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1 Farm Management Information Systems (FMIS) in agriculture have evolved from
2 simple farm recordkeeping into sophisticated and complex systems to support
3 production management. The purpose of current FMIS is to meet the increased
4 demands to reduce production costs, comply with agricultural standards, and maintain
5 high product quality and safety. This paper presents current advancements in the
6 functionality of academic and commercial FMIS. The study focuses on open-field
7 crop production and centres on farm managers as the primary users and decision
8 makers. Core system architectures and application domains, adoption and
9 profitability, and FMIS solutions for precision agriculture as the most information-
10 intensive application area were analysed. Our review of commercial solutions
11 involved the analysis of 141 international software packages, categorized into 11
12 functions. Cluster analysis was used to group current commercial FMIS as well as
13 examine possible avenues for further development. Academic FMIS involved more
14 sophisticated systems covering compliance to standards applications, automated data
15 capture as well as interoperability between different software packages. Conversely,
16 commercial FMIS applications targeted everyday farm office tasks related to
17 budgeting and finance, such as recordkeeping, machinery management, and
18 documentation, with emerging trends showing new functions related to traceability,
19 quality assurance and sales.

20

21 **Keywords:** system analysis, farm software, precision agriculture, farm machinery,
22 decision support system, adoption, profitability

23

24

1 **1. Introduction**

2

3 The rapid technological developments during the last few years have introduced
4 radical changes in the working environment in the agricultural sector. Agriculture has
5 entered a new era in which the key to success is access to timely information and
6 elaborated decision making. The up-to-date and skilled farm manager has to choose
7 between various production options utilizing the latest advancements in research and
8 technology. Decision making is an important aspect in farm management and has
9 been studied by numerous authors (e.g. Sørensen, 1999; Fountas et al., 2006; Magne
10 et al., 2010). Gladwin (1989) argued that the key point in decision making for farmers
11 is to understand why farmers act as they do, using their tacit knowledge. Such an
12 understanding will help researchers provide farmers with supporting tools and
13 knowledge to enhance decision making at specific stages of their production process.

14 The basis for enhanced decision making is availability of timely, high-quality data.
15 However, the current situation in European farming is that most data and information
16 sources are fragmented, dispersed, difficult, and time-consuming to use. This
17 indicates that the full potential of such data and information are not being fully
18 exploited. The integration of spatial and temporal historical data, real-time farm data,
19 knowledge sources, statutory compliance, health and safety guidelines, environmental
20 guidelines, economic models, and so forth, into a coherent management information
21 system is expected to remedy this situation.

22 Management information systems (MIS) solutions in agriculture have evolved from
23 simple farm recordkeeping systems to large, comprehensive Farm Management
24 Information Systems (FMIS) in response to the need for communication and data
25 transfer between databases, and to meet the requirements of different stakeholders.

1 Boehlje and Eidman (1984) defined FMIS as electronic tools for data collection and
2 processing with the goal of providing information of potential value in making
3 management decisions. Lewis (1998) noted that an FMIS exists when main decision
4 makers use information provided by a farm record system to support their business
5 decision making. Sørensen et al. (2010a) defined an FMIS as a planned system for
6 collecting, processing, storing, and disseminating data in the form needed to carry out
7 a farm's operations and functions. Essential FMIS components include specific
8 farmer-oriented designs, dedicated user interfaces, automated data processing
9 functions, expert knowledge and user preferences, standardized data communication
10 and scalability; all provided at affordable price to farmers (Murakami et al., 2007). To
11 improve functionality, various management systems, database network structures, and
12 software architectures have been proposed by a number of researchers. In practice,
13 FMIS have increased in sophistication through the integration of new technologies,
14 such as web-based applications and applications for smart phones and tables (Nikkilä
15 et al., 2010).

16 A key question is whether commercial FMIS are and have been able to capture the
17 functionalities developed in academic research; an indication of the level of transferral
18 and uptake between research and commercialisation. Another question is whether the
19 increased demands from data intensive Precision Agriculture (PA) is being met by
20 current development trends in terms of matching design, functionalities, etc. The
21 answer to these questions will provide pivotal guidelines for future research
22 development as well as provide knowledge on possible redirections for software
23 vendors.

