CPSL
CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2020

1st Conference on Production Systems and Logistics

Socio-technical requirements for production planning and control systems

Günther Schuh[1], Andreas Gützlaff[1], Frederick Sauermann[1], Matthias Schmidhuber[1]
[1]Laboratory for Machine Tools and Production Engineering (WZL), RWTH Aachen University, Germany

Abstract

Due to increasing customer requirements and intensifying competition, manufacturing companies are facing growing challenges in the successful order handling. As a result, employees are forced to make increasingly complex decisions in the shortest possible time. At this, the tasks of production planning and control (PPC) are particularly affected. In response to the increasing complexity of tasks, companies rely more than ever on the potential of socio-technical systems, rendered possible by the integration of information systems (IS) in the daily decision-making process. However, due to the increasing complexity of systems used, many users are not capable to raise the potential of information systems acquired, which is why the benefits of IS implementation often fall short of expectations.

The following paper thus analyses and structures potential decisive factors causing the lack of problem-solving capability in context of using PPC systems. Based on findings from acceptance research, socio-technical influencing factors for the targeted handling of information systems are determined. The developed requirement framework is furthermore compared with current IS implementation strategies to derive future research needs.

Keywords

Information systems; production planning and control; user acceptance

1. Introduction

Today's production environment is characterized by high fluctuations in sales, rising numbers of variants and the increased need to react flexibly to short-term disruptions [1,2]. Particularly affected by these developments are the task areas of PPC, which through their decisions and actions have an instantaneous influence on the logistic target achievement [3]. In order to cope with the increasing complexity, companies increasingly rely on the support of IS [1]. The PPC therefore increasingly develops into a socio-technical field of activity, which is characterized by system factors human factors and interface factors [4].

Despite the existing performance potentials and expectations, collaboration between IS and their user faces considerable problems in terms of potential utilization. True to Ashby's law, which argues that the variety of a control system must be as great as the variety of disturbances occurring to the system to be controlled, commercial IS themselves are characterised by increasing functionalities and complexity [5]. The rising complexity of advanced IS in return is contradicted by human factors striving for simple solutions and therefore complicates the targeted use by employees [3,6]. As a consequence of this mismatch, in practice decision support of IS oftentimes remains ignored, leading to manually adapted order sequences or work in progress (WIP) levels being actively held high [3].

In reaction to the experienced difficulties with IS collaboration, several research endeavours focussed on identifying decisive influencing factors for a successful IS implementation, looking beyond the oftentimes solely technical oriented approaches [7]. At this, critical success factors (CSF) were identified using empirical research methods [8]. However, given persistent reports of lacking performance improvements throughout the IS lifecycle, criticism on consisting IS implementation strategies and the usability of CSF remains [9][10]. In addition to increasing the applicability of implementation strategies, the need for research is seen in particular in the identification and handling of human factors [4]. Addressing these deficits, this paper is structured as follows: In section 2, the results of a literature review illustrating the current research deficit regarding the use of IS are presented. In section 3, existing models describing influencing factors addressing general technology acceptance are analysed, in order to develop a framework of socio-technical requirements for PPC systems. In section 4 this framework will be matched to existing IS implementation strategies in order to derive future needs of action. The summary and an outlook for further research will be given in section 5.

2. Literature Review

2.1 Human system partnership in PPC

The performance of manufacturing companies is, in addition to the products and services offered, primarily determined by the degree to which PPC is capable of meeting logistical targets [3]. Due to the mutual dependencies of the logistic target values, clear and transparent decision-making situations are rarely given, which severely increases the complexity to the decision maker [3]. Given the limited capabilities of dealing with complexity and uncertainty, however the decision-making process often solely takes place within an employee’s individual observation horizon and thus under pursuit of local rather than global, company-wide optima [1,3].

The desire of organizations to make decisions that take into account all aspects of the business is a major reason for the high degree of penetration of IS [11]. According to Alter (2008), IS can be defined as work systems focussing on the processing of information, thus providing support for an organization’s network in terms of information creation, gathering, processing or storing [12]. As a subclass of IS, PPC systems act as central logistical control mechanism, matching a company’s output to customer demands. The basic tasks of PPC systems thus include the planning, releasing and controlling of production orders as well as the monitoring and readjusting of production orders and production plans in case of unforeseen disturbances and deviations. [6] Enterprise resource planning (ERP) systems are among the most widespread and researched IS in manufacturing companies. The primary functions of ERP systems include enabling and processing of business transactions, furthermore addressing the problem of fragmentation by integrating internal processes throughout the entire company. [9] Based on the fundamental functions of ERP, the goal of manufacturing execution systems (MES) is to bridge planning and management systems at enterprise level to control systems on the shop floor, thus enabling an intermediate level of passing information in real time [13],[14,15]. In accordance with the diversity of the business units involved in the order processing, several additional IS systems have been established under the system classifications of operational systems, planning systems, management information systems and cross section systems [16].

