Individual Support in Industrial Production
Outline of a Theory of Support-Systems

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Abstract

Many different production systems for supporting, assisting or helping people at work are already available and even more will be developed in future. Such systems come in various forms and characteristics. This paper will introduce some first steps toward a theory of support-systems. It will focus on individual forms of employee support. The theory will be illustrated by exemplary solutions.

1. Introduction

1.1. Motivation

Production companies and their staff are permanently exposed to new challenges. Nowadays, central challenges are globalization and demographic changes [1, 2, 3]. Both are intertwined but the former leads above all to increased competition and cost pressure and the latter to changed age structures and shifting compositions of population (e.g. men/women, residents/immigrants) in the industrialized regions of world society. These aspects have a strong influence on the planning of production systems and should therefore be taken into account.

In recent years a lot of technical systems for industrial production have been developed e.g. in order to improve the productivity or the ergonomics in the first place. The relevant technical systems are more or less able to either collaborate with the staff or to operate "alone" (without any staff). That is, such systems may support some organizational activity in combination with human work or they may perform tasks automatically (without any support of the staff).

The planning of such systems – generally called production systems – has to consider many aspects and requirements: the kind of product, potential customers, the socio-cultural environment (including the business environment), the company/organization, and the current production system (see extract in figure 1). The features of these factors and their relations influence the design of production systems significantly.

In order to analyze the form of production systems and to determine the kind of support, the subject must be considered in a fundamental way [4]. The emphasis

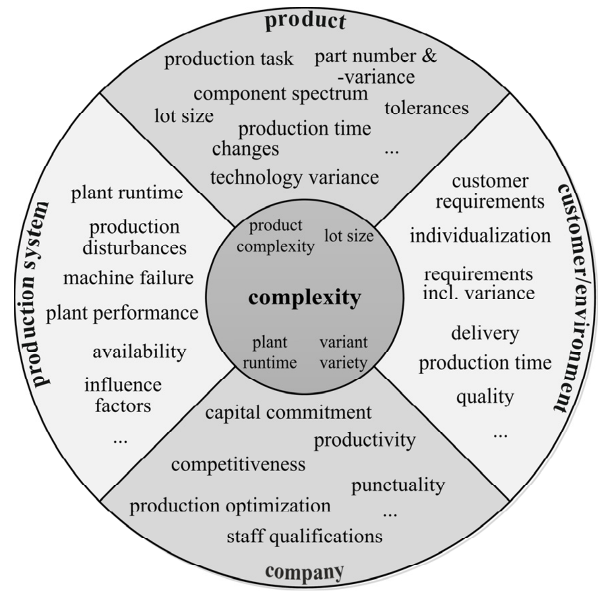

Figure 1. Parameters for planning production systems [5]

is not on the respective components, but rather on the *interaction* of some observable or desirable activity, the support, the user, and the organization. All of them have to be analyzed as one coherent unit (see figure 2). Additionally, in most cases the activity is obviously distributed across organic, social, and technical entities [6, 7].

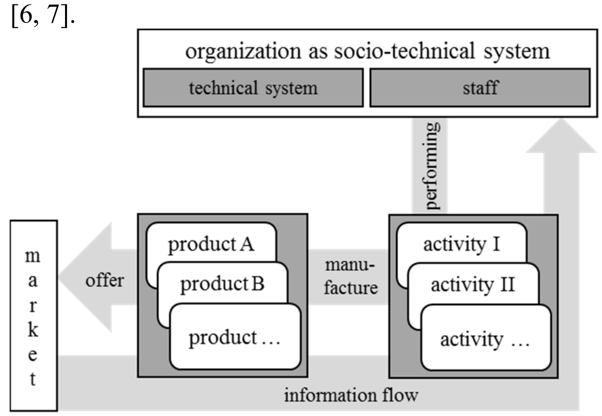

Figure 2. Considered unit of analysis

In this vein, the classification of different kinds of support must not be based on purely technical grounds (see for example the explanation in [4]). Two important

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consequences ensue. First, a classification that tries to classify the participating entities or the technical systems in isolation will miss the crucial problems. Yet getting the problems clear is indispensable for designing appropriate, useful, and widely accepted support systems. Therefore the classification must refer to prevailing *patterns of interaction* between relevant activities. Second, support is neither confined to technical systems nor is it a natural kind. It rather depends on observers, which are dispersed across the boundaries of the production system. Does an operator support the machine or does the machine support the operator? Are robots supporting the organization or do they rather support the operator individually? How do government agencies or journalists observe, for example, the implementation of robotic support? Do they discern social progress, an offence, the problem of rising unemployment or maybe cultural devolution? From a common engineering point of view these questions may appear superfluous or irrelevant. Yet finding them organizational as well as personal answers is necessary for a thorough understanding and appropriate design of next generation social robotics and support systems.