24 The aim of this study was therefore to evaluate current FMIS designs and solutions
25 available for farm businesses from both academic and commercial points of view in

1 order to extract future needs and correspondence with current developments, both in
2 terms of research development and commercialisation. The academic perspective
3 covers the more advanced FMIS designs integrating the newest advances in
4 information technology where systems are supposed to set the trend for future FMIS
5 but not yet fully implemented. The commercial perspective cover the FMIS currently
6 implemented and in commercial. This article is organized into three sections. The first
7 section presents the methodological approach for the selection of the agricultural
8 domain, the procedure adopted to select the relevant scholarly contributions to FMIS
9 development, the procedure adopted for the identification of commercial FMIS and
10 the subsequent clustering procedure. The second section presents a targeted review of
11 academic FMIS concepts and solutions, covering FMIS development and architecture,
12 FMIS for PA, FMIS adoption and profitability, and, finally, FMIS development
13 trends. The last section presents commercial FMIS, showing a possible division in
14 groups created through a two-step clustering analysis focusing on functions currently
15 offered.

16

17 **2. Methodological approach**

18

19 **2.1. Selection of scholarly contributions to FMIS development**

20 The methodology for the academic FIMS review has a principle of using selective
21 keywords for the search in international academic databases. The specific keywords
22 were: (i) farm management information system, (ii) farm software, (iii) decision
23 support systems for agriculture, and (iv) information management in agriculture, and
24 combinations of the formers.

25

1 **2.2 Identification of commercial FMIS applications**

2 The FMIS market is very large covering many cropping systems and the research was
3 targeted according to two specific selection criteria. The first criterion narrowed the
4 research to only cover crop production and, more specifically, open-field crops, since
5 available solutions for greenhouses involve a very different concept incorporating
6 many control algorithms. The second criterion targeted only solutions that identify the
7 farm manager as the main user related to field operations and does not cover solutions
8 related to Enterprise Resource Planning (ERP) operations.

9 The selected FMIS were focused on crop production and were centred on the farm
10 manager as the primary user. Initially, to find relevant commercial applications,
11 international FMIS vendors using English as the main language were selected. This
12 allowed collecting data from United Kingdom, United States, Canada and Australia,
13 as well as from other global software houses which provide their applications in
14 English and have an English-based website. Then, the research encompassed also
15 FMIS as representative of the larger European agricultural software market, made of
16 mid and small companies which require applications in their native language.
17 Therefore we collected data about products provided in French, German and Italian,
18 because at least one of the authors has a good command over these languages (Table
19 1). The data were retrieved through a structured approach: First, we ran a web search
20 in the country-specific languages using different keywords (e.g. farm management,
21 farm software, agricultural management) to create an initial group of applications;
22 secondly, we checked web portals dedicated to farmers; and finally, we validated our
23 group of applications with the top three farmer unions in each country. The
24 information retrieved from the software developers was analysed using software demo
25 versions when available. In 22 cases, the information provided from the website about

1 the functions was ambiguous. Therefore, phone calls were made to the software
2 vendors to collect the necessary information from a sale representative or technician.
3 In total, 141 commercial FMIS from 75 different software vendors were analysed
4 according to services they offer to their respective users. The selected software
5 applications were computer based (i.e. enabling farmers to organize work from the
6 farm office) and supported web-based and mobile applications.

7

8

Table 1

9

10 A total of 11 generic functions were determined as the main functions or services that
11 commercial FMIS offer farm managers (Table 2). The identification of these
12 functions was mainly based on the guidelines provided by Robbemond and Kruize
13 (2011) and Kruize et al. (2013), analysing the different applications and functions that
14 commercial applications offer, together with data exchange protocols. Additionally,
15 the identification of these 11 generic functions was complemented by
16 recommendations of Abt et al. (2006) that agricultural software should include
17 production planning, production process integration, performance management,
18 quality and environmental resource management, as well as sale orders and contract
19 management. Each software application was analysed to define, which of the 11
20 functions it supports.

