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# Mobile Devices Within Manufacturing Environments: A BMW Applicability Study

Beshoy Morkos
*Clemson University*, bmorkos@clemson.edu

Torsten Rilka
*BMW Information Technology Research Center*

Joachim Taiber
*Clemson University*, jtaiber@clemson.edu

Joshua D. Summers
*Clemson University*, jsummer@clemson.edu

Laine Mears
*Clemson University*, mears@clemson.edu

***See next page for additional authors***

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Corresponding Author: Beshoy Morkos

Corresponding Author's Institution: Clemson University

First Author: Beshoy Morkos

Order of Authors: Beshoy Morkos;Torsten Rilka;Joachim Taiber, Ph.D.;Joshua Summers, Ph.D.;Laine Mears, Ph.D.;Georges Fadel, Ph.D.

Abstract: With the realization and need of mobile devices within manufacturing industries, new domains for their use in the automotive OEMs as tools that could be used within different manufacturing processes have emerged. Advent technology has enabled the development of devices such as ultra mobile personal computers (UMPCs) that provide the function of a computer in a compact, mobile configuration and augmented reality (wearable mobile devices) in a production environment where hands-free operation is essential. This paper details BMW's investigation and applicability study of implementing mobile devices within their manufacturing environment to view potential benefits that could be achieved. Manufacturing industries are characterized by many diverse and critical processes, and an effective communication mechanism must be available between such critical processes. It is recognized that the potential for mobile devices in manufacturing process, while realized through current use of mobile phones and PDAs, has not been fully exploited with newer technology. With use of mobile broadband communication, mobile devices can be used for audio and visual communication and provide the ability to transfer large data volumes without location constraints. Overall, the use of mobile devices allows for more effective communication and data sharing/recording. BMW explores the use of mobile devices use within two manufacturing processes: assembly training and pruefcubing. Through an internal study performed, it is realized that the use of mobile devices demonstrates improvements within the manufacturing process in terms of time efficiency, quality, and communication capabilities.

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*Key words: mobile devices; virtual manufacturing; augmented reality, assembly training, pruefcubing*

## Introduction

The manufacturing infrastructure has undergone an industrial revolution with information technology and communication as the driving force behind [1]. Manufacturing infrastructures are becoming increasingly dynamic due to their integration with advanced information technology [2], such as mobile devices. To succeed in demanding market conditions, manufacturers must rely on dependable manufacturing systems in order to produce efficiently at a high quality level [3]. Part of this efficiency will come as the result of effective communication between individuals, departments, and partners (suppliers, venders, etc) within a manufacturing infrastructure. Technologies which improve information and communication internal to a manufacturing infrastructure have the potential to

improve their performance [4,5,6,7]. Further, how communication is designed around a workplace can impact individual and organizational performance [8]. As a result, manufacturing today is demanding a more effective means of communication to achieve better productivity and improve profits. Industries are looking for better information systems to support accurate and reliable decision making processes [9].

This need for communication is apparent within several manufacturing processes. The need exists both internally and externally to a manufacturing industry, as communication is equally important with an OEM's partners as it is with internal associates. The trend from the traditional local, centralized model to the distributed, dynamic model has brought in newer challenges in the processing, integration and communication of information [9,4]. In realizing this, manufacturing systems require the use of modular machines and information systems must be developed [10,2]. Currently many manufacturers implement the use of mobile devices such as phones, PDAs, and laptops [11].This paper investigates the use of other mobile devices as tools within manufacturing environments in multiple manufacturing processes to aid in communication. Specifically, this paper examines processes both internal and external to the manufacturing process. An internal manufacturing process, entailing the use of mobile devices for assembly training is examined for its applicability as a training tool. An external process, pruefcubing, is examined for its need of an effective communication and data collection tool between the OEM and suppliers. It is the purpose of this paper to detail a study performed by an automotive OEM, BMW, of the potential of using mobile devices within their manufacturing environment and infrastructure