The most influential shared ability of IS, regarding the collaboration between user and system, is automation. Automation can be defined as a technology performing tasks, which were previously done by humans [17]. Automation thus bares the potential to extend an employee’s physical and cognitive capacities, enabling a joint achievement of objectives [18]. As described by Bainbridge as “Ironies of Automation”, the role of the user at this becomes, due to unavoidable supervisory functions left with the user, more, rather than less, important within this collaboration [19]. Crucial for an efficient interplay is an holistic automation design which considers characteristics of the joint cognitive system emerging from the combination of humans and automation [18]. Depending on the fulfilment of expectations and requirements from the support operators, determining the individual levels of trust and acceptance towards automation, collaboration with automation can be differentiated between purposeful use, misuse and disuse [20]. At this, disuse due to limited trust describes the case, if employees do not use IS or decline decision support offered by IS. On the contrary, misuse related to an excessive level of trust describes the case, if employees follow automation despite obvious malfunction, due to a missing challenging of results. [20]

2.2 Adoption strategies of information systems

In order to address the complexities accompanied by IS collaboration, several research endeavours focus on adoption and management strategies. In accordance to the life cycle of IS, a common distinction is to be found between research approaches focussing on the pre- or post-implementation phase of IS [21]. The pre-implementation comprises the life cycle phases of adoption decision, acquisition and implementation, whereas the post-implementation phase consists of use and maintenance, evolution as well as retirement [22–24].

Major problems related to the pre-implementation phase can be related to mismatches between IS functionalities and company requirements [25]. At this, requirements management is an essential task of the pre-implementation phase [26]. A requirement at this can be defined as prerequisite or ability a system must fulfil [27]. However, existing approaches to requirements management often face criticism due to primarily technical or cost-oriented perspectives [7]. It is also for the neglect of socio-technical aspects, that around 40 % of the efforts in the IS development or configuration process are related to the implementation of changes [28]. In response to IS performance criticism, several research efforts on pre-implementation strategies accompanied and analysed actual IS implementations projects in order identify CSF [8]. CSF can be understood as those conditions, which must be met in order for the implementation process to work successfully [25].

A considerable proportion of manufacturing companies face problems with IS utilization especially in the post-implementation phase. According to industry reports, 57 % of industrial organisations report considerable process stoppages due to IS problems in the post-implementation phase [29] and 67 % report on missed performance expectations [30]. These failures are among other things attributed to a lack of organizational attention, after overcoming a resource and time intensive pre-implementation phase, and the consequent lack of working on the establishment of processes [31]. A similar shift of awareness also prevails the research agenda, as Esteves et al. (2007) showed, that of all ERP-related articles, 47 % address pre-implementation strategies whereas only 15 % address the post-implementation phase [32]. It is therefore, that a growing number of research articles start focussing on success-related factors influencing the post-implementation phase. At this, DeLone and McLean's information systems success model is the research framework primarily used to determine influencing factors in post-implementation [33] [9,21,31,31,34–37].

2.3 Research Deficit

Given cause to a persistent research deficit regarding IS adoption and usage is found in lasting company reports of unsuccessful IS implementation and user cycles phases. Cases such as Nike’s ERP-failure which cost $100 million in sales and resulted in a drop of stocks in 20 % [38] are thus no rarity, given evaluations such as from Deloitte, which state that of Fortune 500 companies, 25 % are struggling with ERP adoption and performance [36].

Reasons for the persistent problems in dealing with IS match criticism on the IS adoption research, facing inadequate interpretation as well as missing generalizability and applicability of influencing factors throughout the life cycle [10]. Facing interpretation issues, several research contributions state, that sufficient effort was made to address system factors in influencing models, not so however to analyse human factors, consequently biasing conclusions on performance constellations [39]. A further issue of extant adoption literature is the biasing influence of the respective point of view, induced by case related empirical research methods used and therefore hindering the generalisability and thus operational application of influencing factors [8]. This point of criticism is reaffirmed by the strong predominant system focus of ERP systems. Very few research endeavours analyse influencing success factors on ERP system supplements such as MES or advanced planning systems (APS) [40]. Due to the continuing failures and criticisms, the question of the requirements for a successful collaboration between users and PPS systems, especially with regard to socio-technical interactions, continues to arise.

