**Mobile Technology in the Construction Industry – the Impact on Business Processes in Job Production**

Sina Deibert  
University of Mannheim, Germany  
deibert@uni-mannheim.de

Erik Hemmer  
University of Mannheim, Germany  
erik.hemmer@uni-mannheim.de

Armin Heinzl  
University of Mannheim, Germany  
heinzl@uni-mannheim.de

**ABSTRACT**

Research on mobile technologies has received an increasing attention. However, most of the existing literature focuses on the use of mobile technologies on a managerial level, with technology as an enabler for information and communication exchange. The impact potential and their corresponding functionalities at the operational level have not yet been analyzed. This study addresses this gap. The key objective is the development of a conceptual model to explain how mobile technologies impact business processes in the construction industry on the operational level. Thus, a generic model will be developed on the basis of existing literature, especially the concept of Task-Technology-Fit. It emphasizes how task complexity affects the required effort of individual information access, information capturing as well as the timeliness of information. Then, it will be deduced how mobile technologies affect the forces and relationships in this model. The evaluation of the model shows that there is a strong influence of the reduced effort for accessing information on the process performance if there is a high task complexity. In addition to the new level of analysis (the system user is a worker instead of a manager), a new method of performing the model evaluation is utilized. For this evaluation, a 3D-laboratory experiment is combined with a computer simulation.

**Keywords**

Mobile technology, job production, construction processes, operational impact, process performance, 3D-laboratory experiment

**INTRODUCTION**

When looking at the characteristics of the job production industry, it can be observed that different professionals work at different locations. For doing their work effectively in a distributed environment, they need a lot of information, e.g. to coordinate tasks and locate means of labor. The job production industry can be characterized as highly information-intensive (Kajewski and Alwi, 2006). For the success of a project it is very important what information is available and who can access this information. Moreover, the communication, i.e. the distribution of information to other project participants, depends on the quality, quantity and timing of information (Bowden and Thorpe, 2002; Dong, Maher and Daruwala, 2006). However, information capturing and access is largely person-bound. Automating information capturing and access by using mobile technologies is considered the first step to improve process performance in this context (Bowden, Dorr, Thorpe and Anumba, 2004). In the construction industry, a characteristic fact is the inherent mobility of materials, equipments and the required operational workforce. To provide all participants of a project with timely, reliable and relevant information about the status of these resources and their location, the information must be captured and stored, but at the same time it has to be easily accessible (Liu, Soibelman and Trupp, 2004). Another reason why the communication especially on construction sites is crucial is the occurrence of exceptions and disruptions like missing materials, machine failures or unfinished work items. Mobile technology provides the opportunity for managers and foremen to be immediately informed about unexpected events (Rupnik and Krisper, 2003) in order to react on these exceptions within a short period of time (Gebauer and Shaw, 2004).

To summarize, the potential of using mobile technologies stems from the interplay of information access and information capturing because it is possible to provide better methods of resource utilization and to coordinate and plan work steps more flexibly. Therefore, not only the managerial impact but also the operational impact must be taken into account. Since few
contributions reflect specific processes like plant or building construction (Saidi et al., 2002), it is not clearly understood how mobile technologies impact operational processes (Gebauer, Shaw and Zhao, 2002a). The existing literature assumes that work and resource coordination still take place through mutual adjustment and that the adaptation of work plans only takes place in periodic cycles, e.g. once a week. Information about the work progress is gathered weekly or less frequently (Bowden et al., 2004; Liu et al., 2004). In this context, mobile technologies offer the possibility to closely monitor the status of the activities at the project site permanently, whilst providing information which is easy to access and available on time. In this context, the negative consequences of unexpected events (e.g. stock-outs, delays of preceding activities, etc.) may be reduced or circumvented. Both, better information supply and better coordination will enable an improved process performance compared to conventional information supply and coordination.

RESEARCH QUESTIONS AND METHODOLOGY

To analyze the potential of mobile technologies in job production on an operational level, the following research questions will be addressed:

- Which factors determine process performance from an information processing perspective?
- How does the use of mobile technologies change this cause and effect relationship?
- Are there any trade-off relationships between factors that need to be carefully looked at?

The methodology of this paper is theory emergent. Based on the existing literature, especially the concept of the Task-Technology-Fit (Gebauer and Shaw, 2004; Goodhue and Thompson, 1995), a theoretical model will be deduced. It will be analyzed how this construct affects the existing relationships in order to assess the impact logic of mobile technology usage. Thus, the methodological approach followed in this paper is exploratory. It is the first contribution which focuses on the operational level from the perspective of a specific and relevant process (construction). The stepwise development of the theoretical model is considered a valuable approach since it offers a profound perspective towards the impact logic of mobile technologies.