It is hypothesized that the use of mobile devices will lead to more precise and reliable decision making processes, overall increasing their efficiency in multiple facets. Additionally, introducing mobile devices within manufacturing processes provides opportunities to reduce costs and improve quality through effective communication. For example, the media used in performing associate training have an impact on labor costs and quality issues (the effectiveness of how well the associate's duties are communicated, trained, and learned). It is hypothesized that, if associates are capable of communicating with and receiving information effectively and in a mobile manner, they are able to increase their overall task

efficiency. An associate, in this case, does not have to travel to a computer station to enter or view data. The use of mobile devices as an information source allows employees better access to databases with continuously changing information. Further, many mobile devices require hands free operation, not infringing on an associates ability to perform their duties. This study provides an understanding of the opportunities mobile devices provide in the manufacturing environment as well as the limitations that such technology poses. The overall goal of implementing such devices is to increase associate productivity, increase the convenience for the associates, and reduce the occurrence of error that may arise due to lack of communication or inability to retrieve up to date information.
To support this hypothesis, this paper presents the initial stages of a project performed by BMW, which investigates the use of mobile devices within their manufacturing environment. This paper discusses the analysis performed to identify deficiencies within processes which were identified as candidates for mobile devices. These deficiencies are addressed through the use of mobile devices which, as this study suggests and hypothesizes, provide associates the ability to increase work efficiency.

## Mobile Devices

The study performed by the BMW Information Technology Research Center (ITRC) of the use of mobile devices in manufacturing entails an analysis of available mobile computer technology options and their benefits within specific manufacturing processes. The use of mobile devices is proliferating in business processes due to their enhanced availability of wireless communication [9,12]. This unique advantage has provided mobile devices within manufacturing a competitive advantage over other solutions. Coupled with the growth in wireless networks and the increasing trend in the workforce becoming mobile, the applicability of mobile devices has increased [9]. While such advantages do exist, the potential of mobile devices, specifically in manufacturing environments, has not been fully exploited. Using mobile broadband communication, mobile devices are used for both voice and video based communication [12]. Furthermore, large amounts of data can be transferred from locations outside of an associates desk or office. The large amounts of applications that are currently running on desktops have the possibility to function on mobile devices, providing location based

service [13,14]. Many devices are also accommodating to manufacturing environments as wearable mobile device in a production environment is important when hands free operation is needed. Due to the distributed nature of today's enterprise and to the growing number of employees who are mobile, new models of communication are required to cater to the information needs of manufacturing personnel [9].

The growth in the field of Information Technologies (IT) over the last decade provided unimaginable possibilities and convenience within the everyday lives of humans [15]. Mobile devices are not just growing within manufacturing enterprises, they are changing lives everywhere [16]. An example of this technology is the Ultra Mobile Personal Computer (UMPC) and augmented reality. The emergence of such devices has enabled them to become viable tools within manufacturing. The rapid progress of information and networked technologies, especially internet and web techniques, is driving a revolution within manufacturing [17]. Their ability to perform as a mobile tool is an important step in delivering effective communication within a manufacturing environment where mobility is necessary. As this need for mobility increases, businesses have been deploying mobile software to help workers communicate wirelessly with mobile office applications [18]. The key benefits of mobile devices that make them suitable solutions are there [19]:

- Ubiquity: The ability to access information from any locations.
- Reach-ability: Associates can be reached when they are not in their normal location.
- Convenience: When it is not necessary to have access to fixed line connections.

Alongside the growth in mobile hardware, mobile applications for information storing and communication are gaining significant attention in manufacturing companies [9].

There exist many types of mobile device solutions that may be suitable for a manufacturing environment. This paper presents those solutions found to be potentially beneficial based on the available technology, needs of the application, the associate and the environment in which the device will be used.

## Ultra Mobile Personal Computer (UMPC)

The ultra-mobile PC is a relatively new form of computing designed for superior mobility. Born to enable rich internet experience on the go, the Ultra Mobile PCs (UMPCs), has emerged as a leading product [13]. It was developed to fill that need between those who wished to have a computer larger than a Smartphone, yet smaller than a laptop, approximately the size of a paperback book. The UMPC is small and light enough to travel with its user while operating it. Most UMPCs have a 7 to 9 inch screen and weigh under 3 pounds [20]. While the UMPC technology is not heavily used or heavily popularized, it developed to be used by those individuals who had a specific need for a computer of its size. Amongst one of the more poplar UMPC, the Samsung Q1 Ultra, is seen in Figure 1.

The UMPC sacrifices little performance for its superior mobility. The UMPC is capable of data input through physical input (keyboard and touch screen), audible and video. While small in size, UMPCs have enough processing power to support normal communication methods. It allows for information services that are accessible with a mobile device on a network, independent of its location [21]. Such a device offers many key benefits for use within a manufacturing environment. It provides users with multiple types of data entry, through a keyboard or touch screen. It efficiently utilizes space to ensure a small form factor. Its mobility offers users the ability to move within a manufacturing facility without carrying a burdensome load such as a laptop.