1.2 Current Situation and Objectives

Technical support systems for different situations are already in use in everyday and professional life. Applications in industrial production include for example automated systems with industrial robots [8], systems for human-machine cooperation like robot based systems for welding [9], exoskeletons for force support [10], lifting aids/balancers [11], assembly seats [12] as well as apps or web-based navigators and assistance systems [13]. These solutions have in common that they support, assist or help the staff in order to bring them relief or to increase the overall productivity in organizations of production. Consequently, not all systems strengthen the role and position of the employee.

In this paper, the main focus will lie on the relation of the respective technical systems to human beings. To be sure, this focus does not preclude an application of the relevant ideas to other systems like, e.g., industrial robots without (or just with minimal) human contact. We rather present a general approach for technical systems regarding individual support. To this end we will start by deriving the core characteristics of existing production systems, which will pave the way for defining essential characteristics of "individual support". These explications are then transferred into a tentative classification of support systems and will also be used to outline a new approach for "individual support systems", called Human Hybrid Robot. Finally, we illustrate the approach with exemplary systems.

2. Core Characteristics of Existing Systems

It has already been mentioned, that several different or similar technical systems for industrial production exist. In this section some systems will be introduced and characterized with respect to their form – especially design, flexibility, and interaction.

Standardized and freely programmable, mostly non-modular *industrial robots*, e.g., Kuka, ABB, and Stäubli with serial and/or parallel kinematic chains are used for automated solutions (robotic solutions) in industrial applications. Robots can be used as stand-alone solutions [14], in cooperation with other robots or humans [15, 16] or with automated tools [17]. Mostly, those robots are installed stationary [18]. Newer robots are also designed as portable or mobile [19]. Usually, such robots execute simple and/or repetitive activities within a restricted and monitored working area [20]. These activities are stored in their control system and are always performed in an identical fashion. Robots with extra sensors can also detect their environment as well as relevant conditions that affect their operation in order to adapt to trajectories for example. They are programmed by people – but with respect to the performance of the activity in question, human beings are mostly excluded. They are rather confined to only monitoring the technological performance.

Robots are of course also used for *human-machine-cooperation*. The main idea of this latter approach is to divide the desired activity into sub-activities for human and machine within a common workspace respectively [16]. Humans and robots then collaborate to carry out some activity jointly. In this approach robots do only then perform activities, when the safety of the involved people is guaranteed. That is, usually there is a strict separation of machine and human in time and space [16]. There are also approaches allowing temporal and spatial cooperation [21, 22]. A further possibility is the use of torque-controlled robots, which are able to yield when in contact with human motion [23].

Assistive systems can have different forms, e.g., cognitive, haptic and visual. Such systems assist manual tasks by giving e.g. instructions or warnings. People perform the tasks still independently and get information in case the system detects deviations. An active intervention is only rarely possible.

Lifting aids/balancers are widely used for handling and transportation of (heavy) workpieces between workplaces [11]. The motion of lifting aids is directly induced by the user.

Classical exoskeletons increase the force and thereby the mobility or endurance of physical bodies. Such systems can be limited to individual body parts or

Table 1. Comparison and characterization of current production systems (based on [26])]

concept / characteristic	industrial robot	system based on human-machine-cooperation	assistance system	lifting aids/balancer	exoskeleton	tool
root concept	standardized system with or without sensors	distribution of work to human and machine	instruction from system to user	mobile or stationary, standardized and monolithic systems	parallel, wearable elements for force support	standardized system
integration	usually integration in production lines	usually no direct integration, but they work together	no integration, system only assists as separate system	no integration in one system, two separate systems	integration in one hybrid system	usually used by the staff
interaction	sensors for disturbance detection; if disturbance, then no actions	direct interaction and work cooperation.	one-directional interaction (assistance system to human)	direct interaction between user and system about interfaces	direct interaction due to hybrid system	direct linkage to user
locus of control	usually controlled by routines; setpoint generated by programs or sensors	machine only performs predefined task if safety for human is given	pre-defined assistance functionalities	system controlled by user	setpoints by user	control of tool by user, sometimes routines
system configuration	usually fixed and not modular, process-oriented	usually fixed and not modular, process-oriented	usually fixed and not modular, process-oriented, sometimes user-oriented	no possibility for adjustment	fixed, but usually user-individual parameterization	some tools are fixed, a lot of tools can be adapted easily
arrangement/ system boundary	no synchronization and direct interaction	synchronization, but two separated systems	separated system	separated system	parallel structure, hybrid system	usually serial, sometimes parallel
material	usually rigid materials	usually rigid materials, but often safety functionalities	usually software functionalities	rigid portals and cables or similar things	usually rigid kinematic and actuators, soft interfaces	different, usually ergonomic interfaces with rubber or plastic
development	developed system; programming usually task-dependent	fully-developed systems, more new procedures	a lot of assistance systems are fully-developed	fully-developed system	low maturity for industrial application	fully-developed, task-dependent selection
production task	complete activity is performed all the time	separation of the activity to staff and machine	performed by user, assistance by machine	separation of the activity to staff and machine	performed by user, force support by machine	performed by user with support of tool
human support	taking over human activity	taking over some activities, e.g. load	assist functionalities	guiding and carrying support	support of force, endurance, and mobility	support by tools
system setup	custom-built	custom-built for a single or flexible application	custom-built for a single or flexible application	custom-built for a single or flexible application	custom-built	custom-built for a single or flexible application