21

22

Table 2

23

24 **2.3 Clustering procedure**

25 As each software house offers different products that can be combined in a single

1 integrated solution, our analysis targeted functions covered by complete software
2 solutions and a clustering analysis was carried out on these complete solutions. After
3 collapsing the initial group of 141 FMIS into 73 complete solutions, a clustering
4 algorithm was selected with the aim of maximizing the difference between clusters
5 and thereby to clarify the subsequent characterization. Clustering methods are a
6 family of multivariate data analysis techniques that can identify groups of objects that
7 are similar but different from objects in other groups (Hair et al., 2010). Although
8 hierarchical clustering is one of the most common methods, it has limitations in terms
9 of categorical and binary data. Therefore, a two-step clustering approach was adopted
10 to overcome the limitations of hierarchical clustering (Norušis, 2011). The first step
11 involved scanning the data and defining pre-clusters, where every record was
12 determined to belong either to an existing pre-cluster or to a new pre-cluster (Zhang et
13 al., 1996). In the second step, the pre-clusters created in the first step were grouped
14 into a preferred number of clusters. Since two-step clustering is influenced by the
15 order of data, multiple tests were conducted to determine the optimal number of
16 clusters and to check possible changes in the assignment of FMIS to clusters. For the
17 analysis, the SPSS (IBM USA) statistical package was used.

18 The best results were obtained with four clusters. The validity of these four clusters
19 was tested for changes in cluster assignments as suggested by Hair et al. (2010). The
20 two-step clustering results were compared with the outcomes of a classical
21 hierarchical method, in which the selection of the combination of the ‘distance
22 measure’ with the ‘linkage method’ has a significant impact on the clustering results.
23 The former is the criterion for determining the distance between cases; the latter is the
24 criterion for determining which clusters are merged at successive steps. Since many
25 selections were possible, different tests were conducted to select the distance measure

1 and linkage method able to maximize the difference between clusters, allowing for a
2 clear interpretation of results.

3 The binary squared Euclidean distance, in combination with Ward’s method, was
4 selected. The cluster assignments derived from the two different methods were cross-
5 tabulated and less than 17% of the stipulated records were shown to change cluster
6 assignment, which was considered a stable solution according to Hair et al. (2010).
7 Finally, special attention was devoted to profiling the final solution. We conducted a
8 clustering interpretation phase, as suggested by Hair et al. (2010), focusing on the
9 agricultural practice. The outcome of the results were evaluated twice, involving a
10 defined meaningful interpretation of the results as well as assigning names to clusters
11 and commenting on the functions covered by each of them in comparison with the
12 others.

13

14 **3. Academic FMIS concepts and solutions**

15

16 **3.1. FMIS development and architecture**

17 The first FMIS was introduced in the 1970s with applications targeting recordkeeping
18 and operations planning (Blackie, 1976; Thompson, 1976). Canfarm was one of the
19 first applications used by Canadian farmers in 1978, when 10,000 farmers adopted it
20 for recordkeeping and 4,000 for planning (Thompson, 1976). Kok and Gauthier
21 (1986) then presented a FMIS with incorporated decision support algorithms in
22 recordkeeping and planning and consisting of four major components: the processing
23 of permanent data that seldom change, annual data linked to particular cropping
24 seasons, daily data representing daily farm operations, and inventory data related to
25 farm stocks and suppliers. This type of design and architecture is still common in

1 many current commercial applications. The first application to combine decision
2 support tools with recordkeeping and planning was the CALEX system in California,
3 USA, covering irrigation, pest management, and fertilization applications (Plant,
4 1989).

5 The majority of the FMIS and decision support systems (DSSs) described in the
6 scientific literature are based on simulation models or targeted optimization models
7 and methods (Lilbourne et al., 1998; Attonaty et al., 1999; Thomson and Willoughby
8 2004; Sahu and Raheman 2008; Sante-Riveira et al., 2008; Papadopoulos et al., 2011).
9 They are very often based on probabilistic methods (Kamran and DePuy, 2011),
10 including methodologies such as linear programming (Sante-Riveira et al., 2008),
11 dynamic programming (Parsons et al., 2009), rule-based management (Shaffer and
12 Brodahl, 1998), decision trees (Cohen et al., 2008), eExpert heuristics (Trépos et al.,
13 2012), fuzzy optimization (Papadopoulos et al., 2011), generic algorithms (Hameed et
14 al., 2012), and smart elements (Lilburne et al., 1998) to model, solve, and generate
15 optimal strategies.

16 Since agriculture as a biological production system is characterized by a high degree
17 of uncertainty, a deterministic FMIS model as a backbone cannot fully capture the
18 probabilistic nature inherent in agricultural production systems. However, few FMIS
19 deal with uncertainty in farm management problems (Engel et al., 2003; Bange et al.,
20 2004; Harwood et al., 2010), while most revert to solely deterministic aspects
21 (Thomson and Willoughby 2004; Sahu and Raheman 2008; Papadopoulos et al.,
22 2011). In this regard, uncertainty assessment is the least well understood and
23 implemented capability of farm management and DSSs. Future FMIS should provide
24 the farm operator/manager with information about resources across the farm and the
25 potential impacts of management decisions on those resources.

