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*Make Harmony between Technology and Nature, and Your Mind will Fly Free as a Bird*
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# HUMAN INTEGRATION IN TASK-DRIVEN FLEXIBLE MANUFACTURING SYSTEMS

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***Abstract:*** *In manufacturing environments where tasks and task goals are changed frequently, humans instead of (inflexible) machines and devices are used. Due to their natural intelligence, humans are able to adapt themselves more easily to new production conditions and needs. For that, the seamless integration of humans in (semi) automated manufacturing processes is an urgent need of the industry. However, current approaches of human integration on manufacturing systems only cover dedicated activities and use cases. No general model for human integration does exist. This paper presents a holistic method for human integration within the so called the task-driven manufacturing system. This system allows for highly flexible production in mixed automated and human production environments. Differences of machine and human task performance are covered by the novel method. Thus, from task planning point of view, no difference between human and machine work has to be considered. The applicability of the novel approach has successfully been tested in three different approaches.*
***Keywords:*** *flexibility, manufactron, manufacturing, task-driven, human integration, manufactronic workplace*

## 1. INTRODUCTION

Current manufacturing systems are usually divided into three hierarchical layers. On top the Enterprise Resource Planning (ERP) for factory planning processes, the medium layer with the Manufacturing Execution Systems (MES) workflow organization and the shopfloor layer at the bottom where the production is executed. In MES, usually completely automated processes without significant human interaction during the production are executed. In ERP mainly semi-automated planning processes do exist. For planning issues, humans are often supported by software tools for resource planning, scheduling and through put optimization. On shopfloor, both manual and automated processes are in use. Depending on the application area, humans often execute handling or mounting tasks, e.g. feeding machines with components or assembling several components using tools such as screw drivers etc.

However, the integration of human on shopfloor is in a dilemma: On the one hand, planners are forced to increase the level of automation due to high costs for human workers in order to be competitive especially to the Asian market. On the other hand, human expertise and involvement is required in order to produce high quality products. Furthermore, humans can be used very flexible. In contrast to machines, humans are not located in a fixed position within the factory but can easily move from one to another location. Due to their experience, humans can perform multiple tasks without significant task switching times. While task switching of machines usually requires cost intensive change over, humans can easily perform different tasks in random order. In addition to that, humans are more sensitive on potential production failures and can react more flexible in case of process disturbances.

One of the main issues in current manufacturing systems is the leak of methods for human integration into semi-automated production. Either the manufacturing systems are optimized for automated production and the integration of humans cannot be done as smoothly as required or manufacturing is human-driven only with the support of machines and tools. Due to that dilemma, one of the main challenges for future high-quality manufacturing systems is the smooth integration of both, humans and machines. Human workers and machines on shopfloor must be enabled to interact with each other in a smooth and save manner. In addition to that, an easy replacement of machines by humans (e.g. in case of machine failure) and vice versa is required. Due to their flexibility, humans can also be used for absorbing peaks in production when temporary additional resources are required.

In addition to the generic concept, a set of technologies to support human integration on shopfloor is required. Special attention for this is on tracking and analysis of the activities and behavior of humans.

## 2. APPROACHES FOR HUMAN INTEGRATION IN FLEXIBLE PRODUCTION SYSTEMS

Several projects with different approaches and targets in human integration in flexible production systems have been carried out. Some of them provide holistic concepts, however, most focus on dedicated features of human integration, e.g. activity recognition, machine/human cooperation, etc. A generic concept is provided by the approach of the “Holonic Manufacturing Systems” (HMS) which have been developed under the Intelligent Manufacturing Initiative. In HMS “holonic manufacturing shall preserve a place for the human in the system, since he/she is the most flexible and intelligent component in the system.” [1]. Studies of human integration in HMS are provided in [2]. A comprehensive description of the digital factory and the involvement of humans can be found in [3]. An expert system and a human resource database for storing skills and knowledge of humans for workshop activities is illustrated in [4].

