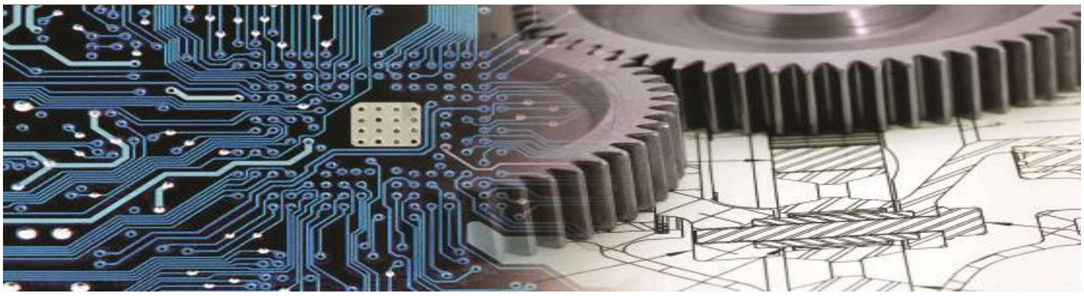
Apps4aME position paper



Apps for Advanced Manufacturing Engineering

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 314156

Will mobile devices and apps revolutionize the manufacturing industry?

Abstract: The transition from mass production to personalised, customer-oriented, and eco-efficient manufacturing is considered to be a promising approach to improve and secure the competitiveness of the EU manufacturing industries. Enablers in this transition are agile IT systems supporting flexibility at different levels: production network, factory, process. Over the past few years, attention has been paid to the use of ICT via mobile manufacturing applications. Although such manufacturing applications are still in their infancy, with many core life cycle activities not yet fully addressed, they may present a promising development that could potentially lead to breakthrough innovations and new manufacturing capability, as shown in this paper.

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1. Introduction

Volatile non-cyclic demands and requirements of producing a high variety of products increase the complexity of various activities of products', processes' and factories' life cycles

Since product mass customization became a viable strategy in the mid-1990s, there has been tremendous market pressure on companies to deliver personalized products and services to customers with mass production efficiency, cost and quality levels. This can only be ensured by developing product platforms that leverage on commonality, modularity and standardization across different product and process platforms by accommodating flexibility and reusability of the production systems. The enormous competitive pressure, shaped by such an emerging mass personalization manufacturing paradigm, compels companies to regularly equip their product and process platforms with new production technologies and factory infrastructure with an ability to fit the explicit requirements of individual customers. This not only results in shortening product life cycles but also in shorter factory and process life cycles. Shorter life cycles and volatile non-cyclic demands, combined with a poor volume-variant relationship, put companies at risk of high internal and external turbulences, affecting the complexity of life cycle activities. Digital tools are required not only to handle this complexity – which in fact can hardly be handled without them – but also to deal with the growing flow of data and information across all life cycles.

Digital tools are required to handle:

- Complexity of planning tasks of all life cycles
- Increasing flow of data and information across all life cycles

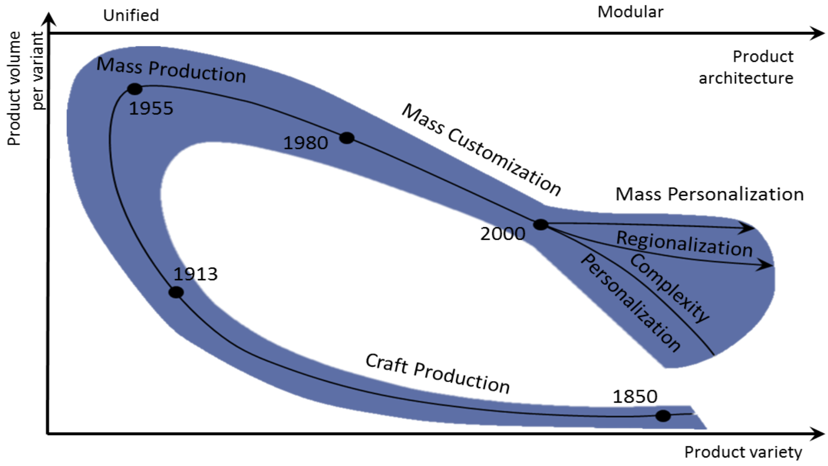


Figure 1 Paradigm transitions and evolution of product architecture, variety and volume

Common drawbacks of existing digital tools limit their use and often lead to failed implementations

Different types of large and monolithic software are used in the products', processes' and factories' life cycles, such as Computer Aided Design (CAD), Computer Aided Engineering (CAE), Production Planning Control (PPC), Manufacturing Execution System (MES), and Enterprise Resource Planning (ERP). All these software types offer distinct value, such as savings in time and costs to different life cycle activities, when solutions have defined roles and are integrated from both the data and process perspectives. In the product life cycle, CAD systems are helpful for a structured administration of product data and high quality of product design. In production, ERP and PPC enable, e.g., automated materials procurement or purchase order disposition. While these software types fulfil perfectly the requirements of mass production, they reach their limits for the new paradigms of mass customization and personalization. Regularly renewing product and process platforms with new production technologies makes it necessary to customize these digital tools frequently. However, these software types have a restricted customization level and are thus inadequate for fast-changing environments. Furthermore, they are characterized by high direct and indirect costs and difficult implementation in decentralized organisations. One major challenge that also makes it difficult to shorten life cycles is the serial nature of the product's, process's and factory's decision making along their life cycles and the lack of data and information synchronisation and integration, as shown in Figure 2.

The interoperability between current digital tools creates barriers between the life cycles of products, processes and factories

While existing integrated solutions can be found on the market for specific life cycle activities, there is no system available dealing with the information used and generated within and among all activities of these life cycles. As a consequence, there are communication walls between product designers, factory planners, production planners and factory operators. The combination of all these drawbacks impedes shortening life cycles and thus often leads to failed implementations.

