. Paramedics had ca. 20 seconds to get the health information they needed and began taking measures according to that. The paramedics saw this solution as easy and good. The piece of jewelry was easy to be found so that the information was reachable by turning the actor. The situation could be made easier if the piece of jewelry or a similar gadget could be read from afar, let us say from a five-foot distance, and then the lifesaving jewelry or gadget wouldn't even have to be found. On the other hand, this poses problems to one's privacy. The problem could be solved with a special scanner and special tag.

Lifesaving jewelry is suitable for everyone who likes jewelry, but first and foremost for risk groups, such as diabetics, those with allergies and chronic illness, those who use prescription medication, and those with a heart condition. On the other hand, the solution is suitable for amnesiacs, children, or animals that may go astray or missing. For those groups, the jewelry may contain contact information of home and people near to them. Jewelry is to be worn daily—at least when the user leaves home, but depending on the user it would be good to wear at home.

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As seen in the picture, the jewelry can be made with style utilizing NFC tag in the design (black element in the middle). Furthermore, there is a topaz and a jewel that was made of silver. Most of the test users liked the design very much indeed. Some were almost revolted by traditional wristbands that gave the user the stigma of being ill. Part thought that the prototype jewelry was too large (diameter of 31.50 mm), and would not wear it because of that. The design of the piece of jewelry in the picture is for females, but with different design, it could be worn by men alike.

Negative reaction on the authorities' side and bureaucracy might be hindrances to lifesaving jewelry's success. The danger of the client's health information getting abused may be seen stronger than the danger of wrong medication or medical procedure or getting them too slowly. The crucial hindrances are thus related to information security and the safety of privacy. Also, the durability and the reliability were questioned, what if the battery runs out, or the piece of jewelry gets wet? How do you update the health data? The last one is easily done with a mobile phone. Lifesaving jewelry has a passive tag, that is, it does not need a battery. Also, the tag has a waterproof coating. The version made of precious metal might be too expensive, so more affordable versions should be available. On the other hand, the data can be in a wristband or a ring along with the pendant, but we must bear in mind the size of the tag. One obstacle is that everyone does not like jewelry, so other alternatives, such as a tag in one´s wallet or watch, or even a microchip under the skin, must be available. 'Selling' the jewelry to the elderly, especially for men, can be challenging. One has to also bear in mind the limited amount of data that is possible to put in a NFC tag in the jewelry. Perhaps, the best solution would be a system based on fingerprints, which enables access to personal info in a database by scanning the fingerprint.

4.3.2. Access control key jewelry

Access control key jewelry (**Figure 9**) is designed for the opening of electric locks and for monitoring working hours. Three different prototypes were made: a ring, a tie tack, and a bracelet. An access control key is inside the jewelry. It is as easy to realize as the lifesaving jewelry, it does not need a power source. The target group is enormous: production facilities, hotels, hospitals, schools, offices etc., and also homes as the electric locks become more popular. The

Figure 9. Access control key jewelry and its field test.

traditional unappealing access control key may be modified to match with the organization's brand and visual look, as well as create personal designs.

Prototypes were easy to make by taking apart traditional access control keys and changing the RFID tags to the designed ring, bracelet and tie tack. The access control system with scanner was left unaltered. In the user test ca. 25% thought that the access control key jewelry was a good idea. The ring was better than the tie tack or the bracelet in usability. The prototype of the ring was experienced as it was too large. The bracelet was deemed fit for only females. The tie tack positioning in the scanner was experienced as too difficult, unless it was detached from the tie. The people not attracted by jewelry wanted to integrate the chip with a watch, mobile phone, or wallet. On the other hand, it would have been taken to use from the pocket as does the traditional access control key. One approach was that the tag could be integrated as an already existing piece of jewelry with user, for example, wedding ring. One possible solution could be if nanotechnology "greased" into the ring surface and printed electronics, but this was seen as a possible future solution.

The price is the bad side of the idea. Access control keys that are 'jewelified' are 10–100 times as expensive as the current ones. In home usage, this could work better, as the quantities are more small, and individuals may decide on the budget themselves. On the other hand, the material choices are at least partly limited because of the weak penetration of standard signals, which in turn limits design.