3. Socio-technical requirements for user acceptance

In response to the persistent criticism, the following paper will shift the focus of IS adoption from the company perspective to the individual user perspective, analysing factors influencing the collaboration between user and IS. This is in line with research and practice insights, according to which the employee adoption and use rate are still major barriers for the success of IS [41].

3.1 User acceptance models

Research on IS has long studied the rationale of how and why individuals adopt new technologies [42]. One of the early but still widespread model is the Innovation Diffusion Theory (IDT) by Rogers (1995) [43]. Diffusion in this context can be defined as the process by which technology spreads across a population of organizations [44]. The IDT thus represents an empirical construct from the field of sociology that enables the evaluation of user acceptance of technical innovations and thus investigates the question of how, why and at what rate innovative ideas and technologies prevail in social systems. [44][42]. As relevant influencing variables on innovation acceptance Rogers identified: *relative advantage, compatibility, complexity, trialability and observability*.

As another representative of the user acceptance research area, Goodhue and Thompson (1995) developed the Task-Technology Fit model (TTF) [45]. The objective of the TTF is to predict technology acceptance by means of increasing the individual performance of its user [45]. For this purpose, the theoretical model draws from the supplementary research insights, using user attitude as predictor of utilization and task-technology fit as a predictor of performance [45]. As relevant influencing variables on task-technology fit the TTF identified: *quality, locatability, authorization, compatibility, ease of use, production timeliness, systems reliability and relationship with users*.

Within the framework of the Unified Theory of Acceptance and Use of Technology (UTAUT), Venkatesh and Davis (2003) worked towards the aggregation of several user acceptance work streams. The resulting theoretical model merges individual, organizational as well as work related perspectives on user acceptance [42]. As relevant influencing variables being suitable to aggregate in the UTAUT Venkatesh and Davis identified: *performance expectancy, effort expectancy, attitude toward using technology, social influence, facilitating conditions, self-efficacy and anxiety*.

Being among the most applied theoretical models explaining user acceptance is the Technology Acceptance Model (TAM), being initially developed by Davis in 1989 [46]. Drawing from the theory of reasoned action (TRA), Davis acknowledged every behaviour being preceded by a behavioural intention which is influenced by attitudes and subjective norms [46]. Transferred to his research subject, Davis identified the variables of perceived usefulness and perceived ease of use as prerequisites for user acceptance and hence technology usage [41]. In continuation of the research results, the TAM was extended by variables explaining the influence on the construct of perceived usefulness (TAM 2) [47]: *computer self efficacy, perception of external control, computer anxiety, computer playfulness, perceived enjoyment and objective usability*, as well as the on the construct of perceived ease of use (TAM 3) [41]: *perceived ease of use, subjective norm, image, job relevance, output quality and result demonstrability*.

3.2 Synthesis of relevant requirements for user acceptance

Analysing the results of the user acceptance models shown in section 3.1, a total of 32 empirical constructs influencing the user acceptance on the individual level were identified. After the consolidation and exclusion of the redundant influencing variables across the models, the following 18 socio-technical influencing variables on user acceptance were derived. The result Table 1 lists all requirements, including a model assignment and a description aggregated from the models.

Table 1: Socio-technical acceptance requirements

#	TAM 3	TTF	IDT	UTAUT	Requirement	Description
1	X			X	Anxiety	User are not exposed to apprehension or fear when facing the possibility of using the system and thus the risk of incorrect use.
2			X		Appropriate Complexity	Using and understanding an innovation is perceived as an appropriately difficult task.
3		X	X		Compatability	The innovation is perceived as beeing consistent with the existing values, needs and past experiences of potential adopters.
4		X			Data Locatability	User are easily capable of determining what a data element on a report or file means, or what is excluded or included in calculating it.
5		X			Data Quality	Data meets user needs in terms of currency, maintaining the right level of data as well as the right level of detail.
6	X	X			External Control	User have access to organizational and technical resources to support the use of the system.
7	X			X	Intrinsic Motivation	User have an intrinsic, positive attitude towards using technology.
8	X	X			Job-Fit	The system fits the users' job/activity requirements and corporate goals.
9	X	X		X	Output Quality	The system performs its tasks according to the job requirements.
10		X			Production Timeliness	The system meets pre-defined production turnaround schedules.
11			X		Relative Advantage	Using an innovation is perceived as being more advantageous as using its precursor.
12	X		X		Result Demonstrability	The results of system usage are tangible, observable, and communicable.
13	X			X	Social Influence	The variables determining the social variables are aligned to the acceptance and use of the systems. This includes subjective norm (addressing people being important to the user) and image (addressing the social status within the company).
14	X	X		X	System Self Efficiacy	The supporting functions of the system allows users to complete a system job or task in case no external support is available.
15		X			System Reliability	The system is dependable in terms of access and uptime.
16			X		Trialability	Innovations can be carried out on a limited basis prior to adoption.
17		X			User Authorization	User obtain the authorization to access data necessary to do their job.
18	X	X		X	Usability	Daily usage of a system is associated with little effort and learning a skillful handling of the system is easy.