Dedicated work for activity monitoring of workers can be found in [5], [6] and [7]. Furthermore, different approaches for worker behavior modeling are provided in

[8] and [9]. Approaches for the intelligent Human Machine Interfaces (HMI) can be found in [10].

## 3. TASK-ORIENTED PRODUCTION

A new paradigm in manufacturing is the so-called “task-driven production”. In contrast to the traditional recipe-based approach, machines and devices do not receive process parameters for performing their job. They only receive a description of the task they shall perform. The task description consists of “what” to be done under the given boundary conditions. The machine is able to execute the task without further information from outside. Task descriptions are communicated via standardized documents (Task Description Document; TDD) [11]. During the task execution, the quality of the process is measured via a quality measuring and estimation system. After performing the task described in the TDD, the result of the task execution is communicated. For that purpose, Quality Result Documents (QRD’s) are issued. Machines and devices with such properties are called “Manufactrons” **Error! Reference source not found.**.

The core functionality of the Manufactrons is the so-called “Task-to-method transformation”. During this transformation, the task description is interpreted and a proper method for the task execution is selected. For storing and selecting methods for task performing, the Manufactrons knowledge system is responsible. The Manufactrons knowledge system usually consists of a database for storing the methods, an intelligent search and retrieve mechanism for finding and querying the best fitting method(s) for the given task as well as of an adaptation mechanism in order to fine-tune the selected method before executing it. The methods are generated by a learning system in which process methods are either be generated by physical experiments or process simulations or human experience is formally described.

Manufactrons residing on the shopfloor level are called “Production Manufactrons”. Production Manufactron receive their task descriptions for the “Workflow Manufactrons”. The Workflow Manufactrons receive the task descriptions from the ERP level and carry the TDD’s along the production flow from Manufactron to Manufactron. After each production step, they gather the QRD’s from each Manufactron. By interpretation and consolidation of the QRD’s a complete quality report on each product is available.

## 4. HUMAN INTEGRATION IN TASK-DRIVEN PRODUCTION

### 4.1 General aspects

In order to overcome the limitations of current approaches of human integration in manufacturing systems, a new approach is proposed. Based on the task-driven production paradigm, methods for a smooth integration of humans in production processes on shopfloor are proposed. Doing so, humans are able to overtake tasks from machines (e.g. in case of machine failures or to compensate temporary production bottlenecks) and to cooperate with machines in an effective and safe manner.

To do so, humans as well as task-driven machines (Manufactrons) must be equipped with similar interfaces to their environment. In other words, humans must be enabled to understand task description documents and must issue a quality result document after executing their job. Fig. 1 illustrates this approach.

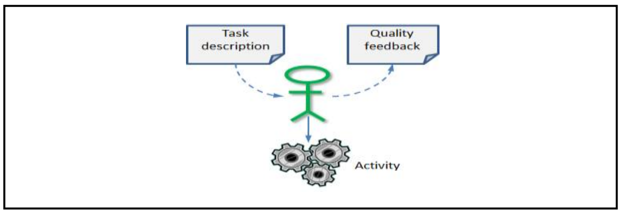


Fig. 1. General concepts of human integration in task-driven production

### 4.2. Similarities and differences of automated and manual work

Even if the general method for human integration in a task-driven environment is similar to the machine integration, several aspects have to be taken into account. In order to profit most of human’s expertise and knowledge, the task execution should not as fixed as for machines. In a human-oriented workplace some freedom for acts and decisions on how to fulfill a given task, e.g. in which sequence different working steps will be done should be given. This can also contribute to an improvement of efficiency by finding best practice for an already established task.

Another aspect belongs to the interpretation of the TDD. In case of human integration, the machine-readable TDD has to be converted in a worker understandable and executable method. Proper methods for displaying the task content have to be present. Online help and guidelines including advanced presentation technologies such as movies, 3-D animations, etc. should be available.