4.3.3. Bola jewelry

Bola jewelry is a communication device for the pregnant lady and the unborn child, possibly also after birth. A piece of traditional Bola jewelry makes a noise of mechanical jingling, when in the smart version (**Figure 10**) you can create or upload many a voice – mother, father, and grandparents talking, music, and different kinds of voice recordings. A personal connection is made to an unborn child. Music and recordings of those nearest soothe strengthen the bond with the baby and the outside world. When the child is being born, she remembers and reacts to the sounds she has heard in the uterus, and that creates feelings of safety and calms the baby. Smart Bola jewelry could be worn elsewhere than the neck, for example, the wrist.

A designed and even tailor-made piece of Bola jewelry becomes an object for everyday use and a memento for the kid and the mother, or both. Why not for the whole family. After the birth, even the father can use the jewelry with the child. The prototype was built by creating

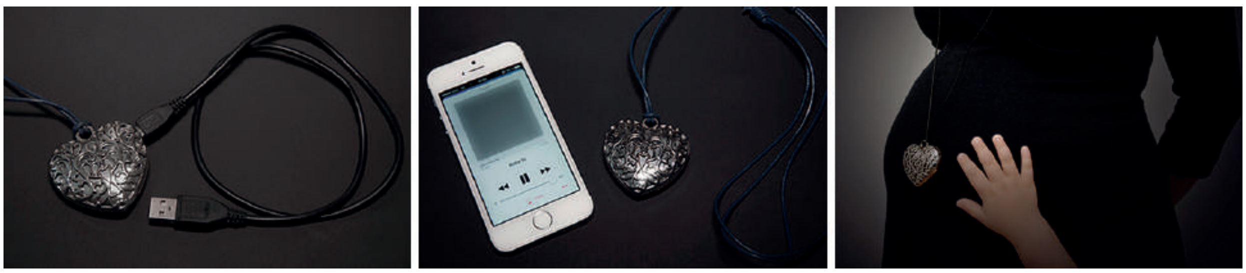

Figure 10. Smart bola jewelry.

a streaming from mobile phone to the Bola jewelry via Bluetooth. A hands-free receiver and a loudspeaker were installed to the jewelry. The source of the sound of Bola jewelry was a mobile phone. Optionally, the contents could be downloaded inside the jewelry. Ideas for further development: could the fetus or the baby communicate back to the parents—possibly including heart sounds. Vibration and light could be added to Bola jewelry, as well as auto-timer so it would not be on all the time.

The fear for electronics can be a hindrance when acquiring Smart Bola jewelry. As the product is meant during pregnancy and newborn, the authorities might limit its use by legislation or the security demands are lifted so high that the price would too high for the consumer. Quality jewelry, well made, is always expensive. Furthermore, tradition is in the way of use of Smart Bola jewelry. Traditional Bola jewelry is interesting because of its design and history. Smart Bola jewelry got the least enthusiastic reception of all the smart jewelry in this study. For a certain part of the women, Smart Bola jewelry made their blood boil because they were disgusted by the idea. It might be noted though that no young mothers were a part of this user test, but mothers who have given birth 10–20 years ago.

5. Conclusions

The smart jewelry is positioned in the so-called suicide quadrant of innovation when creating new products and new markets. According to this study, the smart jewelry seems to be a so-called high concept, which arouses people's interest. On the other hand, the smart jewelry sellers are already on the market but have not yet broken through the big scale. The markets and products are still in the introduction phase of their lifecycle. In other words, the market development degree of smart jewelry is low. The technology already exists and trends also seem to be moving toward smart jewelry, but the demand is not there yet, with the exception of low cost bauble and toy jewelry.

People are especially concerned about the duration, safety, security, and maintenance of technology. The marketing message should focus on alleviating these doubts. Of course, the tradition also has great impact. Jewelry has a long history. It is a big jump to suddenly switch to jewelry with technology inside. Some people will never accept this. It would be useful if a couple of big and credible companies started to focus on smart jewelry more prominently. This would also pave the way for other entrepreneurs in the industry. So far, mainly startups and researchers have made the work of activists ("Believe me, let's move forward together") in the creation of markets, but now more powerful market builders are also needed ("You have the need and we have the solution") to develop market to the next level.