New methods and approaches that aim to (i) synchronize all data and information shared between and within the life cycle of products, processes and factories, and (ii) address the increasing complexity of life cycle activities are required.

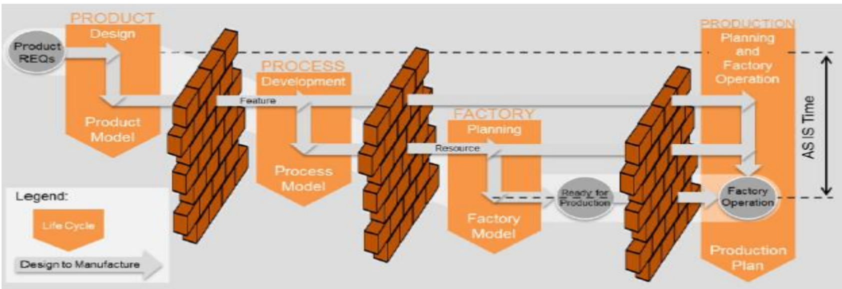


Figure 2 Barrier between product, process and factory life cycles

A uniform data control system is required to synchronize all data and information shared between and within the life cycles

A uniform data control management system by means of a life cycle-oriented data model to synchronize all data and information shared between and within the life cycle of products, processes and factories, in order to break down these walls is required. This model would make it possible to have an electronic representation of a specific factory and its objects and to maintain the contents appropriately up-to-date in response to the evolution of its synchronized life cycle. Taking into consideration that, in the past, competition was between individual companies and it is now between networks of interconnected organizations, including all partners, e.g., suppliers, distributors, retailers and customers, collaboration and mobility solutions are needed to enable global cooperation.

The synchronization of the life cycles of products, processes and factories and its management across all stakeholders involved induces a level of complexity that can hardly be handled without the support of ICT technologies.

Concurrent with the rapid evolution of ICT usage, society has become dependent on the availability of electronic devices. Through the increasingly broad expansion of the Internet, ICT devices have spread to both developed and developing countries, bringing enormous advantages in, ICT is the major contributor to manufacturing innovation and productivity

for instance, education, communication and banking, as well as in manufacturing. It is widely accepted that ICT is the major contributor to manufacturing innovation and productivity. In order for Europe to maintain its competitiveness, efforts are needed to support innovation and to continuously provide better solutions to improve manufacturing companies' flexibility and productivity.

Manufacturing applications are slowly being adopted for specific business and plant operations

Over the past few years, attention has been paid to the use of ICT technology through mobile manufacturing applications. While 79%[1] of consumers use their mobile devices for games and social networking, more and more manufacturers are slowly adopting apps designed for specific business and plant operations. Indeed, a transition can be observed from the rigid enterprise systems currently installed to decentralised and distributed cloud-based IT systems. Cloud-based applications including e-business, e-commerce, on-demand collaboration, event-driven decision support systems are emerging. The increasing trend of adopting cloud computing technologies is shown in the global revenue of enterprise cloud computing in Figure 3.[2] The statistics in Figure 4[2] compare the global cloud and non-cloud revenue from enterprise applications, combining all current digital tools cited on the first page. It seems clear that the market for classical digital tools has decreased, making room for cloud-based enterprise applications.

Enterprise cloud computing market is growing dramatically

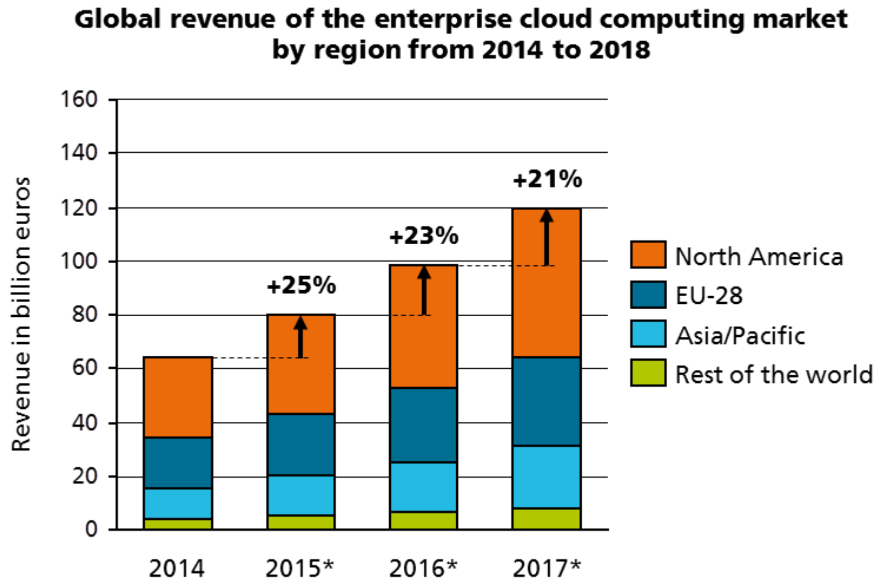


Figure 3 Global revenue of the enterprise cloud computing market

Customer service and sales-related apps are two of the top five mobile applications used.[3] Despite the significant costs of the requisite initial capital investment in hardware, software, manpower development, and business processes, the adoption of these technologies is slowly growing.