The paper is organized as follows. Section 2 shortly describes the state of the art of mobile technology research in the construction industry. An extended state of the art can be found in Deibert, Heinzl and Rothlauf (2008). In section 3, our research model regarding information impact of mobile technologies is presented. Section 4 provides an overview how the extended model is tested. Section 5 gives a brief description of the results of the model test. The paper ends with an intermediate conclusion of this research.

STATE OF THE ART OF USING MOBILE TECHNOLOGY IN THE CONSTRUCTION INDUSTRY

To summarize the state of the art described in Deibert et al. (2008), it can be stated that there are a lot of mobile applications in use in the construction industry, but nearly all of them are used by project managers only. The impact which can be gained when workers use the mobile technology is not analyzed. On the other hand, a lot of authors mention the potential of the use of mobile technologies for tracking work and accessing information (Loefgren, 2005; Saidi, Haas and Balli, 2002; Bowden et al., 2004).

In contrast to the papers reviewed in Deibert et al. (2008), which focused solely on the usage of mobile technologies on a managerial level, the purpose of our research is to analyze the potential of mobile technologies in construction sites on the worker level. It concentrates on construction site workers (and not construction managers) using mobile technologies in order to offer timely access to accurate information. This improved information supply offers a better basis for resource utilization which in turn allows for the improvement of the process performance. Especially the possibility of a faster and more frequent plan adaptation enables a better exception handling and resource utilization.

RESEARCH MODEL

Based on the literature on mobile technology (for details see Deibert et al., 2008), the following model (Figure 1) is developed. It has been carefully deduced with the help of existing studies. The model combines task, technology, and information characteristics (Chenhall and Morris, 1986; Daft and Macintosh, 1981) as well as elements of the concept of the Task-Technology-Fit (Goodhue et al., 1995). In general, a good Task-Technology-Fit promises significant performance improvements (Goodhue et al., 1995; Lee, Lee and Kim, 2004). This type of fit has been analyzed in combination with mobile technologies by different authors (Gebauer, Gribbins and Shaw, 2005; van der Heijden and Valiente, 2002; Lee et al.,
They postulate that task characteristics (e.g. task size, complexity, uncertainty) and technology characteristics (e.g. display size, input-methods and context) have to be taken into account when analyzing the Task-Technology-Fit in combination with mobile technologies.

The benefit of mobile technology utilization will be measured by the increase of process performance, i.e. the reduction of the finishing time for the building or the plant. To do this, the concepts mentioned above are integrated into the developed model. A trade-off can be found between effort for capturing information and reduced effort for information access. Moreover, the use of mobile technology to support the planning intensity, i.e. the frequency of re-planning work steps is included. The result is a reduced overall processing time (Gebauer and Shaw, 2002b; van der Heijden and Valiente, 2002). In contrast to the reviewed literature, the user’s role who applies the mobile technology is not only managerial but primarily operational. Thus, the technology will be used by workers and handcrafters.

In the following, the different constructs and relationships will be explained (see Figure 1). The dichotomous construct “Mobile technology” denotes that a mobile technology (e.g. a personal digital assistant) is either used at one point in time or not. The construct “technology intensity” describes the intensity, mobile technology is used and implies the extent to which information collection is done automatically in order to obtain information about the position, the time, the skills of a worker or the status of material and equipment. Moreover, technology intensity implies dimensions like usability (e.g. how comfortable it is to capture information). Therefore, low intensity means that no information is captured automatically and the technology is hard to use. Thus, two different constructs for representing mobile technology are deployed in the extended model. The construct “Mobile technology” refers to the change in effort for a single worker who has not used mobile technology before. His work process will change with the use of the technology. The construct “technology intensity” takes into account not only one worker but the overall construction site. It is a moderator regarding the relationship between task complexity and the information constructs in our model. This implies that the impact of task complexity on the effort for capturing information will vary across different levels of technology intensity. This characteristic refers to the notion of the ‘Task-Technology-Fit’ (Goodhue, 1995; Venkatraman, 1989) which claims that different task characteristics require different technology features.