UMPCs have many unique advantages such as their size, mobility, convenience and interactivity. The concept of using mobile computers to control and monitor manufacturing systems has been realized [22]. UMPCs have also been found to improve user experience and interaction with the device in comparison to similar devices due to their size and form [23].

Figure 1: Samsung Q1 Ultra UMPC

## Augmented Reality

Virtual reality offers the ability to view a completely different environment where the user controls their surroundings. However, the disadvantage with such a system is it’s seclusion from the actual environment. Augmented reality, however,

enables users to compliment the actual environment with that of a simulated environment to provide enhanced information and data without sacrificing the information stored within the real environment. Augmented reality is used to describe a system that superimposes computer generated information overlaying the real environment [24]. Using augmented reality, manufacturing associates can select, place and manipulate construction components in an easy and intuitive manner [25]. While continually growing, as computer technology has emerged, the concept of portable, high performance system computer system for augmented and virtual reality has become feasible [26]. The idea of augmented reality is to superimpose information in the form of audio, text, graphics and other sense enhancements over a real environment in real time. For instance, as seen in Figure 2, an augmented reality user may be walking down a street and is able to see additional information surrounding their environment such as nearby locations, shops and prices of products [27]. The environment around us provides a wealth of information that is difficult to duplicate in a computer [28] and augmented reality makes use of this information. The information, be it textual, graphic and/or audio, is received from a computer screen and placed in the perspective of the human, so it may seem as if it's a real time environment. An augmented reality system generates a composite view for the user. It is a combination of the real scene viewed by the user and a virtual scene generated by the computer that augments the scene with additional information [28]. Most research toward the use of augmented reality has been implemented toward special applications. To be used in a manufacturing and assembly, augmented reality applications must be flexible and one handed, in order to enable easy adaption to different tasks [24,29].

Unlike television, augmented reality goes far beyond the static graphics technology where the graphics imposed do not change with the perspective of the user. A Global Positioning System (GPS) receiver handles the user's position while a head mounted device handles orientation tracking [26]. This is a feature that cannot be accomplished through the use of mobile video players or any other mobile device technology. In all those applications the augmented reality presented to the user enhances that person's performance in and perception of the world [28]. To the user of an augmented reality system it would appear that he/she is looking at a single real scene with information overlaid, as seen in Figure 2.

Figure 2: Example of Augmented Reality

The three basic components of an augmented reality system are the head mounted display (HMD), tracking system and mobile computer for the hardware. The head-mounted displayed provides the user with the visual overlay of information, and example is seen in Figure 3. The tracking system provides the system information as to where the user is located and the orientation of the user.

Figure 3: Augmented Reality HMD

A major advantage of the augmented reality system is its ability to identify where the user is and the orientation of their viewing perspective. This system is able to identify the user's location in reference to their surroundings and uses this information in conjunction with their head movement [26].

Currently augmented reality is used for many purposes within industrial manufacturing [30]. A pioneer in augmented reality within manufacturing, Boeing makes use of augmented reality in their manufacturing of cable harnesses One of the most well-know implementations of augmented reality in the assembly domain is the assembly of cable harnesses at Boeing [31]. Specifically within the automotive domain, augmented reality has been used in assembling vehicle doors [32].

## Objective of Applicability Study

The objective of this investigation is to analyze manufacturing processes where the use of mobile devices and mobile device applications can create a substantial benefit. Additionally, the appropriate technology must be investigated to ensure a suitable device is selected. The overall target of this study and the scope of this paper are:

1) Presented in this paper:
    a) Perform an analysis of candidate manufacturing processes.
    b) Evaluate the applicability of specific mobile devices to suit the identified manufacturing processes.
    c) Implementation of system.
2) Future Work
    a) Development of Proof of Concept.
    b) Collection of associate data to enhance system operation.

This study will investigate the technical maturity and the benefit potential of using mobile devices within a manufacturing environment identified by BMW. Specifically, the manufacturing processes of interest are assembly training, pruefcubing, and other identified potential processes will be investigated for potential candidacy.

Analysis of the manufacturing process must be performed so an adequate understanding of the process can be considered before the selection of a suitable device. Once an understanding of the manufacturing processes is established, a survey of potential technological devices must be performed. This analysis is to view which mobile device technology is most applicable for each process.

This type of analysis is concerned with the selection of media most suitable for transferring information to specific users [33].