For the inspection of the quality of the performed task and for the safety interaction of workers and machines, several technologies for worker behavior monitoring can be used (see below). However, the measures for those activities have to be balanced very well. Worker monitoring must not be abused for total surveillance and control of the worker. Legal aspects for such measures which are potentially country-specific have to be taken into account.

### 4.3 Roles of humans in production

When looking into the details of human integration on shopfloor, it can be seen, that humans take over different activities. There are two which are most important for further analysis. Firstly, humans often perform manual handling and assembly tasks. For example to put tools or components in place, assemble components to sub-assemblies or perform mounting tasks such as screwing, hammering, etc. A human in this role is called “worker”.

A different human activity is the monitoring of the activity of an autonomous machine and the eventual execution of correctional measures to compensate for machine errors. We call such a role an “operator”, who can be considered to be part of the control of the process control system. The operator can take two more sub-roles. Firstly he executes maintenance activities to the machine and secondly he performs tool changes in order to adapt or to upgrade a machine.

There is a fundamental difference between the role of "worker" and "operator": The "worker" executes a production (mostly handling) process and should therefore constitute a "Manufactron". The "operator" performs services within a process executing machine. Consequently, when the process executing machine is a Manufactron, the operator is a Manufactron component. The roles of "maintenance" and "tool change" require specific knowledge and skill. This implies that these roles should also be filled by entities with Manufactronic structure, thus representing sub- Manufactrons with the specific capabilities.

### 4.4 Manufactronic workplace

According to the findings described above, the logical consequence is the embedding of humans in the Manufactronic concept as special Manufactrons. This also guarantees the seamless integration in an environment of arbitrary (mixed) human/machine arrangements. This point of view requires that all functionalities of a (Production) Manufactron can also applied to the integrated human, only having some additional, specific features. Such an embedding is called "Manufactronic workplace", which represents a concept for true human-machine cooperation.

The resulting functional scheme of the Manufactronic workplace, which is a Manufactron from the outside point of view, is shown in Fig. 2.

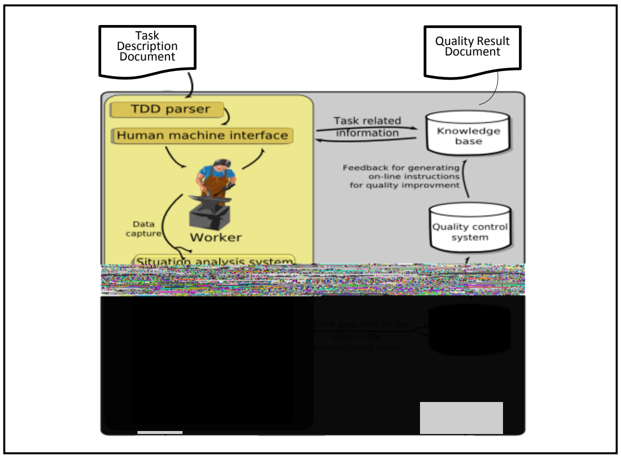


Fig. 2 Manufactronic Workplace

On the left hand side, those components are shown, which have to be added to the regular Manufactron structure in order to realize the extra cases in addition to the ones of the common Manufactron use cases.

The structure of such a Manufactronic Workplace is generic. It performs the same activities in the case of both roles in human integration. In case of workers it acts as an entire Manufactron where all activities are performed by the human. In case of an operator who e.g. is responsible for maintenance or tool change operator, it forms a "maintenance Manufactron" or "tool change Manufactron" in combination with the operator.

In order to fulfill those roles for human integration, the Manufactronic Workplace is responsible for the following main activities: i.) Receiving of Task Description Documents, converting them into a worker executable method and presenting the method to be executed in a human understandable way. ii.) Monitoring the worker's activities and behavior, iii.) Detecting the achievement of the goals described and communicating the goal achievement automatically to other cooperating Manufactrons; iv.) Assessing the quality of the task execution and giving feedback to the human, v.) Monitoring the space occupied by the human and communicating the occupied space to cooperating moving Manufactrons for the safety of the human.