![Figure 1. Research Model: Mobile Technology – Information Using – Process Performance](image)

**H1: The higher the task complexity, the higher the effort for information access.**

Task complexity in the building or plant construction industry can be expressed with different factors like size of a building (Tawfik and Fernando, 2001) (number of rooms and floors), number of workers, number of assembly sections as well as the number of dependencies between tasks. Information in this model is information about the work progress and the status and position of machines, material and workers. Dong et al. (2006) and Oglesby, Parker and Howell (1989) state that the management’s demand for information is influenced by the size and the complexity of a task. In order to get information in a building (e.g. about the work status in different rooms or the status of machines), the worker has to walk around and/or ask other workers. If the building is large, getting information means walking longer distances and/or asking more people. Thus, the effort for accessing the required information turns out to be higher. Bowden et al. (2004) point out that the collection of
information from different sources is time consuming. With a growing number of rooms, the number of sources increases and so does the time for collecting this information, which is however a prerequisite for having access to that information. Furthermore, with a growing size of the building or plant, the complexity of the task grows and the respective information needs increase as well (Dong et al., 2006).

**H2: The higher the effort for information access, the lower the process performance.**

The process performance is determined by the time which is necessary to complete a task/process (Gebauer and Shaw, 2002b). If the effort for the access of information (which must be used to fulfill a task) increases, also the total process duration increases. The result is a lower process performance (Bowden et al., 2004). The time for building an object, which means the time until every process step is fulfilled, is the sum of the duration of all process steps and all delays during the process steps (Oglesby et al. 1989). If the different process steps are completed faster, this leads to a faster finishing time. On the other hand, if the process steps take more time or if there are more waiting times during the process steps, the finishing time grows and this leads to a lower process performance (Boussabaine, Grew and Currin, 1999).

**H3: If mobile technology is used, the effort to capture information increases.**

Before mobile technology is used, every worker conducts her/his work (e.g. coating, tiling, etc.) in one part of building or site (e.g. room or floor) and then proceeds to the next room. In doing so, she never stores any information about her/his work progress. When using mobile technology, she now has to enter status information like login information, location, work item, and job starting time. After that the worker starts her/his actual work and after finishing it, she has to key in the corresponding job end time and, presumably, the materials consumption. Since mobile technology influences the work of a professional directly, the construct “mobile technology” has a direct impact on the effort for information capturing. The process of capturing information is an additional activity which is inevitable for later use of the information. Thus, the effort for information capturing occurs as a prerequisite of the mobile technology use (Saidi et al., 2002).

**H4: A higher effort for capturing information leads to a decrease in process performance.**

The collection of information is – of course – time-consuming (Bowden et al., 2004). With the use of mobile technologies, storing information is an additional activity in the work process of site professionals. Since every work item consumes time for information capturing and more work items need to be conducted in order to finish the work, the performance of the process decreases. The operational work process (e.g. coating, tiling, etc.) is, at best, not influenced by the use of technology.

**H5: The use of mobile technology has a lowering effect on the (positive) impact of task complexity regarding the effort for information access.**

With the use of mobile technologies, it is possible to access critical data at every time and at every place (Sheng, Nah and Siau, 2005). This leads to a lowering influence of the effect of the task complexity like for example the building size because with the help of mobile technologies the worker can see the state of the different work steps directly on his/her mobile device. So the workers don’t have to walk around for this information. The result of using the technology is that the duration until the workers find out about the state of different work steps is lower because they have to walk around less on the construction site than without the technology. So the process of finding/getting information is more efficient (Bowden, Dorr, Thorpe and Anumba, 2006).

**H6: The higher the mobile technology intensity, the lower is the (positive) impact of mobile technology on the effort to capture information.**

As mentioned before (H5) the effort for capturing information increases with the use of mobile technology because now additional work steps (the data capturing) have to be done by every worker. But with the intensity of the used mobile technology (e.g. the way in which data is collected automatically, the ease of use of the mobile technology) the effort for capturing data will be lower or zero (Bowden, 2005; Loefgren, 2005; Rebolj, Magdic and, Babic, 2004). The use of modern technologies like RFID tags, reduces the effort for data capturing in a very significant way (Bowden et al., 2002; Kajewski and Alwi, 2006) and thus, the process of data capturing can be done more efficiently (Bowden, 2005).

**H7: The higher the mobile technology intensity, the higher is the lowering impact of mobile technology on the (positive) impact of task complexity regarding the effort for information access.**

If a worker employs a mobile application which uses context data instead of a mobile device without this possibility, the worker has to key in less data when for example searching for a special machine. So, when using context data, the mobile device “knows” who is searching something. This has the effect that for example the application can filter the result list and the user has a reduced scrolling effort to locate the machine he/she is looking for. Another example for the benefits of using
context data is that the application shows only such machines which are in the worker’s immediate neighborhood so that he/she can reach the respective machine very quickly (Bowden, 2005; Loefgren, 2005). This results in less effort for searching things (Kjeldskov, 2002; Rebolj et al., 2004).