Future work includes the development of a proof of concept based on the information discussed in this paper. This proof of concept will be used to collect of user data from associates. This user data will investigate the associate's interaction with the device and its ability to provide the benefits discussed in this paper. This is critical to the success of this research as involvement of stakeholders and monitoring device use is needed when developing such systems [34,35]

## Assembly Training

After the employment of a newly hired associate, the individual must attend training sessions for their specific position. The training sessions are in place to ensure the associate understands their duties and to minimize waste due to mistakes that result from improper work. During training, an associate learns from a trainer assigned within a specific process or department. The trainer explains the process and allows the associate to perform the operation under direct supervision. Over time, the trainer provides the associate with greater freedom until the trainer is confident the associate can perform their assigned tasks and duties. Every manufacturing process performs separate training procedures used to fit their need. Though differences exist between training, their goal is to educate new associates with minimal error. In doing so, it is required that a trainer be present to ensure the newly acquired associate is performing their task properly.

As a result of the need for a trainer, the assembly training process is cost intensive. Nonetheless, well trained associates are needed to ensure:

- Manufactured products meet demands
- Quality is maintained
- Requirements and standards are satisfied
- Regulations are met

As a premium manufacture of high quality vehicles with facilities worldwide, BMW must ensure their training is standardized and effective. Many manufacturers maintain the same sense of responsibility to their new associates. This need for an effective, efficient, and less costly training process provides augmented reality an opportunity to fill a need. The objective is to analyze the assembly training needs that must be satisfied. The appropriate augmented reality technology also requires investigation to ensure the technology selected is suited for the training environment. The main target is to develop a device which will support the assembly training process. This is performed so that the overall training costs and training throughput time are reduced.

## Technology

Upon viewing potential mobile devices to serve as training tools, augmented reality is selected as a potential mobile technology. The main goals are to reduce the training costs and the training throughput time. Augmented Reality is selected here because it offers hands free operation. The system is capable of transferring data between the associate and system without hand operation or relocation to a computer. The device will incorporate a simple and easy to use operator interface. Furthermore, functions will be implemented to update any new training scenarios that may be required for further training. This will ensure a standardized form of training, independent of manufacturing site location. Additionally, this will minimize, or potentially eliminate, the need for a training associate. A cost savings could be directly associated with this savings as a trainer will no longer, for long periods of time, be needed.

Augmented reality is a mobile device that can be used by any associate in an assembly line. The associate will simply be trained on how to use the system and given training sessions. The device can improve several aspects throughout the assembly training process by allowing trainees to learn at their own pace.

Associates are provided an opportunity to improve their work by reviewing previous training sessions to ensure their work is acceptable. Training is supported through use of audio and visual media, providing the user with a new experience.

## Existing Training Process

In implementing a mobile device within the training process, the process will require modifications to accommodate the use of a mobile device. In doing so, the existing process will be evaluated for its deficiencies and a proposed process will be provided to ensure the proposed training process is not more time consuming or costly. Upon implementing the proposed process, it will be observed for its abilities to more effectively train associates at a reduced cost and time.

The current assembly training process consists of a manual introduction to the process through a trainer. The associate is provided an orientation process where the basic skills and techniques are presented. Upon completing the orientation process, the associate is introduced to the manufacturing process that will pertain to their work. The associate is provided a trainer who guides them through the process. After an introduction, where the associate is able to view the process and inquire with questions, the trainer allows the associate to participate on the assembly line. The trainer monitors their work, ensuring to correct any mistakes that occur during their training. As the associate become more familiarized with the process, they are provided greater responsibility and the trainer monitors them incrementally less. Eventually the associate is given full responsibility where they do not communicate with a trainer.

## Proposed Training Through Augmented Reality

The proposed assembly training consists of an associate undergoing an autonomous training process. The associate will be provided an introduction into the training process, including an introduction to how their augmented reality device will guide them through the process. The associate will be provided a head mounted display (HMD) to wear. The HMD retrieves its information from a mobile computer connected to a wireless network. This information includes training information, procedures, and scenarios. Additionally, the associate can learn the assembly steps autonomously. While a trainer will not be completely necessary, a trainer could be used for external support if needed by the trainee.

This support will not require the trainer engagement needed in the existing process. Additionally, with such a system, training exercises are more predictable [36].