[1] www.flurry.com

[2] www.statista.com

[3] www.infosys.com

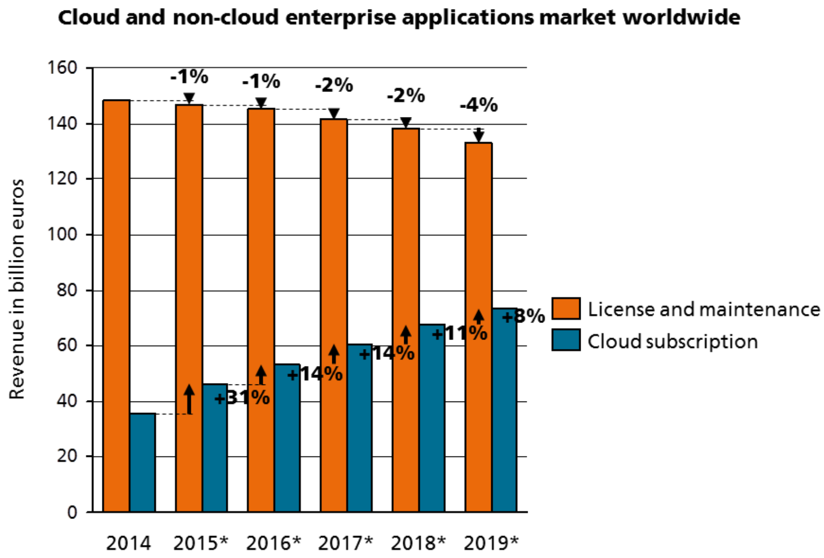


Figure 4 Evolution of cloud and non-cloud enterprise applications market

While mobile ecosystems have been targeting the enormous masses of end consumers worldwide, a growing interest for manufacturing applications has become evident. However, only a few manufacturing apps are currently available and the exploitation of them is still in its infancy. Furthermore, many core activities of products', processes' and factories' life cycle have not yet been covered.

"Can mobile applications address the requirements referred to above and offer a better alternative to the current digital tools in manufacturing engineering?"

The current article aims to answer this question by providing an overview of new methods and approaches developed in the Apps4aME[4] project. In order to support all stakeholders in the various life cycles' activities and decrease the resulting complexity, so called Engineering Apps (eApps) – mobile applications enriched with knowledge use and re-use – have been developed. However, when discussing mobile devices in the manufacturing environment, new questions regarding security and privacy can arise.

"Will the concept of eApps be accepted in the manufacturing environment?"

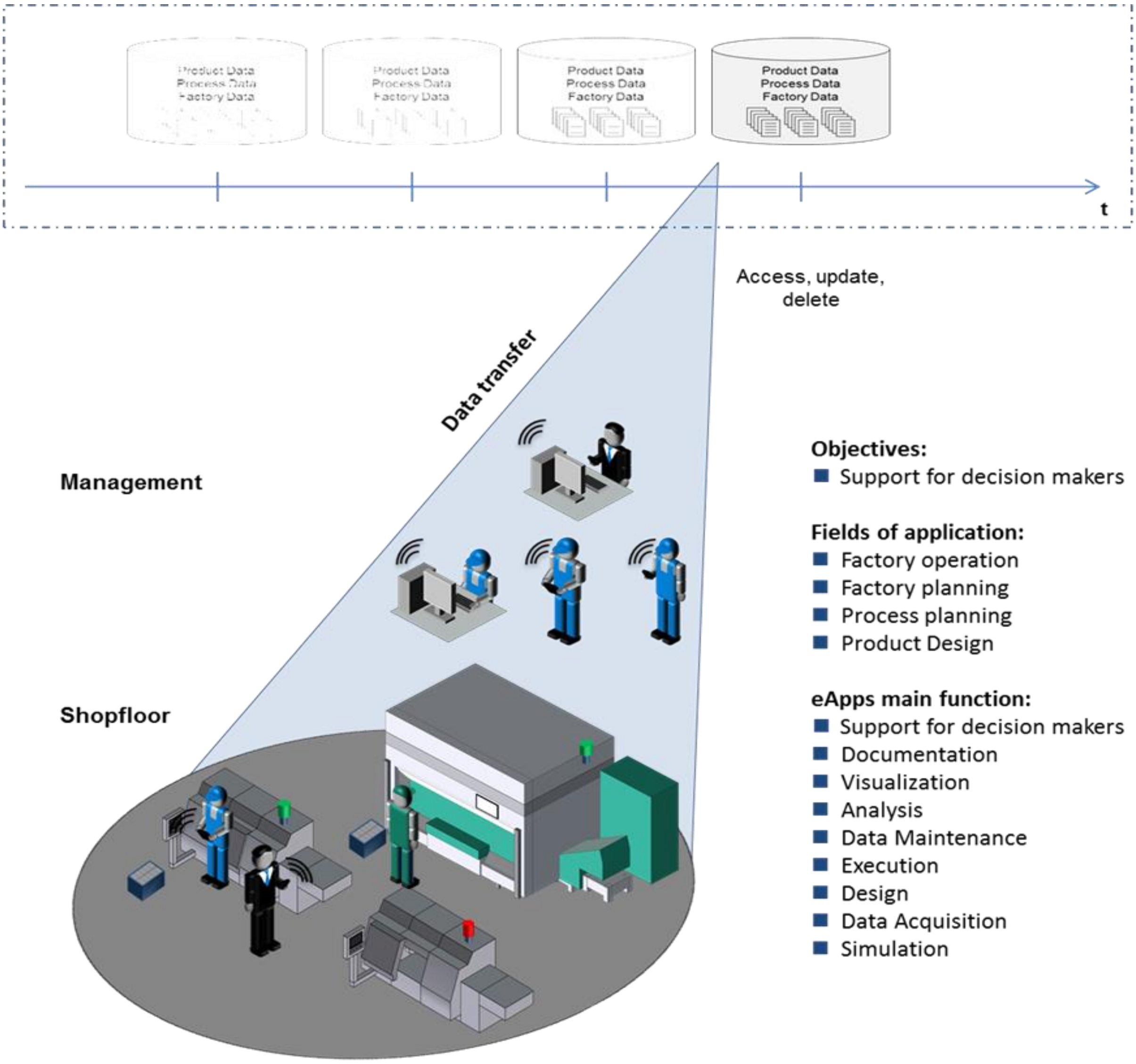
2. Engineering Apps and Knowledge re-use

The necessity of developing new methods and approaches embedded in eApps and knowledge re-use is emphasized by addressing the drawbacks listed above. eApps and knowledge re-use offer the following new manufacturing possibilities. As stated before, while activities within life cycles are becoming more complex, the exploration of highly constrained solution spaces becomes difficult with the current available solutions.