MODEL TEST

As mentioned before, it is difficult to test the research model under real-world conditions. In order to judge the relationships between the constructs, many variations in the entities “Mobile technology” and “Task complexity” have to be tested. Three major arguments restrict applying methods of direct observation in this early stage of research. First, the technologies and software solutions required to support construction processes are rarely used on construction sites at this point in time. Second, varying task complexities and the scope of mobile technology use would generate enormous costs for the companies involved in the construction project, because various scenarios would have to be repeated several times with slightly adapted parameters. Third, disturbing factors such as a low motivation of workers to use mobile technology would influence the results by making it difficult to decide whether specific effects are caused by the manipulation of independent model variables or by disturbance variables which are hard to identify. Those facts lead to the requirement of finding a new method for testing the model. Following a recommendation by Meredith, Raturi, Amoako-Gyampah and Kaplan (1989) for positivist research approaches in which it is hard or impossible to “study [reality] through direct observation” (Meredith et al., 1989, p. 308), a combination of a virtual reality laboratory experiment with a computer simulation has been selected.

In the laboratory experiment (see Figure 2), a virtual 3D construction site is visualized on a PC using an open source real-time 3D engine in combination with XML (Collada) models of buildings, generated with Google Sketchup. A subject in front of the PC solves different tasks (for example searching a machine on the virtual construction site). To do this, (s)he uses a physical mobile device which helps her/him to find the required objects and which is directly linked to the 3D engine. Then, the subject is asked to walk through the virtual building to pick up the object she/he is looking for. In the backend, the time is captured, which is required by the subject to enter data into the mobile device and to find different objects. The variation of the different constructs (task complexity, technology intensity) is realized in the laboratory experiment by changing the building under construction and second by changing the way in which the mobile technology is used (no technology, technology without context usage, technology with context usage).

As explicated in Bonoma (1985), it is a common characteristic of a single research method, that threats to internal and external validity cannot be minimized simultaneously. Laboratory experiments usually imply a high degree of internal validity but a low degree of external validity. The latter and less desirable fact was mitigated in this research by visualizing the construction plans of two real construction projects. In addition, experts from the construction industry with several decades of work experience were involved in the process of designing and evaluating the 3D laboratory experiment, which allows for a basic generalization of the data captured in the experiment and thus follows the advices given in Bonoma (1985).

![Figure 2. Entities of the laboratory experiment](image)

After the laboratory experiment was performed with 20 subjects (each experiment took 90 minutes) the recorded time information is used to calibrate a computer simulation. With the help of this simulation, the final model test has been conducted. In order to calibrate the computer simulation, the authors tried to identify a characteristic distribution function concerning the time needed to fulfill the various tasks in the laboratory experiment, e.g. searching for a machine on a large construction site. Since such a distribution function could not be discovered, a different approach was selected: For simulating the duration of tasks such as looking for a machine, a dataset from the laboratory experiment is picked randomly.
Since in the laboratory experiment objects like machines were spread evenly over the construction site, a distribution of search times close to reality is achieved. To test the effects of different task complexities, two scenarios are simulated in a Java-based simulation engine: the construction of a one-family house and the construction of a multi-family house. The probability for the need to search a machine or a material on the construction site is varied from 0% to 100% in 10% steps (11 settings). At the same time, the number of persons performing the work is varied from 1 to 3 to 5. All those variations are applied to both scenarios so that there are 66 different settings in total which are analyzed in 100 simulation runs each.

In a last step, the so-collected data is analyzed by using the Partial Least Squares (PLS) approach. Compared to other covariance-based methods of Structural Equation Modeling, PLS can also be used in scenarios with a small sample size. Furthermore, a normal distribution of sample data is not mandatory (Chin, 1999). Thus, PLS is suitable in case of this research since the study is based on a rather small sample size of 20 subjects and a characteristic distribution function could not be identified. Statements about the significance of relationships between constructs of the research model are based on a t-test with a level of significance of p=0.05.

RESULTS

As a first result of the laboratory experiment, we can state that the use of mobile technology significantly lowers the effort to access information such as the location of machines or material. The following diagrams show the strength of the correlation of the constructs (y-axis) as well as the variation on task complexity (x-axis). Task variation is done with two different object sizes, different probabilities of exceptions (machine/material failure) in 10% steps and different numbers of workers for each maintenance group. Figure 3 shows that this positive moderating influence of using mobile technology is even more obvious in case of high task complexity which is represented by a high probability of machine/material failure and the coordination of several workers in the building process of a six-family house.