Prototypes, surveys, trial runs, design probes, participatory and passive observation, interviews, workshops, and storytelling were used as methods to increase user understanding and explore business potential of smart jewelry. Almost all people interested in traditional jewelry reacted to smart jewelry with a strong or fairly strong emotion, positively or negatively. About 40% of these people saw smart jewelry as fun, cool, fantastic, and an inevitable future. About half of them loved the smart jewelry. On the other hand, 25% of people could not tolerate the idea of smart jewelry. The remaining 35% were unable to form a clear opinion. One-fourth of the test users were not "jewelry people." They did not use even traditional jewelry. This group was studied to find out if smart jewelry could attract new customers as jewelry users. According to the study, however, potential buyers of smart jewelry nowadays use traditional jewelry.

People expect from the smart jewelry to experience esthetic, functional, emotional, ecological, symbolic, social, and cultural value. The weighting of these values varies among different kinds of smart jewelry. The esthetic value, however, is common and the most important to potential users. Next comes emotional and symbolic values. These three values are causes why people could use jewelry instead of other products that do functionally the same thing. That is why the smart jewelry users will mainly come from subgroup of traditional jewelry users.

As wearable technology and the Internet of things become more common on the consumer market, the smart jewelry market will also probably grow. The healthcare and wellness industry seems to be a particular force for growth. A different sensor technology has increased and become considerably cheaper. Besides functional value, people appreciate jewel-like devices rather than an engineered appearance that may also be connected to some illness and thus create sense of shame. This seems to be the only cause to tempt nonjewelry people to smart jewelry users. According to the study, there are many target groups for functional smart jewelry. Therefore, the business potential is big.

Designed light jewelry has the potential as well, but for considerably smaller target group than functional jewelry. They could be directed at five target groups: (1) for women and their spouses born in 1960s and 1970s that have a positive outlook on life, (2) for tourists as a souvenir, (3) for different kinds of communities, (4) for entertainment business, and (5) for pets. Young people were not interested in light jewelry. However, some young test users said that jewelry should be challenged more comprehensively and forget the traditional shape of jewelry.

When the market is immature, there is no even common language among people—so-called market definition. If there is no common definition of the market and a subsequent shared language, it becomes difficult to create new demand and supply. As a result, the market will grow slowly or may die completely. In this study, an initial market definition was named concisely" smart and digitalization comes to jewelry." Later it created more specific definitions and own definitions for the light jewelry and functional jewelry. A value proposition can be considered to be a focused market definition. It connects supplier's offering with the customers´ expectations, needs, and benefits. For example, the value proposition of light jewelry for positive women born in the 1960s and 1970s was defined as follows:

> *Light jewelry produces moments of joy for you, your family, and friends. It emphasizes your self-confident and bold trendsetter image—including your playful personality. Light jewelry is a vibrant mystical object. Just when you think you see something, the jewelry shapes into something else entirely. Light jewelry has adjustable color options and allows flexibility in various costumes and uses. In addition, light jewelry is distinct from traditional jewelry by being stunning also in low light. On the other hand, the jewelry is stylish in the absence of light, so that it also suits peaceful moments.*

> *Every piece of light jewelry is unique. The jewelry combines the blacksmith's craft and technology. The jewelry is made of silver. Light jewelry has no need to be charged and is ecological because it derives its energy from body heat and solar energy. Inside a piece of jewelry containing LEDs and other electronics is a 6000-hour warranty, which means the use of over 3 hours a day through the course of 5 years. The jewelry is recommended to be serviced every five years, with regard to electronics and to replace the necessary components. You only need to send it to service center.*

As a summary, the smart jewelry seems to have a business potential, but as often with radical products and new markets, there is much of uncertainty. First early adopters have been caught but there is yet miles to go. A good sign is that some people are genuinely enthusiastic about the smart jewelry. On the other hand, the smart watches can somehow equate with the smart jewelry. After the initial interest, the eagerness toward them has faded. It is uncertain; can the smart jewelry revolutionize the jewelry industry—and if it is able to do that, when will this happen? At least nowadays, the business is still quiet. Maybe, the killer application is still missing.

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