[4] www.apps4aME.eu

eApps are defined as highly specialized solution-oriented and service-based software components, systems, and digital tools that aim at a fast and more accurate decision-making support system.

Following the concept shown in Figure 5, eApps access, update and use the contents of the life cycle-oriented data model, providing a consistent information interchange between all processes and stakeholders involved and making related information understandable, reusable, and changeable throughout the entire production system life cycle.



- **Figure 5 Concept of eApps and the life-cycle oriented data model** eApps, a new age of software tools enabling better and faster decision-making. Why adopt eApps?

- Crosslinked applications
- Context based applications
- Easy to use and intuitive
- Mobility
- Support decision-making
- Cost attractive

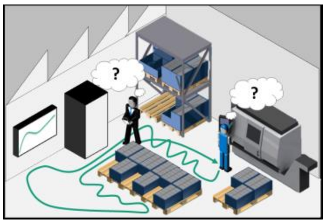
eApps, which are mobile applications that are technology-independent (tablets, phones, PC), enable increasing stakeholders' visibility and productivity across the entire value chain. On the one hand, eApps can be deployed and used on smartphones or tablets, where stakeholders can use mobile solutions for decision making on the shop floor. This is one key element in supporting life cycle activities directly and increasing the efficiency in the production planning and factory operation by inherent collaboration enabled when they are used. On the other hand, they can also be deployed on conventional devices like PCs. Therefore, eApps are intended to fulfil their purpose not only on the shop floor but also in other indirect areas, such as production planning and scheduling. Allowing the use of eApps in direct and indirect areas can support the propagation of information in the product, process and factory planning phases and also improve information disposition for the various stakeholders, shortening the time for finding and absorbing information. This flexible integration is realised through modern integration technologies by means of a life cycle-oriented platform. Furthermore, eApps, which are defined as highly specialized solution-oriented and service-based applications, propose only a few specialized features and functions that better fit specific challenges, facilitating the customization level in this highly turbulent and changing environment. Given their user-friendliness, simplicity and intuitiveness, they can easily be used not only by experts but also by untrained stakeholders, which is in contrast with currently available digital tools. By using a life cycle-oriented model, eApps can be easily connected with solutions already existing and increase data quality and availability, including data accuracy, completeness, timelines, or accessibility, common drawbacks in current solutions. Given the eApps' service orientation, stakeholders can perform CPU-intense calculation and access the results directly on their mobile devices. With recent advances in ICT, the computational burden can be removed from the client side and handled by supporting infrastructures. These service-oriented solutions also enable companies to enlarge their apps portfolio by easily buying new extensions on top of existing components. By means of cloud-based eApps, the last few months have shown that more and more CAD/PLM vendors are starting to promote cloud computing, cloud applications and services. Another challenge addressed by the eApps concept is the exploitation and reuse of knowledge. While current solutions do not directly handle knowledge reuse, eApps can handle the storing, retrieval, enhancement, and sharing of knowledge among them. This enables capturing and sharing knowledge in all phases of manufacturing engineering. Taking into account that knowledge is closely linked with innovation and has become a major driver for competitiveness and economic growth, eApps can deal with the complexity defragmentation and trade off management between conflicting objectives, addressing the competitiveness imposed by current market demands.

eApps are:

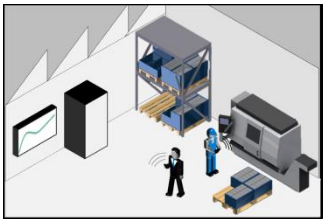
- Standard-based
- Intuitive
- Adaptable
- Context-aware
- Proactive
- Interconnectable

In sum, the characteristics of eApps are defined as follows: (i) standard-based, (ii) intuitive, (iii) adaptable, (iv) context-aware, (v) proactive and (vi) cross-linked. In order to enable an efficient integration and deployment in existing manufacturing environments, eApps have to be based on existing well-established standards and exchange formats. Furthermore, they should also be easy-to-use and adaptable. One other characteristic should be their context-awareness, idea through which these eApps would be able to operate and react accordingly to a specific situation. They should also

Intransparent processes before the introduction of eApps



Transparent processes after the introduction of eApps



generate autonomous recommendations for automatic or manual improvements in manufacturing engineering and operation, based on captured, modelled and stored knowledge. Last but not least, they have to be cross-linked. With their power to provide timely, accurate and reliable information, eApps make any activity of a given life cycle more robust and resilient without undermining its efficiency. Through their mobility and the use of a life cycle-oriented data model, eApps can improve the performance of both local firms and partners in the whole supply chain by enabling information sharing and other forms of collaboration between them.