Figure 4 illustrated the flow of information within the proposed training process (through use of augmented reality). The server holds the relevant information consisting of TVG (abbreviation of the German word 'Teilevorgang', which describes the process steps for assembly). One step on the assembly line consists of several TVGs. TVGs can come in the form of videos and audio instruction. The TVGs will include audio and visual input into the HMD that assist the associate in completing the training exercises. The associate is able to communicate with the system through audible input. For example, the associate may state "Repeat Step" if they wish to repeat the step may state "Slow Down" if they want the system to go through a specific step slowly. Each associate input will trigger a different TVG video or audio response.

Figure 4: Augmented Reality Network

### Limitations

The use of augmented reality removes the need for human interaction with the associate. However, this tool will introduce technological complexity within the training process. This will require the user to become familiar with the use of augmented reality. The training process may require a greater amount of time to ensure the user is able to adapt to the use of augmented reality. While a more effective training session could potentially decrease the time required for a trainer to be present, the increase in training time needed for the user to become acquainted to the augmented reality system is not desirable. Further, existing augmented reality systems are relatively expensive solutions.

## Pruefcubing

Pruefcubing is a process in which an OEM supplier is able to view, in person through physical testing, how their part or subsystem fits and mates with the vehicle it is designed for. For example, if Hella (manufacturer of BMW's headlamps) wants to test the fitness of their system on a BMW 3 series. This starts with the use of a machined vehicle body. This body is machiend to "zero

tolerance" so that it may have a "perfect shape." This is done so that any deficiencies identified can be related back to the part, not the vehicle. An example of this vehicle can be seen in Figure 5. As seen, the vehicle is placed on a coordinate measurement machine so that any parts placed on it may be measured. With the ability to pruefcubing, suppliers and OEMs are able to verify, through testing, new car parts during the development process. To take advantage of this testing capability, hundreds of car parts are handled during the weeks pruefcubing is available to suppliers. The manner in which data is collected is inefficient and non-structured. Suppliers are left to gather their own data through their own means and in most cases don't share this information with BMW. Some suppliers wish to manually insert data on a notebook, while others will take pictures and document in photos any part errors. Mobile devices are proposed as a means of documenting and sharing information with suppliers. Through the use of mobile devices, suppliers will have a structured process by which they are able to collect their data. BMW may also be able to view this data through this method as the data collected in the mobile device will be shared between the supplier and OEM. Through use of a mobile device, the measuring performed by suppliers may be eliminated. Further, the supplier may be able to spend more time inspecting their product on the vehicle, instead of leaving the vehicle to input their data elsewhere. A mobile device will serve as an easy to use tool for recording part deviations.

Figure 5: Pruefcubing vehicle

## Technology

By introducing mobile devices within this prociess, mobile devices will assist in capturing textual and visual data from suppliers. This will function as a tool that suppliers are able to use during their visits to BMW. With such a device, suppliers may be able to perform their duties in a more accurate and efficient manner. Through a study of suitable mobile device, the device selected for this process is a UMPC. Using mobile devices in the pruefcubing process, with consideration that textual and photo documentation is needed, a UMPC is a viable solution. Alongisde textual data entry, the UMPC is able to provide picture and video capturing capabilities. Through the use of mobile device, suppliers are able to efficiently take notes and capture pictures improves. This improves their ability to

transfer data within a quality management system. Additionally, such data could be shared with BMW.

## Existing Pruefcubing Process

Through examination of the current pruefcubing process, an improved, mobile device incorporating process can be proposed. This will requirement suppliers to use the UMPC for data capturing during the pruefcubing session.
Currently there exist no standard pruefcubing process. Suppliers are able to enter the facility and make the needed measurements at their convenience. Suppliers may approach the vehicle whenever they please and capture data through any means. There is a coordinate measuring machine (CMM) that can be used for measurements to assist the suppliers, however multiple suppliers attempt to use similtaniously. For example, if a headlamp supplier wishes to view their part on a vehicle, they first attach their part to the vehicle, as seen in Figure 6. Upon placing the headlamp in its proper location, textual data is collected on the points of interest. This data is internal to the supplier. Measurements on the vehicle are then captured using the CMM. The data collected on the CMM is given to the supplier on a sheet of paper as seen in Figure 7. If they wish to do so, the supplier may mark on the vehicle points of interest and capture photos of such points as a mean of documenting each specific point. An example of this is shown in Figure 6. This data is collected and formally documented at a remote location where a computer is available to the supplier. The format and formality of the documenting is depends on the supplier and the form in which they must present their findings. However, most supplier will input the data collected (pictures, hand notes, and CMM measurement copies) into a document package to present to their coworkers upon return to their corporation.