![Figure 3. Relationship between task complexity and effort for information access (underlying assumption: mobile technology is used with full intensity)](image)

Figure 4 shows that the negative correlation between the effort for information access and process performance is confirmed when a high coordination effort is given. Thus, the correlation is significant in cases of a high task complexity.
In small objects, there is not necessarily a positive effect when using mobile technology since the effort for information access has only a low influence on the process performance. But if the mobile technology is used to support the building of a big object (high task complexity), there is always a positive effect.

The positive correlation between the use of mobile technology and the thereby induced effort to capture information can be clearly confirmed. The results suggest that this influence is rather independent of object sizes and task complexity since the strength of correlation is constantly in the range between 0.996 and 1.000. Still, the effort to capture information does not have a considerable impact on the overall process performance, which will be discussed later in this study.

An additional interesting finding is the fact, that H4, “A higher effort for capturing information leads to a decrease in process performance”, could not be confirmed. In case of the one-family house, the strength of correlation oscillates between -0.354 and 0.474, for the six-family house the values even fluctuate in the range between -0.493 and 0.806. A correlation between object size, number of workers and probability for machine/material failure is not visible.

Altogether, the results of the simulation show that up to 90% of the variance of the dependent variable “Process performance” can be explained with our model in scenarios which are characterized by a high task complexity as illustrated in Figure 5. At the same time it can be observed, that there is a huge gap between the degree of explained variance when comparing the one-family house scenario with the six-family house scenario.

![Figure 4. Relationship between effort for information access and process performance](image1.png)

**Figure 4. Relationship between effort for information access and process performance**

![Figure 5. Simulation results: Explained variance for the construct “Process performance”](image2.png)

**Figure 5. Simulation results: Explained variance for the construct “Process performance”**
Figure 6 summarizes the results of the computer simulation: Six relationships could be confirmed (H1-H3, H5-H7), one had to be rejected (H4).

![Tested Research Model](image)

**DISCUSSION**

One major finding in the context of this research is the fact, that the high effort to capture information, as induced by the use of mobile technology, is outperformed by the reduced effort to access information in complex scenarios with a high coordination effort. The influence of a high task complexity on the effort to access information could be proved. Interestingly, an increase of the number of workers did not lead to an increased effort for information access as one could suspect when taking into consideration that the activity of additional workers has to be coordinated. The reasons for this are twofold. First, in this study, the communication overhead arising from a scenario in which several workers collaborate was not considered. Second, the results suggest, that in both scenarios analyzed in this study (one- and six-family house) there are sufficient tasks to be done by the workers so that it is unlikely that one worker interferes with another which would cause a higher need and effort for information access.

Additionally and as set out before, the influence of the effort to capture information on the process performance is not significant. The simulation even shows a decreasing influence of the effort to capture information on the process performance in scenarios with a higher task complexity. This leads to the conclusion that the time required to enter information into mobile devices can be neglected in complex scenarios, because the benefits generated by improved data availability and optimized planning processes based on those data have a significantly higher influence on the overall performance of the construction processes analyzed in this study.

**CONCLUSION**

The developed research model for using mobile technology in job production like construction engineering extends the Task-Technology-Fit in order to demonstrate the trade-off between the data capturing effort, information accessibility and timeliness. This trade-off is significantly influenced by the intensity of the mobile technologies deployed. Thus, the model explicitly integrates the interaction of task complexity and technology intensity.

Our model itself focuses on the worker level because especially those users will be empowered through the potential increase in process performance generated by the use of mobile technology. It has been outlined that mobile technology itself may serve as a tool for automating and improving information capturing and planning of work steps. Thus, the impact logic of mobile technologies in job production has been clearly elaborated. Our model helps to explain for which level of task
complexity the introduction of a distinct level of mobile technology is likely to have a positive impact and how the intensity of mobile technology should be designed (e.g. using context, RFID tags, sensors, etc.).

The paper concentrates not solely on the development of a research model but especially describes and discusses the findings of an extensive simulation study based on data obtained from a 3D laboratory experiment. The test was done by varying the task complexity as well as the technology. Since it is hard to exercise control in field experiments, laboratory experiments in combination with computer simulations appeared to be an appropriate research strategy for testing variations in task complexity and technology usage. The results show that the positive effect of the use of mobile technology depends on the task complexity as well as on the used technology. It can be said that for a low task complexity, no positive impact of using mobile technologies on a construction site can be seen. But when a certain task complexity is given there is a high positive impact on the process performance. The results have to be validated in future research projects by applying complementary methods such as case studies.

REFERENCES

Mobile Technology in the Construction Industry

Deibert et al.