Taking (i) the operation area, (ii) the function, (iii) complexity, (iv) platform and (v) end device into consideration, eApps can be classified as shown in Table 1. This classification shows that eApps cover a wide range of purposes on different levels of complexity and characteristics. As stated before, eApps can be used in direct and indirect areas. As an example for indirect areas, plant managers are able to access monitoring applications of the whole plant.

eApps offers new business possibilities

Regarding the perspectives, new business models exploiting all potentials in the mobile market can be created. Indeed, most of business models used in the mobile sector follow a B2C strategy. Companies provide uncustomized solutions targeting the need of a wide range of users. However, manufacturing apps address B2B with highly customized applications developed for specific requirements, where integration needs increase according to company dimension. Nowadays about 20% of mobile app developers primarily target enterprises and the 64% of enterprise app developers are making enterprise-specific apps.[5] In some cases, these apps are sold as part of a service offering, while in other cases they are entirely customized apps designed and built for one company. For this reason, most of business and revenue models used in the B2C mobile market cannot be applied in the B2B with manufacturing apps. Therefore, enterprise app developers have a very different mix of revenue models with respect to consumer app companies. The most popular revenue model is “contract work” and is used by 49% of enterprise developers. The 27% of enterprise app developers applies subscriptions according to Software-as-a-Service model.

In contrast to traditional mobile application in the context of mobile business (e.g. Customer service and sales-related), which mostly run on laptops the novelty and potentials of eApps can be characterized by:

- **Mobility**: eApps can be used anywhere and anytime
- **Integration**: eApps can be easily installed by end-users without the need for a complex setup process
- **Context-based**: eApps provide decision support for very targeted task. eApps are role-based and usually only provide a single function being highly aligned with a specific role of the end-user in process
- **Price**: New business possibilities are offered, which better fit the need of SMEs. Indeed, through cloud platform, there is no initial capital investment in hardware and software.

[5] http://www.developereconomics.com/

Opportunities and challenges for eApps are the development of standards, Manufacturing-specific standards and unified device management and centralized method for the distribution of eApps

In terms of opportunities and challenges, as it has been stated, the whole eApp concept requires also standards for development. The effective development of eApps requires manufacturing-specific frameworks and standards, e.g. life cycle-oriented data model developed in the Apps4aME project. Furthermore, a unified device management and centralized method for the distribution and update of eApps is required. At this stage, two application stores must be distinguished; (i) first, publicly accessible mobile application stores, which provide a possibility to restrict the selection of usable applications for specific companies; (ii) secondly, companies' own application stores, where in-house applications can be distributed directly to employees, customers and partners. Last but not least, the use of eApps poses, however, new requirements on the enterprise IT architecture. As stated before, back-end-integrated eApps need a unified and easy access to a central data management. This engenders the need to integrate eApps in a coherent, scalable and manageable fashion, requiring a new IT landscape based on service-oriented architectures and web technologies. Shortening life cycles will also decrease the life cycle of eApps, and thus this service-oriented architecture also needs to be flexible to quickly define and install new eApps. eApps also require an eApps store in order to deploy and manage eApps across multiple platforms. Since all eApps have to be deployed there, their reliability with respect to security and privacy is of significance. As consequences, three major topics need to be addressed, namely back-end integration, mobile devices and communication channel security. Authorization and authentication mechanisms to access internal data in the central data management through back-end systems are required to prevent the illegal use of resources. Mobile devices and their operating systems also need precautions, not only to ensure the confidentiality of data used regarding typical malicious software, but also additional security systems in case of stolen or lost devices. Communication between the various eApps and central data management, e.g. through Wi-Fi or UMTS, also needs to be encrypted to prevent security and privacy issues during data exchange. Corresponding protocols like Transport Layer Security (TLS) or its predecessor, Secure Sockets Layer (SSL), which are well established, have to be used consistently for all communication activities. The anonymity of end users is also an important requirement. Disclosing a mobile user's identification enables unauthorized entities to track e.g. his/her moving history or current location. Security is one important requirement for the entire eApp concept. Indeed, the number of global users for mobile devices exceeded the number of users for stationary devices in 2014,[6] and mobile devices are becoming more and more interesting for data thieves.

Security of eApps, devices and communication is, however, of high importance

Back to the first question,

"Can mobile applications address the requirements referred to above and offer a better alternative to the current digital tools in manufacturing engineering?"

[6] www.comscore.com

Table 1 Classification of eApps regarding their properties

.Operational area	Complexity			eApps platform		End device
	Computational power	Autonomy	Integration	Operating software	Hardware	
Product Design	Low	Stand-alone	None	Independent	Independent	Mobile
Process development	Middle	Client-server-based	Data-based	Adjusted	Adjusted	Stationary
Factory planning	High	Web-based	Local API			
Factory operation		Cloud-based	Web-based API			

The next chapter aims to provide an overview of various eApps that were developed in the Apps4aME project in order to assess how they improve performance.

3. Performance Evaluation of eApps

Within the Apps4aME project, eApps suites covering all possible configurations shown in Table 1 were developed for three industrial sectors. This chapter will provide a comparison of the as-is and to-be situations, in which specific processes were improved by using eApps, in order to show various improvements through their use.

- CarmOlimp: food sector
- Volkswagen Autoeuropa: automotive sector
- N. Bazigos S.A.: machining sector

3.1. CarmOlimp: Food sector

As concerns about food safety, quality and transparency continue, the food industry has evolved from make-to-stock to a demand-driven model, where products are shipped directly through the whole facility to the customer and no longer sit in a distribution centre or storage. Growing regulations have encouraged the food industry to improve their processes and quality monitoring in order to better track products throughout the whole supply chain and identify goods that do not meet the quality regulations. While each product is customer-specific and has a defined delivery date, the food industry has to ensure that the production orders are scheduled and executed on time and delivery requirements are consistently met. This significantly complicates integrated planning of production and logistics.

The food industry is facing a turbulent market and increasing monitoring requirements

CarmOlimp, located in Ucea de Jos in Romania, began in the meat processing business in 1993 with a slaughterhouse and a meat processing facility. Over the past twenty years, CarmOlimp has grown from a facility with 15 tons/day to one of Romania's largest vertically integrated suppliers of fresh and processed meat, with a daily capacity of around 200 tons. CarmOlimp uses an Oracle Business Suite as ERP system. While most of the information is present in the ERP, some information is paper-based, showing customer-specific constraints related to delivery time windows and packaging process.