Figure 6: Headlamp Pruefcubing

Figure 7: Headlamp CMM Measurements

## Proposed Pruefcubing through UMPC

The proposed pruefcubing process would allow for use of UMPC within the process. The use of a UMPC would eliminate the need for a paper process as the original process required hand notes by the supplier. Through the use of a UMPC,

no hand notes are needed as the supplier representative is able to capture the textual information through the keyboard or screen touchpad. Any pictures needed could also be taken with the UMPC. A significant advantage here is the ability to mark the photo while on the UMPC. This does not require transferring the photo from one medium to another (camera to a computer) so that editing may take place. All CMM information may also be directly transferred to the UMPC. This eliminates the need to find a means to transfer the CMM data sheet into the computer. With all this information provided, the supplier representative will not require the use of a computer at a remote site away from the CMM. All information collecting can take place nearby the vehicle, providing for an easy data gathering process. The OEM would automatically have a copy of all this information stored on the UMPC if needed.

### Limitations

The major limitation with the use of a UMPC in the pruefcubing process is the willingness of the supplier to record product data on a device that does not belong to the supplier. Additionally, many suppliers must complete a company specific form that may not be available on the UMPC. The transfer of such information will be needed as to ensure the UMPC carry all information needed for the supplier to conduct their pruefcubing test.

## Discussion

Two manufacturing processes are presented with the possibility of improving both of these processes through the use of mobile devices. An applicability study was performed for both manufacturing processes to view their deficiencies and how these could be mitigated, or eliminated if possible. The study suggests possible technological solutions that could be used to make the process more efficient, less time consuming, and more convenient for the associate and supplier. Additionally, a new process is suggested that would account for the implemented technology. Within assembly training, the use of augmented reality suggests it would provide the ability for standardized training. The use of augmented reality as a training tool will decrease the costs needed for trainers. The new trainees will be able to work at their own pace and go through the training sessions as needed to ensure they understand their responsibilities. If this training session is standardized, an

associate may move from one plant to another with minimal differences in responsibilities or duties. The trainee may go through several different training sessions based on their preference. This training session would be completely independent of a trainer. The trainee may also attempt to train themselves within different assembly lines. With such capabilities, the need for a trainer and time slots is not needed. A trainee is simply capable of learning new assembly lines at anytime they please. The use of augmented reality during assembly training can be used as a pilot test for implementing augmented reality in other facets of BMW. For example, the use of augmented reality during vehicle repair and maintenance by service technicians may reduce the time exhausted by employees and reduce the occurrence of error. BMW augmented reality provide support for maintenance work on complex vehicle services [37]. An example of this is shown in Figure 8.

Figure 8: BMW Augmented Reality Support for Vehicle Services

The pruefcubing process benefited both the supplier and BMW through the use of mobile devices. Originally, the pruefcubing process was unstructured and inefficient in how suppliers collected information. Many deficiencies were identified within the pruefcubing process that related to data recording and documenting existing data. The paper process provided an inefficient data collecting method that required the supplier to transfer data from one medium to another, located in different areas of the facility. This posed a threat as information could potentially be lost or misinterpreted when transferred from one medium to another (from sheet of paper to a computer document). Use of mobile devices also provided the supplier the ability to stay in one centralized location. There was no need to travel from one location to collect data to another location where data may be stored within a computer. With use of a UMPC, which is provided by BMW, all CMM data may be directly transferred to the UMPC based on the need of the supplier. Further, pictures may be taken and edited immediately from the vehicle location. Suppliers are able to collect more data in less time, which is important when dozens of suppliers are working in parallel.

### Limitations

Limitations will be encountered when introducing devices such as augmented reality or UMPCs. This is due to lack of user familiarities with the system. This lack of familiarity, if not overcome, may prohibit a user form effectively using the system and result in efficiency losses. Every associate will require training on using the system. A user will have to encounter a learning curve with using augmented reality and how to function with an environment overlay before using the system. While a learning curve will be required, the increase in efficiency, time and cost savings, and user convenience is beneficial and desirable.

When potential users were presented with the idea of implementing mobile devices into their manufacturing process, the response was positive. Users felt the system would be engaging and allow them to complete their work will less error and at a faster rate, hence increasing their efficiency. Users expressed a need for capabilities that could be met through the use of mobile devices.