can support the whole body [24, 25]. Usually integrated sensors detect the human motion. The kinematic chain and actuators of such systems determine the fidelity of motion with respect to human movements.

Tools can be used to facilitate human activities such as drilling, screwing or checking. In general, the tools cannot be adjusted to the user, but "only" to the activity, e.g., the replacement of drills or bits. Normally, the user has to adjust to the tool. The direct interface (i.e. handles) is adjustable only rarely. Routines, if available, can usually not be changed or adapted easily.

In our view, most production systems have been developed above all with the purpose to increase the productivity and not to support human beings. These systems are usually designed in a monolithic and process-oriented way. They have only limited possibilities for small adaptations. Their essential characteristics are summarized in table 1.

3. Outline of a Theory of Support-Systems

It is crucial to cherish the simple but obvious finding that support can take very different forms and that it is highly dependent on the observer of the support-activity unit [4]. Furthermore, descriptions of support, assist or help are currently not distinguished. This leads to terminological confusion, which in turn blurs possible points of leverage for the solution of particular problems, e.g. in production or health care.

Therefore, a theory of support-systems must be able to deal with the following structural conditions: (1) the variety/complexity of support, (2) the inevitable and persistent interference of diverse corporate and individual observers with different interests, and (3) the difference of support in contrast to other similar forms of activity like help or assistance. These are certainly not the only requirements for a theory of support systems, but any substantial theory of support-systems has to address them in one way or another.

The basic idea first took off as a theoretical approach about how an advanced technical system can be seen to support the individual person with reference to the functionalities it needs. It then evolved into the concept of Human Hybrid Robot (HHR) [26] and the substantiation of three general determinants of support-systems, which refer to the interaction patterns between the participant technical, physical, and social entities [4]. With this background we now present first steps toward a theory for support-systems. Regarding the multiplex structure of the problem such a theory has to take on an interdisciplinary approach.

3.1. Framework

The framework should define the general structure that provides a kind of architecture for particular classes of similar applications in an abstract way (see definition in [27]). Our framework, which can also be seen as a methodology, is illustrated in figure 3. Such an approach is necessary in order to fulfill the overall requirements for development, configuration, implementation, and application of support-systems. Hence the framework should help the developers, users, and organizations to adapt common procedures to a new way of thinking support-systems.

Realizing individual support depends on different aspects that derive form the demands of the user, the industrial production and the overall strategy. We use the approach of Human Hybrid Robot (HHR), which can be deployed for different kinds of support and activities. For this purpose, several enablers are utilized in order to impact the system user, the organization, and even national economy. To allow individual support, a construction kit systematic is employed. The development as well as the application of such systems can be facilitated by appropriate methods.

All these interacting aspects describe the various problem dimensions of support. Hence they have to be considered for theory and will be described in the next subsections with more detail.

3.2. Forms of Support

Production systems can contain support operations in various ways and with differing targets. In the field of production, as in other fields (e.g. care), such systems can relieve either the user or the organization that implements such a system or both. The use of a system to support something or someone is contingent on different motivations, characteristics, implementations, and applications. It also affects quite different areas.