In their initial situation, business was based on oral meetings, production and logistics planning carried out based on past experience, rules of thumb, and obsolete and inaccurate planning data. As a successful customer-oriented company, CarmOlimp has always wished to improve its processes to access new markets and improve customer satisfaction.

Digital tools are required to handle the complexity of a turbulent market and increasing monitoring requirements

The current as-is situation can be improved by addressing the following challenges:

- Flexible planning systems needed for a dynamic market;
- Improving monitoring systems for better transparency;
- Disseminating information faster;
- Standardizing knowledge from past experiences;
- Making better use of individual expertise;

Four eApps were developed, enabling automatic performance of the truck allocation process, support of the decision maker in the packaging process, and monitoring the temperature of specific orders. The fourth eApp enables an overview of the current status of all processes and orders in the whole factory. Such an eApp can be used as a monitoring system, but also as a way to identify optimization potential.

Comparing the as-is and to-be situations, it can be seen that the KPIs in Table 2 were optimized. Furthermore, eApps enabled better fulfilment of the requirements of production efficiency, costs and quality.

Table 2 Improvement in KPIs by using eApps

Short Description of KPI	% Savings
Average time required to pack various orders	**88**
Average utilization of the trucks	**24**
Deviation between the defined delivery time and the actual delivery time for all customers	**33**
The number of trucks used and the distance travelled by them	**49**
The number of complaints due to temperature regulations not being heeded	**4**
Customer satisfaction index taking a range of criteria into account, such as delivery on time and delivery of products of good quality	**4**

The eApps are already offering major improvements to daily work in the company. It is indicative that the benefits achieved include improved customer satisfaction, higher flexibility, reliable and structured digital Information, live monitoring, and better decision making.

3.2. Volkswagen Autoeuropa: Automotive sector

The automotive industry plays an important role in Europe’s economy. It comprises a huge number of companies involved in the design, development, manufacturing, marketing and selling of vehicles – from materials and parts supply, R&D and manufacturing, to sales and after-sales services. Typically, automobile plants group a large number of automotive suppliers at the same location or in the close vicinity, contributing enormously to the economy of regions and countries. This industry has a trained and developed highly skilled workforce, producing quality products for domestic and international markets. With more than 2.3 million direct jobs and 10 million it is responsible for 10.2% of the EU’s manufacturing employment, according to the European Automobile Manufacturers Association (ACEA)[7]. Since the economic crisis of 2008, the automotive sector has needed to have more and more efficient and effective production systems. Furthermore, cars are equipped with more and more safety features and customers are becoming more demanding and searching for more customized products, increasing the complexity of production. This complexity can be summed up by taking BWM – another important automobile company - as an example, which offers, through its car configurator module, up to 10^{32} different variants (at least theoretically).

Volkswagen Autoeuropea is an automotive manufacturing plant of the Volkswagen Group located in Palmela near Lisbon, with activity since 1995 and an important impact on the Portuguese economy. Using a production system based on a multi-product manufacturing principle, VW-Auto is a factory with very complex dynamic behaviour. The automotive industry is the first to be touched by the poor volume-variant relationship depicted in Figure 1. Every time the Volkswagen Group modifies or launches a new car, a project plan is established defining milestones and new stamping parts to be developed by the product engineering department. To produce new parts, a new die set project for stamping is required and needs to be managed by a dedicated planning team that has to handle a huge amount of information flowing through different stakeholders and across several project phases.

The following challenges were addressed to optimize the processes:

Optimisation potentials in project management and monitoring involving multi-disciplinary teams

- Better involve multi-disciplinary departments;
- Decrease dependency on individuals;
- Better disseminate information;
- Reach the right information more quickly;
- Improve on-time/online monitoring of time-dependent processes;
- Standardize knowledge gained from past experience;
- Decrease the risk of misinformation.

Having analysed the as-is state in detail by mapping the processes, it became clear that providing means for a pro-active approach in the die set manufacturing process, following a hybrid approach, bringing the flexibility of ad-hoc managed systems to the same domain and at the same time bringing the control and efficiency of big enterprise workflow management systems, would all improve the current as-is situation.

The solution was evaluated in a real engineering environment inside the company by the stamping planning team, which consists of eight planners and a manager for each project. It was possible to measure and calculate the KPIs defined and compare the results, leading to the savings presented in the following table. All eApps developed for this use case enable a reduction in lead time of an overall project and the reaction time on critical status. Furthermore, the eApps developed also enable better tracking of the project schedule variance and consequent reactions.

[7] www.acea.be

Table 3 Improvement in KPIs by using eApps

Short Description of KPI	% Savings
Time required to create an overall report	**83,0**
Resources necessary to create an overall report	**77,8**
Mean time elapsed between when specific problems arise and their resolution	**75,0**
Mean time between the start of a project type phase and the effective closing of that phase	**12,5**
Variance between the project schedule and its real execution time	**50,0**

3.3. Bazigos: Machining sector

N. Bazigos S.A. is a mould making shop, market leader in Greece, specialized in the manufacturing of plastic injection moulds and high precision parts. Mould-making is a knowledge- and labour-intensive domain that requires coordination, and efficiency in all aspects of the mould life cycle. Moulds are complex mechanical assemblies formally characterized as one-of-a-kind first-time-right engineer-to-order products. The business process initiates with the customer sending an inquiry request. The specifications of the mould are documented in an oral discussion together with the manager. This is followed by an empirical cost break-down and time-related aspects are estimated. After iterations of discussions with the customer and a joint agreement, a new production order is initiated. A detailed 3D design of the mould components is created. This step is based on knowledge gained in previous projects. The required processes, their sequence, and the selection of machines and cutting tools are documented by the engineering department.