4. Comparison of socio-technical acceptance requirements with IS implementation strategies

In order to compare the identified socio-technical acceptance requirements with IS implementation strategies, a literature research was conducted to identify current pre- and post-implementation approaches. The literature research was carried out using the common search engines and literature databases: google scholar, researchgate, sciencedirect, and excluding contributions with a publication date prior to 2010. A combination of the following terms was used as keywords for the search: IS OR information system OR ERP OR MES OR APS AND implementation OR pre-implementation OR post-implementation OR success factors OR performance assessment.

4.1 Research contributions on pre- and post-implementation strategies

Addressing the pre-implementation process, Hailu and Rahman (2012) reviewed industry and academic literature in order to evaluate key success factors influencing ERP implementation [48]. Dezdar (2012) used the survey approach to collect data throughout Iranian companies in order identify tactical and strategical factors being crucial for a successful ERP implementation [49]. Behehsti et al. (2015) used a qualitative research method to study six diverse manufacturing companies in the US in order to identify CSF for ERP implementations [50]. Chatzoglou et al. (2916) used empirical methods in order to test a conceptual framework including factors enabling a successful ERP implementation especially for Small and Medium Enterprises [51]. To the best of our knowledge, Lee et al. (2012) contributed the only research paper focussing on critical success factors for the MES implementation process, therefore conducting a survey throughout 163 manufacturing companies in South Korea [14].

Addressing the post-implementation process, Ha and Ahn (2014) evaluated factors affecting the post-implementation performance of ERP systems using pilot studies throughout Korean companies [36]. Hecht et al. (2013) conducted an extensive literature research in order to identify factors influencing the post-implementation success of ERP systems and to derive requirements and capabilities for ERP maintenance [21]. In their research contribution, Hsu et al. (2015) analysed how different qualities of ERP system affect the post-implementation success, especially regarding the user perspective [31]. Ifinedo et al. (2010) investigated the relationship among six models of ERP post-implementation success measurement models from an organizational level [37]. Using a fuzzy analytic network process, Moalagh and Ravasan (2013) developed a practical framework for assessing companies' ERP post-implementation success [9].

4.2 Comparison of socio-technical requirements with implementation strategies

The results of the comparison of the socio-technical acceptance requirements derived in section 3.2 with the implementation strategies as outlined in section 4.1 are shown in Table 2. Harvey balls following the semantic depicted in Figure 1 were used in order to assess the comparison.

	Description
●	Requirement is directly addressed through a corresponding requirement in the implementation strategy.
◕	Requirement is directly addressed through a corresponding action described in the implementation strategy. (anxiety - user training and education)
◑	Requirement is indirectly addressed through a corresponding action or requirement in the implementation strategy. (intrinsic motivation - user involvement)
◔	Requirement is loosely addressed through a generic action or requirement in the implementation strategy. (social influence - top management support)
○	Requirement is not addressed by the implementation strategy.

Figure 1:Semantic evaluation model

The results of the comparison show, that the implementation strategies mostly cover the basic technical aspects identified in the acceptance requirements, such as data quality, output quality, usability, system reliability and trialability. Furthermore directly addressed through corresponding actions and requirements, details in parenthesis, were the organizational requirements of external control (IT & vendor support) and job-fit (user involvement & user requirements) as well as the user related requirements of anxiety (training), intrinsic motivation (job-enhancement & user satisfaction) and production timeliness (timeliness &

performance). Not or mainly generically addressed were the mainly organizational and user related requirements of relative advantage, compatibility, appropriate complexity, result demonstrability, data locatability, user authorization, system self efficacy and social influence.