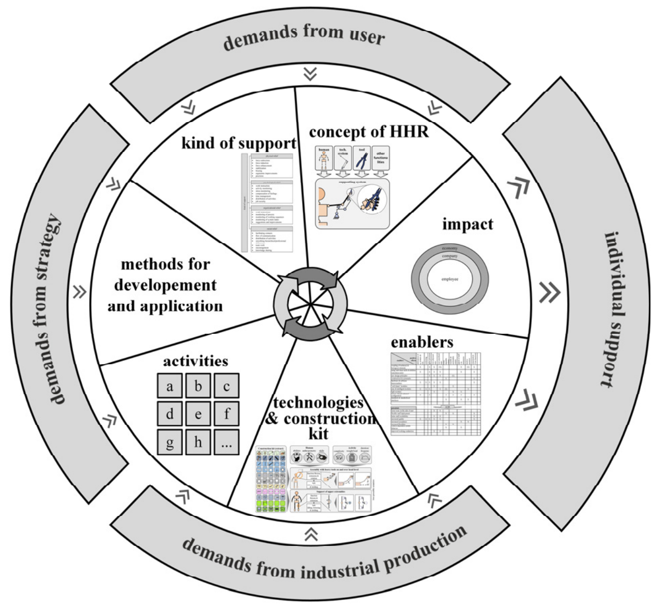

Figure 3. Framework for the prospective theory

The *motivation of support* may have different reasons. On the one hand, support might be necessary to compensate some gap between observed actual abilities and skills of the user and socially demanded potential abilities and skills. This is a form of motivation that arises without explicit attributable purpose. On the other hand, the motivation might be attributable to such an explicit communicated purpose. An organization may increase the requirements by making activities more complex and by enlarging the scope of work. Such changing conditions may be caused by a customization of products, globalized markets, technological and/or demographic change or increased demands on quality.

The support can also have different *characteristics* (especially with regard to form and scope). All the characteristics primarily refer to the interaction and integration of the components of the support-system. This point includes three aspects in particular. First, the *level* of support relative to the supported body parts may vary: body parts (up to the complete body) can function as support but may be also affected by support (described separately in a separate item). Second, the *degree* of support may vary: support in form of assistance (the user is performing the task with assistance), support by taking over some sub-activities (e.g. 10 % of force), and support that takes over most sub-activities, or even the complete activity (100% – support then is in the hands of the technical system). The latter amounts to a substitution of the activity. The third aspect that is included when it come to the characteristics of support, refers to the *strength* of integration, that is, the technical component of a support-system may for example be body-worn, simply held or communicated via particular media.

Technical systems affect different *areas of support* as well. As mentioned above, one criterion is the level of support with respect to the supported body parts. Another criterion is the kind of relief. This can be physical, psychological, process-oriented, and social relief (see figure 4). Some aspects of these four fields of relief are overlapping, other aspects are redundant or additional. For *physical relief*, the support systems can be used for force redirection and induction, force enhancement, stabilization, bracing, precision or ergonomic improvement. For *psychological relief* such systems are needed for work instructions, monitoring of the activity and musculoskeletal stress, compensation of feelings, time management, distribution of activities, and job security. *Organizational relief* (including *process-oriented relief)* is for example achieved by working instructions, suggestions and improvements as well as the monitoring of processes, and the definition of work sequences and system states. *Social relief* ensues when the support facilitates the coupling and decoupling of people and the flow of communication, when a (re-)distribution of activities is possible so as to activate team expertise in shifting contexts, or when unavoidable hierarchical or professional differences can be suspended.

Note, that all of these areas are very probably affected simultaneously and that interference between them might have preferable but also detrimental effects. Being aware of these areas is necessary in order to be able to anticipate and assess possible effects or to contain unexpected negative ramifications.

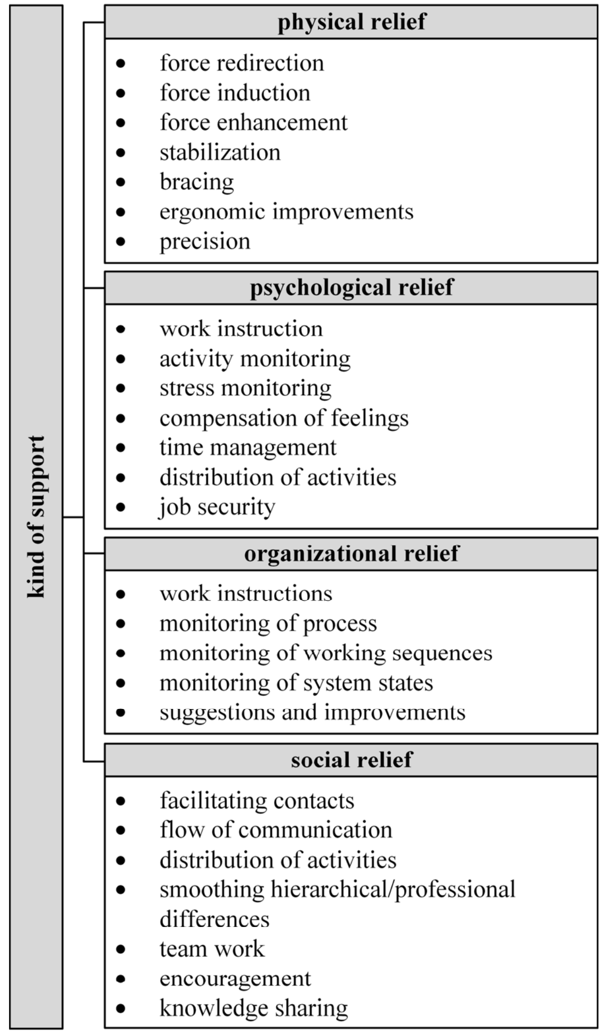

Figure 4. Areas of support with examples

3.3. Paths of support

The classification procedure should be able to trace different paths (see [4]). Three basic determinants with regard to the relation of activity and its observed or intended support have been identified: spatio-temporality, integration, and locus of control. A classification along these lines proceeds by describing the form of support from general into more detail.