The current as-is situation of this successful SME is based on oral meetings, empirical KPI estimations, production planning using rules of thumb, handwritten reporting and timekeeping, and scattered data / information in legacy systems. It can be improved by:

Optimisation potentials in order management and production planning

- Better order management
- Better involving multi-disciplinary departments
- Reaching flexible production planning and scheduling

The new app-enriched age introduces a set of knowledge-enriched apps to support the entire life cycle of the company, from the initial stage of gathering the requirements from the customer, to engineering design, then to manufacturing control and monitoring (Figure 6). The six eApps are already offering major improvements for daily work in the company. It is indicative that the benefits achieved include improved customer relations, reduced time to market, reuse of engineering knowledge and speed-up of new project ramp-up, reliable and structured digital information, improved resource utilization, live activity reporting, monitoring capabilities and accurate backtracking.

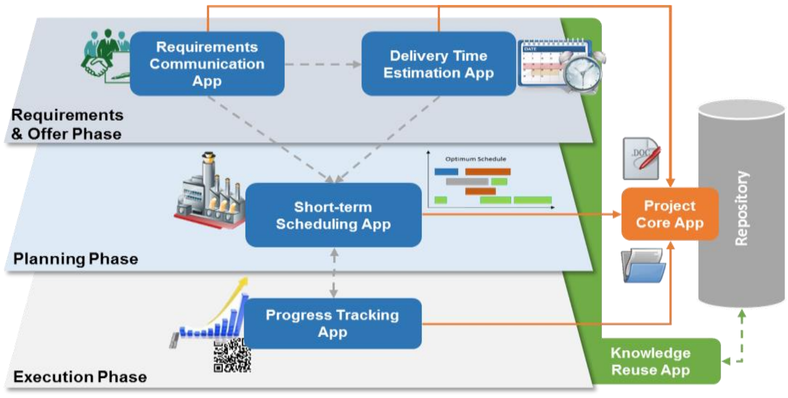


Figure 6 The eApps introduced in the N. Bazigos S.A. Case Study

3.4. Results

In addition to quantifiable KPIs presented, the eApps suite enabled to improve the flexibility of direct and indirect processes. Furthermore, eApps provide easy access to information. Last but not least, they also enabled the elimination of paperwork. Among quantifiable KPIs, the use of eApps also improved the accuracy of data, improved resource utilization, and increased the time required to collect information. Additionally, each company improved its flexibility and responsiveness regarding internal and external turbulences.

Back to the question,

"Will the concept of eApps be accepted in the manufacturing environment?"

A technology acceptance model (TAM) was developed, which is a version of the Theory of Reasoned Action specially tailored for modelling user acceptance of technology. Many empirical studies have demonstrated that TAM is a powerful and robust model of technology acceptance behaviour. TAM has been used in the past to assess the acceptance or rejection of mobile banking and e-learning. TAM suggests that when users are presented with a new technology, a number of factors influence their decision about how and when they will use it. The influence of different factors was studied by means of a questionnaire sent to the end users of the eApps. The questionnaire was clustered into the following factors:

- The **perceived usefulness (PU)**, defined as the extent to which a person believes that the technology under study will enhance their productivity or job performance. In the end user's view, it is the perceived likelihood that the technology will benefit him or her in performing a specific task.
- The **perceived ease of use (PEU)**, defined as the extent to which a person believes that using a technology will be simple. It is a construct tied to an individual's assessment of the effort involved in learning and using a technology.
- The **perceptions of risks (PR)**, defined as a consumer's perceptions of the uncertainty and the possible undesirable consequences of adopting a new technology.
- **Subjectivity (S)** is defined as the past experiences with mobile devices and the readiness for innovation.

- **Attitude (A)** is defined as a person's inclination to exhibit a certain response towards a concept or object.

The table below shows an example of questions used in the questionnaire to perform the TAM.

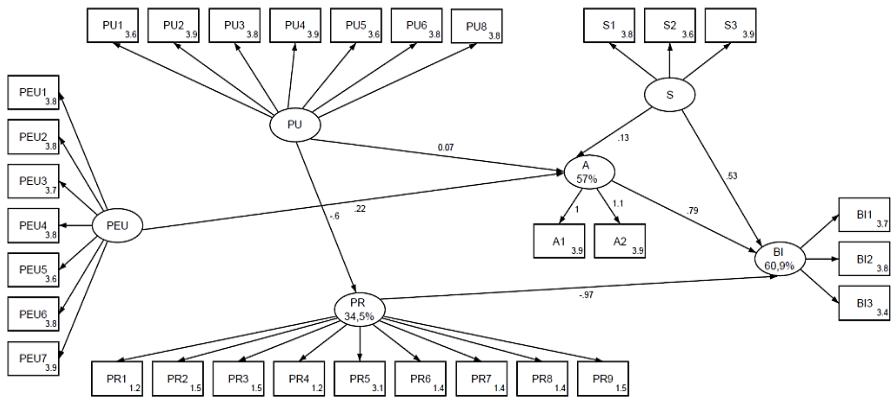
Table 4 Sample of questions in the TAM questionnaire

Construct	Numbers	Measurement Items [a]
Perceived ease of use	PEU1	My Interaction with the eApp was clear and understandable
	PEU2	I found it is easy to navigate in the App
	PEU3	Learning to operate this system was easy for me
Perceived Usefulness	PU1	Using the eApp would improve my job performance
	PU2	Using the eApp would increase my productivity
	PU8	Using the eApp would enable me to accomplish tasks more quickly
Perceived risks	PR2	The use of eApps on mobile devices is dangerous due to industrial espionage
	PR3	There is a high risk of sensitive information being compromised by the use of mobile devices
	PR4	The developed eApps disrupted the usual business workflow
Attitude	A1	Using eApps is a good idea
	A2	I am positive about using eApps
Behavioural Intention	BI1	Given the chance, I intend to use eApps on permanent basis
	BI2	I expect to continue using eApps in the future
	BI3	I intend to purchase other eApps in the future
Subjective	S1	I have enough computer skills to manage eApps
	S2	I usually use mobile devices in my private life
	S3	I am ready for innovation