## Conclusions and Future Work

Through an internal study, it is realized that the use of mobile devices within manufacturing demonstrates improvements within the manufacturing process in terms of time efficiency, quality issues, and communication capabilities. Unfortunately, when introducing any technology, high costs will be encountered. In some of the cases presented, a cost savings could be associated with the use of mobile devices that counters many of the implementation costs. Nonetheless, the benefits of using mobile devices in manufacturing cannot be ignored. There exist many other potential domains where mobile devices could be used. Such domains are currently under investigation at BMW. A business case must be performed to assess if implementing such systems yields a justifiable return of investment. The need for effective communication and mobility in manufacturing is increasing and the technology presented here can be used to address this. The systems used today to meet such needs will not be sufficient for the future when associates are transferring larger amounts of data, from a greater number of locations to a greater number of people. It is important that technology such as the one of mobile devices is developed and used where appropriate.

To ensure that the efficiencies discussed within this paper can be objectively captured and that the user feedback for the system is positive, future work

includes the development of a proof of concept. This proof of concept will be used to collect user case studies to further support the hypothesis and arguments presented in this paper. Additionally, the data may be used to investigate further areas within the manufacturing environment where mobile devices may proliferate. Upon completing the use case studies using a proof of concept, a final recommendation supported by the material presented in this paper may be made as to the appropriateness of using mobile devices within manufacturing.

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**Figure3**

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**Figure4**
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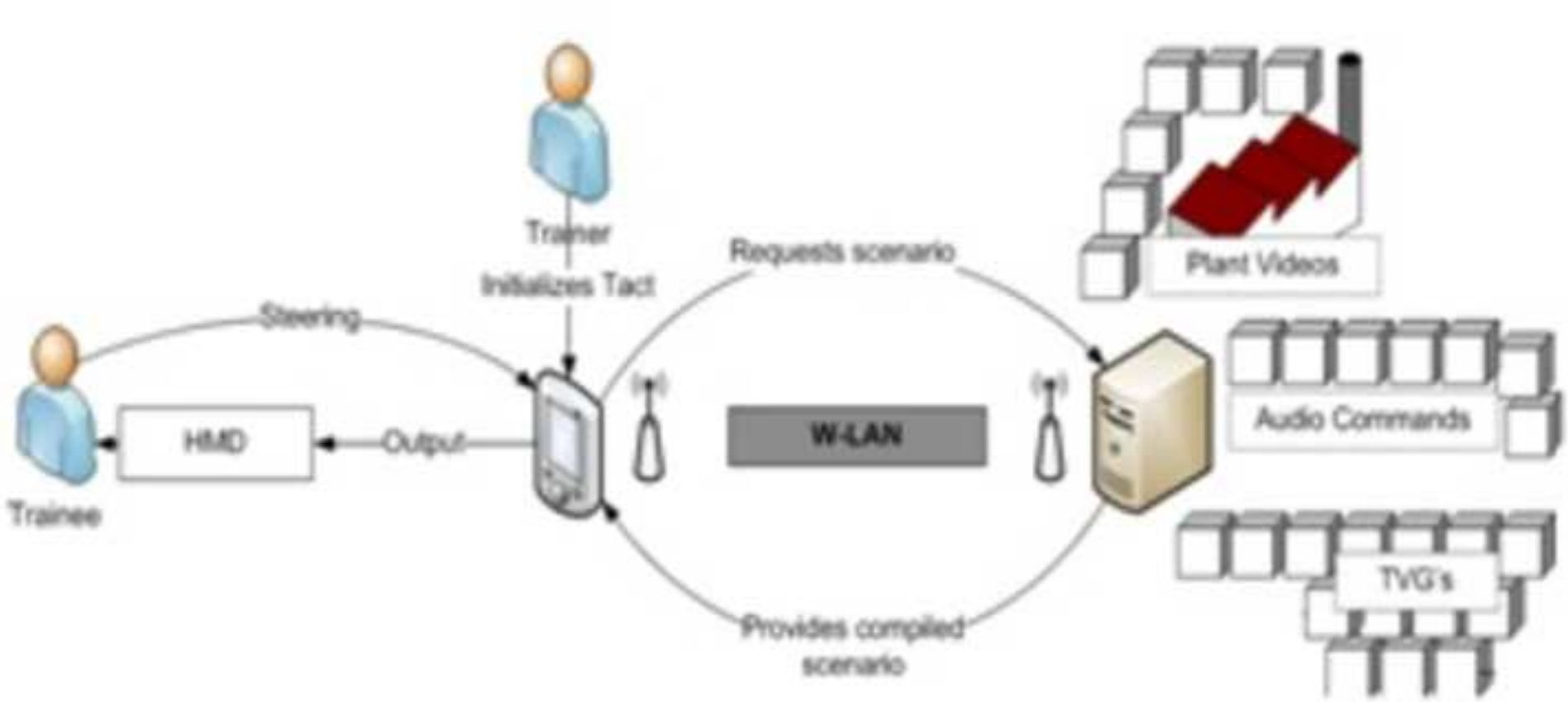