Any classification of support-systems should not begin by looking at the technological artefacts or other components of such systems. When faced with the detailed differences of the numerous variants of such systems and with the dynamics of the field such a classification strategy would either turn out to be futile or it would lead to a simple pigeonhole procedure without producing any scientific insight. What is needed in order to achieve a manageable, scientifically sound, and methodologically useful classification is a specification of just a few criteria that do not refer to clear-cut entities but rather to the interaction patterns of participant entities within such systems. We found that there are three basic distinctions that determine the observation of basically all possible (i.e. not exclusively technical) support-systems. They are, therefore, essential for classification. Starting with the most basic, but necessary distinction between an activity that is to be supported and the supporting activity (without this distinction no support system could be developed at all) one has to (1) ascertain the spatio-temporal relation/interaction between the relevant activity (of diverse entities) and the observed or desired support of this activity. That is, support can be spatially close and immediate, e.g. wearable technology or lifting people in a nursing home, or it may happen from distance and be mediated, which might be the case when financial or moral support is granted. (2) One has to pay attention (or make a choice) about the form of integration between activity and support. Support can either be contextual, for example when the accomplishment of the activity is facilitated by assistance, or it is rather highly integrated when it turns out to be a necessary condition for the accomplishment of the activity itself (for example: halting the traffic to ease the crossing of the street for an old man, which is contextual and amounts to assistance, versus stabilizing his walk to enable him to cross the street). (3) The third determinant of support-systems is related to the issue where observers locate the control of the system. This is not self-evident. Does a driver control the brake assist simply because he might be able to switch it off? When the brake assist is on then it rather controls the driver as much as it is controlled by him. This simple example shows that the observation and attribution of control is a crucial issue with regard to the design of support forms.

3.4. Methods for development

The theory of support-systems should result in a number of methods, approaches, and principles that are all important for future development and configuration of such systems as well as for their concrete application. The framework given above can be considered as the general structure in which the basic approach is embedded. The corresponding methods are the appropriate tools for realization. The generation of individual support depends on this structural arrangement (see again figure 3). Solutions devised with reference to this framework and theory will be of a different kind due to a novel human-centered approach and an innovative perspective that is obtained from bringing together engineering science and social science with additional support from other disciplines like law or biomechanics.

Currently we think about methods for identifying needs, standards for support systems, and systematics for a construction kit. Requisite methods do also address module and system development, modelling and simulation of human-machine systems, user-centered design and technology evaluation, and system configuration. Furthermore there must be manufacturing methods and technologies for user-centered modules (e.g. additive manufacturing technologies for realizing individual adaption and low cost systems), for programming (e.g. active system, control strategies), and algorithms (e.g., for comfortable movement of technical elements in respect to user conditions and process parameters). These methodological requirements are all directed towards gaining intuitive usability, and facilitating implementation and application.

3.5. Approach of Human Hybrid Robot

The concept of Human Hybrid Robot presents one possible approach for individual support. It is a promising concept because it closes the gap between free programmable robots and manual workplaces further than other current approaches [26]. The basic idea is to support manual activities at work and in daily life by building a hybrid and intelligent system. Such systems can be characterized by a direct coupling of human movement, technical systems, and primitive or advanced tools and functionalities (e.g, a mechanism for integrated quality assurance; see figure 5). The crucial point is the integration of technical and biological elements as well as the realization of a synchronous and bi-directional interaction between human and mechatronic and/or mechanic elements in the same workspace. Systems based on this approach are not replacing the human by a machine. Rather the position of the human is determined with reference to a compensation of lost functionalities.