Table 2: Evaluation of IS implementation strategies

		Pre-Implementation					Post-Implementation				
#	Requirement	*Hailu & Rahman* 2012	*Dezdar* 2012	*Behehsti et al.* 2014	*Chatzoglou et al.* 2015	*Lee et al.* 2012	*Ha & Ahn* 2011	*Hecht et al.* 2011	*Hsu et al.* 2015	*Ifinedo et al.* 2010	*Moalagh & Ravasan* 2013
1	Relative Advantage	◔	○	◔	◔	◔	○	○	○	○	○
2	Compatability	◔	○	◔	◔	◔	◔	◔	○	○	○
3	Approp. Complexity	◔	○	◔	○	○	○	○	○	○	○
4	Trialability	○	○	○	○	○	○	●	○	○	○
5	Res. Demonstrability	○	○	○	○	○	○	○	○	◔	○
6	Data Quality	◑	◔	◔	◔	◔	◑	◑	●	●	●
7	Data Locatability	○	○	○	○	○	○	○	○	○	○
8	User Authorization	○	○	○	○	○	○	○	○	○	○
9	Usability	◑	◔	◑	◑	◑	◔	◑	●	◕	◑
10	Job-Fit	◑	◑	◑	◑	◑	◔	◑	●	●	●
11	Prod. Timeliness	◑	◔	◑	◑	◕	◔	◔	○	◑	○
12	System Self Efficiacy	○	○	○	○	○	○	○	○	○	○
13	External Control	◔	◔	◔	◔	◔	◑	○	●	◑	◑
14	Output Quality	◔	◑	◑	◑	●	◑	◔	●	◕	●
15	Anxiety	◕	◕	◕	◕	○	◕	◕	◕	○	◕
16	Intrinsic Motivation	◔	○	◔	◔	◔	○	◔	◕	◕	◕
17	Social Influence	◔	◔	◑	◑	◔	◔	◔	○	○	○
18	System Reliability	◔	◔	◔	◔	◔	◑	◔	●	●	○

5. Summary and Outlook

Employee adoption and user rates of IS are still today major barriers for IS success [41]. This study thus examined the most well-known user acceptance models and derived an aggregated framework of socio-technical influencing factors on IS user acceptance. In order to examine the existing criticism of IS implementation strategies, the study furthermore checked the identified acceptance requirements for conformity with the findings and recommendations of current research endeavours on implementation strategies. The results lead to the following three conclusions for current and future IS research: (1) Implementation approaches only take into account a section of the relevant influencing factors (missing completeness); (2) Implementation approaches lack concrete feasibility for companies (missing operationalisabilty); (3) IS implementation approaches in the PPC environment neglect advanced systems like APS, MES, etc. (ERP focus).

As shown in the matching overview in Table 2, the aggregated implementation strategies together, cover entirely only seven of the 18 identified acceptance requirements. Accordingly, none of the individual approaches achieves a degree of coverage of more than 33 %. As has already been the subject of criticism, the focus here is mainly on the technical requirements of user acceptance [4]. Acceptance requirements of the user- and organization-oriented perspective remain for the most part neglected. Thinking in terms of IS utilisation (use, disuse and misuse), aspects such as IS rejecting social structures or authorities (social influence), restricted IS authorization (user authorization) or non-transparent relative advantage of IS compared with existing customised solutions (relative advantage) pose a major risk for disuse of introduced systems. Requirements such as a self-explanatory support functions within IS (system self-efficacy) or user knowledge about the design of the operational information structure and its operating principles (data locatability) furthermore are fundamental in avoidance of system misuse.

Restrictions of the operationalisability of current implementation strategies become transparent, especially in view of their application to the entire IS life cycle. While many IS success models of post-implementation approaches feature a comparatively high level of detail in the sense of requirements management, CSFs of pre-implementation approaches are characterised by a high level of abstraction, which is why factors such as top management support or vendor support remain intangible. Future IS research should therefore be directed at holistic implementation strategies covering the entire IS life cycle (pre- and post-implementation) as well as the concretisation and operationalisation of CSF in the sense of controllable requirements.

The results of the literature research on existing IS implementation strategies further indicate a dominant focus on ERP systems. As for the search criteria used, this study only found one research paper focusing on success factors for MES implementation and no research contributions addressing success factors relating to APS. The question of PPC-stakeholder requirements for dealing with IS, especially including blue collar user close to the shopfloor, therefore remains largely unadressed and demands further research focus.

Acknowledgement

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany´s Excellence Strategy – EXC-2023 Internet of Production – 390621612.

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