**Figure5**
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**Figure6**

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**Figure7**

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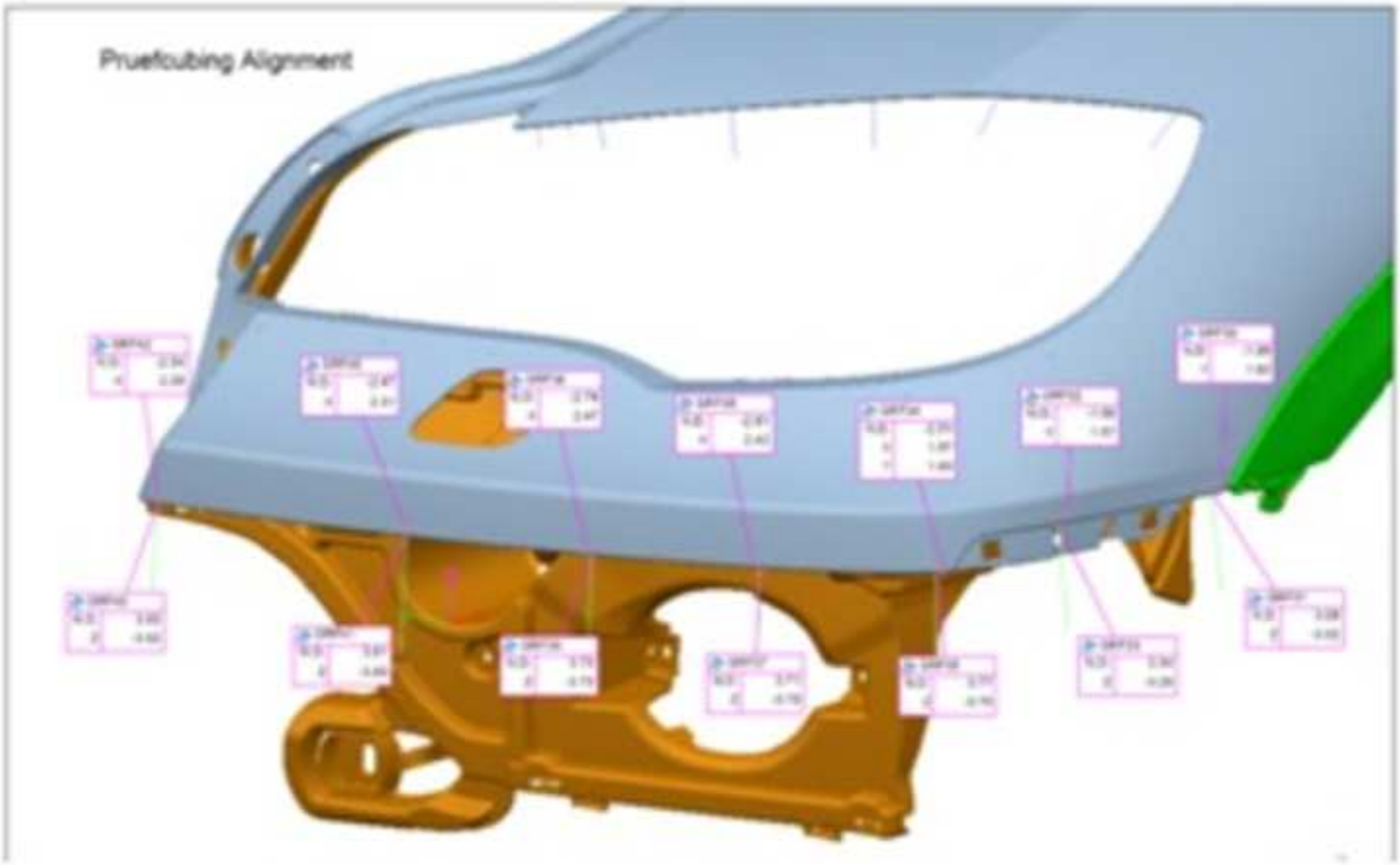

**Figure8**

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