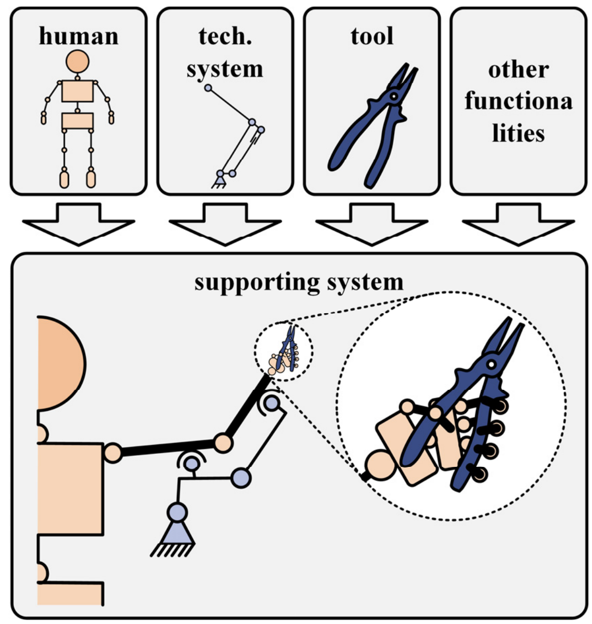

Figure 5. Concept of Human Hybrid Robot [26, 28]

The concept of HHR is based on a *modular* system architecture. A construction kit with pre-defined hardware and software modules allows an ad hoc configuration and reconfiguration of systems. This will be achieved by compliance to standards for e.g. interfaces. Design and configuration of the support system are determined by human characteristics, e.g., skills, abilities and anthropometry, and the activity, e.g., complexity, load, and frequency/duration/repetition (see figure 6). For example, the highly developed sensory abilities of human beings and the high endurance of technical systems are used simultaneously. Each module of the construction kit has one or more functionalities. A certain functionality may well be realized by different modules. In general, the modules can be clustered into different classes, e.g., biological modules, tools mechanical modules, actuators, joints, algorithms, sensors and interfaces. The support of human features and abilities is achieved by using and combining these modules.

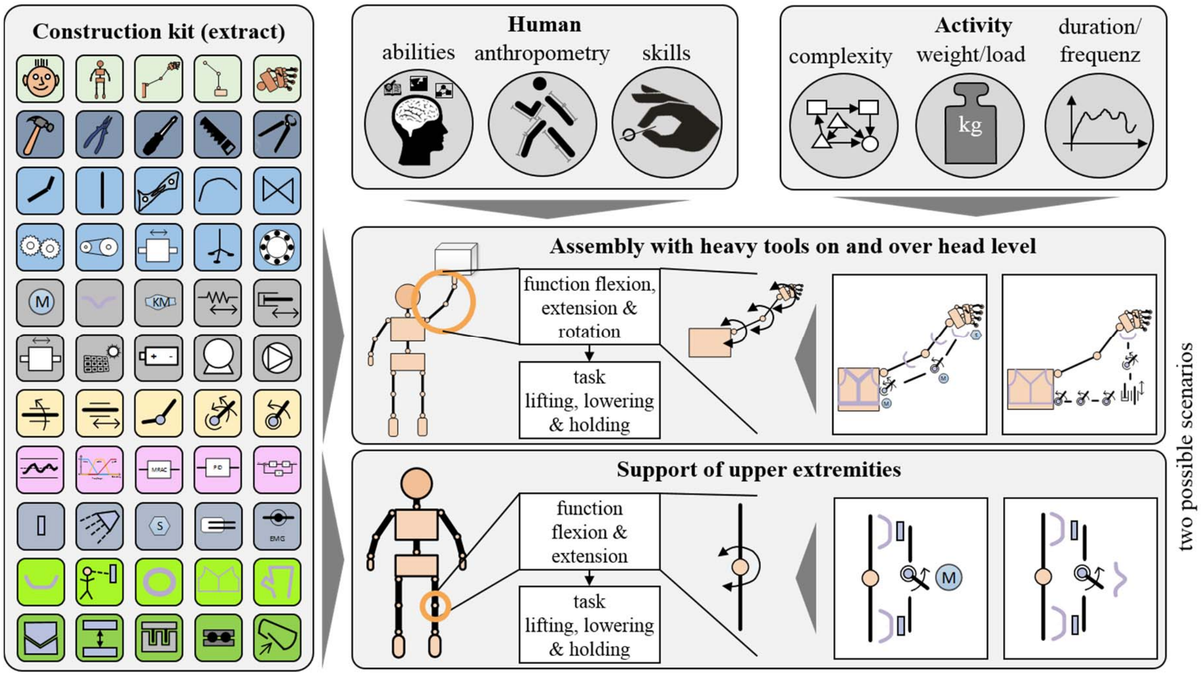

Figure 6. Construction kit systematic and exemplary configured system for two scenarios (based on [26])

3.6. Enablers, effects, potentials and impact

Support systems can be used for different applications with different requirements, e.g. from micro production to the production of fuselage. Different key enablers allow significant technical, economic and social improvements. The key enablers, as well as resulting positive effects and potentials, are shown in figure 5. An integral part of systems based on our approach is that the user is the locus of control within the support-system. The user is supported by technical functionalities in order to increase, for example, quality, productivity or ergonomics without being controlled or replaced by machines. Biological and technical elements are coupled serially and/or in parallel and adapted to the relevant person and the task. As a result, individual abilities and skills can be used simultaneously: the high flexibility and well developed cognition of human beings as well as the high endurance and repeatability of a machine. In effect, this can decrease the physical and psychical strain due to supporting functionality and increase the quality of work due to integrated stabilization and quality insurance mechanisms. The relationships of other enablers, effects, and potentials can be found in table 2.