Even if those activities are generic for each Manufactronic Workplace, such a solution requires application specific technologies to realize the (software) components. Especially the components "Human machine interface", "Activity monitoring layer" and "Behavior monitoring layer" must be adapted to the applications and their boundary conditions.

## 5. APPLICATIONS

The novel approach for human integration on shopfloor has been tested in different applications. The Manufactronic Workplace for "workers" has been verified in two different stages of automotive production. The "operator" role has been tried out in the fuselage production of airplanes.

### 5.1 Manual spot welding in automotive industry

In this application the workers is responsible for the movement of a welding gun and for placing weld spots to the desired positions. A complete Manufactronic Workplace has been installed, consisting of features for task interpretation and presentation for the worker, gun tip location mechanisms based on video tracking, welding sequence detection as well as of communication mechanisms for synchronization with the welding control unit. After performing the complete task, the Manufactronic Workplace issues a quality result document which consists of values for welding spot location, spot quality and time consumption of the complete task.

### 5.2 Final assembly and body-in-white assembly in automotive industry

In these test cases dedicated research activities in the field of worker activity and behavior monitoring has been tested. In final assembly, the mounting of a dash board has been supervised by the usage of wrist-worn accelerometers. For this, the worker received detailed information on the mounting sequence and other relevant data for performing his job properly. After that, the usage of the correct tool (screw driver, hammer, and spanner) for performing the assembly had been monitored.

In the body-in-white scenario, the correct sequence of mount of the components of a car door has been tested. An advanced HMI for displaying the assembly job to the worker in combination with a video tracking system and RFID sensors for the identification of components and their location has successfully been installed.

### 5.3 Operator assistance in aeronautics industry

In contrast to the two application scenarios described above, the third scenario concentrates on the "operator role" of human integration. In this case, the combination of human and machine defines the Manufactronic Workplace. The application for this scenario is the movement of a complex tool for drilling, countersinking and riveting in the aircraft production. The operator has to move the tool to the desired position and has to perform the joining process. To do so, camera systems with video tracking have been installed. An online simulation of the tool's movement helps the operator to avoid collisions in case of complex component geometries and hidden obstacles.

## 6. IMPLICATIONS AND CONSEQUENCES

The implementation of the novel approach of human integration in semi-automated production will result in several benefits, both for the production itself as well as for the individual worker. For the first time, a holistic concept of human integration is provided. The visual task presentation allow enables humans to learn quickly and to perform very different tasks. This allows for fast ramp-up of production and for the manufacturing of different products by the same human resources. Having those features, factories are enabled to react flexibly on different demands of product types and volumes. By the detailed task presentations and activity and behavior monitoring features, potential failures can be avoided which leads to better quality of products, decreased costs and decreased waste.

The Manufactronic Workplace's Knowledge Base gathers and conserves human expertise and best practice. By this, the production processes are improved continually and the newest methods are available for all workers.

The implementation of the novel approach can also improve the daily work of the single worker. By the detailed task presentations, learning of new tasks is much easier. If the task description allows performing tasks flexibly (e.g. rearrange the sequence of assembly steps), the worker can also adapt the task execution to his needs. The worker activity tracking in combination with the occupied space monitoring can improve the safety of the human in a mixed human and machine environment.

## 7. CONCLUSION

Despite that production equipment becomes more and more intelligent and flexible, humans play a very significant role in future production systems. Because of their natural intelligence and their capability for self-organization, humans are the most flexible entity in production environment. This paper describes a novel method for bringing in humans in future manufacturing systems based on a new paradigm of task-oriented production. It shows how humans can be integrated smoothly in the concept and how the most important capabilities of humans are used to improve future production systems. Furthermore, it also shows how task-driven production improves the conditions of human's daily work.

Further research work in the field of human integration concentrates on the improvement of human behavior and activity modeling. Furthermore approaches for the improvement of monitoring of the occupied space of humans and machines will be tested. Finally, the introduction of human team work into the concepts of task-driven production will be investigated.

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