[a] All items measured on a five-point Likert scale ranging from 1 = "strongly disagree" to 5 = "strongly agree"

A structural equation modelling (SEM) method was used to assess the correlation between these factors and their influences on each other. This method refers to a diverse set of unrelated algorithms and statistical methods that aim to fit networks of data. The results presented in Figure 7 indicate the direct and indirect relationships among the various factors (circles). This figure indicates that the structural model explained about 60.9% of the variance on the behavioural intention of adopting eApps. This value indicates the predicative power of this model and suggests that there is a significant combined effect of all data. The other two factors, attitude and perceived risk, had variances explained by 57% and 34.5% respectively. This figure also shows that the direct relationships between the perceived ease of use (PEU), the perceived usefulness (PU) and attitude (A) are positive respectively. The same can be stated for the path between attitude (A) and the behavioural intention (BI) to adopt the eApps. Having a look at the three constructs with a direct influence on the adoption of eApps, it seems that the perceived risks (PR) and the attitude (A) regarding the concept developed have the most important impact. Indeed, while the perceived risk (PR) has a negative influence on the behavioural intention (BI) to use the eApps, it can be stated that since there is no path between the perceived risk (PR) and the attitude (A), the perceived risk (PR) does not influence the attitude regarding the whole concept. Subjectivity (S) also has several influences, direct and indirect, on the adoption of eApps. Subjectivity (S), representing past experiences with mobile devices, plays an important role in the behavioural intention to adopt the concept. Trust plays an important role in increasing the usability of eApps.

Subjectivity and trust are key factors in the adoption of eApps in the manufacturing environment.



R^2 values are below letters in circles

Figure 7 Standardised Path Coefficients in the TAM

Taking the results and the questionnaire into consideration, it can be stated that the eApps concept was adopted by end users and that the technology acceptance model aims to point out which factors may play an important role in the decision to adopt eApps. 92% of the end users intend to use the eApps on a permanent basis; 98% expect to continue using eApps in the future; 90% expect to purchase other eApps in the future.

"Can mobile applications address the requirements referred to above and offer a better alternative to the current digital tools in manufacturing engineering?"

Through the use of a central life-cycle oriented data model, eApps can, by using accurate data, improve specific processes and support any decision-making process. Indeed, where classical digital tools reach their limits, eApps aim at providing better solutions. Furthermore, through this central life-cycle oriented data model, eApps can easily be added or removed and do not require any adaptation of the IT architecture. While end users within the Apps4aME consortium accepted the eApp concept, the question of acceptance outside the consortium may arise. Indeed, successful implementation and acceptance of the eApps approach is related to their acceptance by companies and society. Fears and reservations must be taken seriously into consideration and the opportunities have to be explained.

4. Summary and Outlook

Mobile devices and apps can only revolutionize the manufacturing industry if privacy and security issues are solved

The transition from mass production to personalised, customer-oriented, and eco-efficient manufacturing is considered a promising approach to improve and secure the competitiveness of manufacturing industries in the EU. Focusing on the first transition, one condition is the availability of agile IT systems supporting this level of flexibility at different layers, namely: (i) production network, (ii) factory, and (iii) process. The development of the Internet, communication techniques and new generations of computers trigger the transformation from traditional production-oriented manufacturing to service-oriented networked manufacturing, as well as cloud computing. Attention has been paid to the use of ICT technology through mobile manufacturing applications. While a couple of manufacturing engineering eApps have been developed, the exploitation of them is still in its infancy. Indeed, though a few applications have been reported, many core activities of products', processes', and factories' life cycles have not yet been covered.

We proposed an overview of manufacturing applications developed in Apps4aME, eApps, which support this transition by using a framework comprised of eApps and a life-cycle oriented data model. With three use cases, Apps4aME has convincingly demonstrated that eApps offer a better alternative than the current digital tools in manufacturing engineering. Additional steps need to be taken to enable a full deployment, namely to address the security and privacy issues that may arise with mobile technologies. Indeed, two major points have not reached maturity, namely the security and privacy of the whole concept. The consequences are that three main issues still need to be addressed to fully make use of the power of eApps and revolutionize the manufacturing industry, namely back-end integration, mobile devices and communication channel security. Authorization and authentication mechanisms to access internal data in central data management through eApps are required to prevent illegal use of this information. Mobile devices and their operating software also need additional security systems in case devices are stolen or lost. Communication between eApps through Wi-Fi or UMTS also needs to be encrypted to prevent security and privacy issues during data exchange. Last but not least, end users' privacy also needs to be addressed by allowing them to prevent unauthorized entities from tracking private information, e.g. their moving history or current location. However,

"If mobile devices and apps are predestined to offer a better alternative than current digital tools, does this imply that stationary devices and perpetual licences are at the end of their useful life?"

Depending on the requirements of the end-users, mobile devices are not always necessary to bring full advantages. As seen in Table 1, eApps can be used on stationary devices by means of web eApps. However, as shown in Figure 4, the market for classical digital tools has decreased, making room for cloud-based enterprise applications. Thus, once all security and privacy issues will have been addressed, eApps will not only provide better alternatives than current digital tools but also be accepted in the manufacturing environment. This does not imply that software types, e.g. ERP, will disappear, only that they will be replaced by eApp-oriented concepts by means of cloud solutions.

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