Such support systems can be used to support the employee as well as the company. Moreover, this new approach could have an enormous impact on national and international economy [29]. It might also induce changes of diverse occupational structures.

Support within those systems is both preventive and operative for the user during manual tasks, e.g., physically and psychically strenuous work. It is important to highlight that users are not replaced by machines. Rather a hybrid system is established and uniquely designed to support human capabilities. This has several positive effects:

- ensuring employee productivity and thus (long-term) security of the workplace,
- flexibility of support systems,
- widening the range of employee deployment and resulting possibilities of job rotation,
- improvement of the ergonomics and mental relief, improvement of the quality of life for skilled and unskilled labor to prevent diseases,
- acceleration and facilitation of learning processes,
- ease of reintegrating handicapped or injured persons,
- improvement of accuracy, precision, and error prevention at work, and thus increased product quality,
- positive influence on direct and indirect costs related to diseases, and thus enhancement of the national and international competitiveness.

4. Exemplary solutions for individual support

Based on the outlined theory for support systems, we finally show four exemplary solutions that take into account the central aspects discussed here. The solutions are shown in figures 6 a) to d) and are applied for, e.g., the support of tasks in micro production (examples a and c) and assembly (c) as well as the support of tool

Table 2. Enablers, positive effects and potentials of the described approach

enablers \ positive effects	stabilization of e.g. posture & tools	monitoring	higher precision	lower physical strain	lower psychical strain	ad-hoc adaptable systems	wearable & comfortable systems	support of staff & no substitution	intuitive operation	compensation of lost functions	...
coupling of technical & biological elements	X		X	X	(X)			X	(X)	X	
using individual skills & abilities (simultaneously)	X		X	X	X			X		X	
new design principles			X	X	X		(X)				
construction kit systematic						X				X	
hardware & software functionalities	X	X	X	X	X					X	
"soft-frame" modules				X			X				
easy & intelligent modules	X	X	X		X	(X)			X		
light modules				X			X	X			
person- & task-adapted configuration	X		X			X	X	X		X	
standards & standardized interfaces						X		X	X		
...											
potentials						result					
lower wear on the side of user				X	X						
flexible staff deployment						X	X			X	
better staff availability				X	X					X	
incresead quality	X	X	X	X	X					X	
increased acceptance								X	X		
increased flexiblity						X	X				
context-dependent system behavior						X		X			
improved working conduction				X	X						
...											

handling (d) and arm/elbow functions (b). They are all developed with the purpose to increase precision, quality, ergonomics, and mobility. All these applications are built with standardized modules.

Passive workbench consists of only passive elements for stabilizing the working position in order to increase precision. The actuation of the kinematic elements is realized by pneumatic actuators, which generate the compensating force. Through integrated linear and rotary axes, the operator can move quite freely. The interface to the user can be customized (through integrated technical interfaces). Simultaneously, a feed unit for high precision manufacturing tasks can be controlled by a user panel.

The *arm support system* has also a modular system architecture. The system shown in figure 3b consists of three different elements – human-machine-interface (three), flexible kinematic elements (two; one torsion spring and one compliant mechanism), and a joint element with an integrated spring for actuation. Due to the modular construction, every module can be chosen and adapted: e.g, the passive joint can be substituted by an active joint or one might change the kinematic elements. Moreover, the kinematic element can be adapted in length.

The *active workbench* (figure 3c) consists of hardware and software modules for movement specification and monitoring, control, selection of assembly tasks and assembly instructions, quality assurance, and in order to avoid errors [30]. The system supports the user by bracing the arms, monitoring the workplace to ensure product quality, and specifying task- and person-adapted trajectories and movement corridors.

The *wearable tool support system* (figure 3d) enhances the ergonomics when handling heavy components or tools. This configured system consists of kinematic-elements, a human-machine interface and an

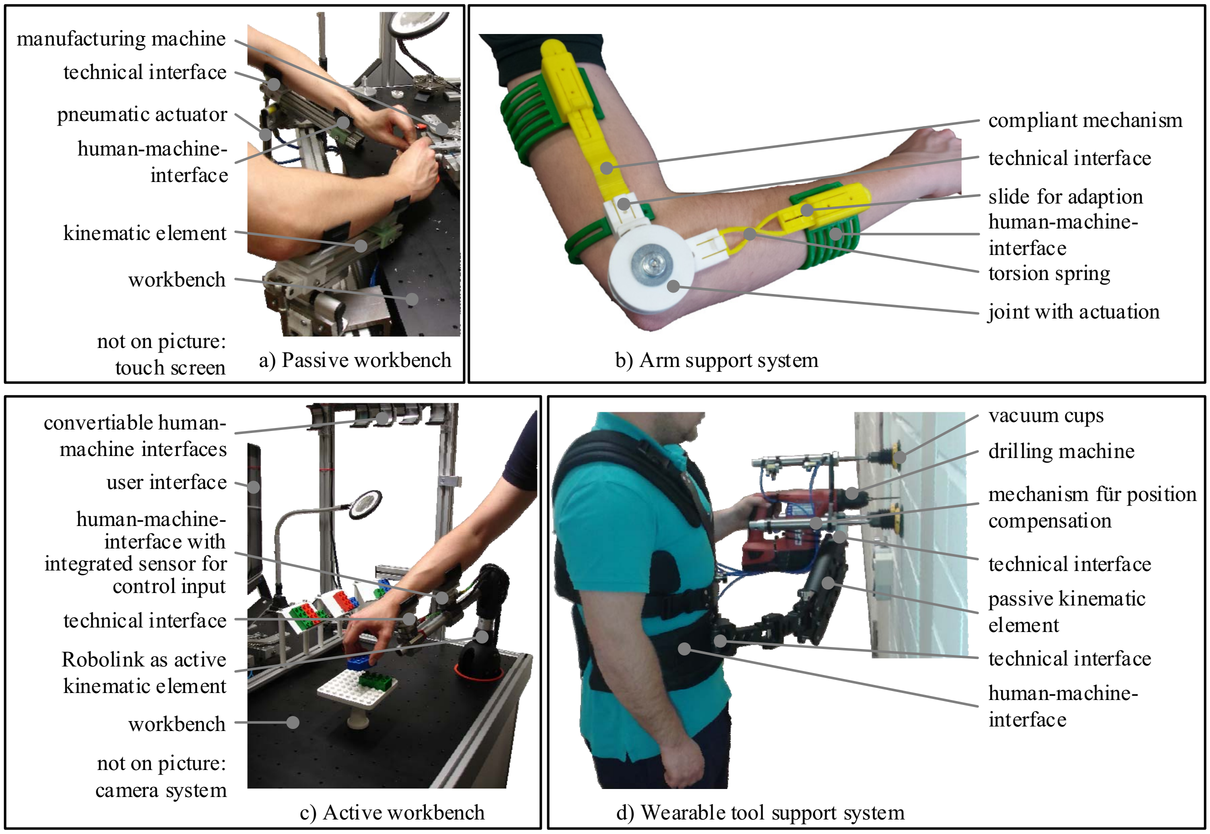

Figure 7. Exemplary solutions for individual support

endeffector for drilling with an integrated device for accurate positioning and locking. All elements are passive.

All the systems presented here are configured by standardized modules individually and with respect to the focal activity. For any of the used standards, e.g. standardized interfaces for force and torque transmission, an ad-hoc adaptation is possible. The technical elements do always support the users by providing additional functionalities. No system introduced here replaces the user. People are not integrated into these hybrids to support machine operations, which in the end only prepares their complete substitution. Rather the technical components support the physical and mental abilities of people. Thereby the personal and the organizational role of every employee can be strengthened concurrently.

5. Conclusion

This paper has outlined a theory for support systems with a focus on human beings. Central aspects for a general and comprehensive theory are introduced. The described approach is not yet fully defined, but it summarizes essential points: it points to methods for development, devises the main concept, and enumerates the impacts. An extension is possible at any time.

The outlined theory takes into account applications from working life as well as from everyday life. It can be employed for the design, development, and evaluation of systems for individual support. Such a description will help developers of technical systems to ascertain individualized forms of support, assist, and help and could also serve as a decision premise for organizations to find appropriate solutions.

6. Summary

Different kinds of production systems have been and will be developed and used for industrial applications. They respond to different requirements and appear in different forms. Production is accomplished by some mixture of automated processes and personal work. Until recently, the relation of machines and work force has been mainly considered as kind of separated or mutually exclusive. Support systems – and individually adapted support systems in particular – allow for hybrid combinations. They support people during their activities. Not all common systems fulfill user-centered criteria. This paper outlines a theory for individual support. It discusses their core characteristics, kinds of support, enablers, concepts and various impacts. The theory for support systems claims to be universally applicable and can be extended if necessary.

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