1 To improve FMIS functionality, a number of software architectures and designs have
2 been introduced with increased level of sophistication, using, for instance, web-based
3 applications or other emerging technologies in agricultural production (e.g., PA,
4 automated data transfer). Farm Management Systems implemented with web-based
5 services facilitate collaborative research over the Internet by connecting
6 geographically dispersed teams (Schweik et al., 2005) such as farmers and crop
7 advisors or customizing end-user data for analysis or presentation purposes
8 (Chaudhary et al., 2004). Additionally, web services facilitate the use of standard
9 language for data exchange between systems and services based on Extensible
10 Markup Language (XML) and a service bus as message-oriented middleware for the
11 connection of web services (Murakami et al., 2007).

12 Finally, holistic FMIS have been recently presented to capture all data flows from the
13 various actors linked with FMIS. According to Sørensen et al. (2010a), an FMIS is
14 needed to advise managers of formal instructions, recommended guidelines, and
15 documentation requirements for various decision making processes. For these
16 purposes, the architecture must consider the farmer the central decision maker with
17 regard to planning, controlling, and operating a crop production system and outlining
18 how the operational field data need to be collected and transformed in an automated
19 way. To cover all activities ranging from planning to execution and evaluation
20 activities, a reference architecture design has been presented (Sørensen et al., 2010b),
21 identifying the actors involved, their roles, and the communication specifics related to
22 decisions and control processes. The knowledge content of the decision processes and
23 the data embedded in the information entities has also been documented (Sørensen et
24 al., 2011). While most of the recent holistic FMIS architectures have focused on the
25 farm manager as a focal point, a FMIS architecture based on the collaboration and

1 automated acquisition of operational farm data between farmers, governmental
2 organizations, service providers, and machinery manufacturers in the agrifood
3 production chain has been presented (Teye, 2011). In summary, the design of new
4 FMIS requires a user-centric approach to serve specific farm operations strategies
5 while simultaneously maintaining their ability to be integrated in a holistic managerial
6 scheme with the farm manager at the centre of the system.

7

8 **3.2. FMIS for Precision Agriculture**

9 Early FMIS operated largely in a non-spatial realm, using computer simulation
10 models to project current conditions onto alternative future scenarios (Lilburne et al.,
11 1998; Attonaty et al., 1999; Jensen et al., 2000). In that context, precision and
12 accuracy proved insufficient, requiring the development of spatial management
13 features (Thorp et al., 2008; Cohen et al., 2008; Cardín-Pedrosa and Alvarez-López,
14 2012). The advent of PA information technologies and electronic communication
15 along with the development of more accurate global positioning systems (GPS) at
16 reasonable costs have enabled farmers to acquire large amounts of data to be used
17 effectively in site-specific crop management (Stafford, 2000; Tozer, 2009). This has
18 created the need to design and develop dedicated FMIS to cope with this increased
19 amount of data generated by applying PA in field production. Figure 1 conceptually
20 outlines the spatial management of field operations involving the acquisition of spatial
21 and temporal data and the subsequent processing and inference within the realm of an
22 FMIS for final decision support within the operations management and activity
23 documentation aimed at external stakeholders.

24

25

Figure 1

1

2 This development aimed to support decision processes with inherent spatial
3 requirements. The employed methods include dynamic spatial links that allow the
4 simulation at one location to impact other locations at each time step. This
5 functionality is essential for whole farm simulations, because individual parts of a
6 farm often share or transfer resources. Additionally, whole farm simulation models
7 are expected to facilitate PA by targeting conservation measures that provide
8 environmental benefits (Berry et al., 2003). To organize the increasing data generated
9 by PA applications, Fountas et al. (2006) defined the information flows involved with
10 decision making in PA and Nikkila et al. (2010) defined the requirements for the
11 architecture of a FMIS for PA. Compared to a traditional FMIS, such an architecture
12 is more focused on the digital transfer of data and storing, managing, and handling
13 geographic information systems data since most of the calculated data originate from
14 external sources. The formulation of operational plans and the ability to manage
15 several transformations of the acquired data to achieve interoperability with all
16 relevant systems and services are also required by an FMIS targeting PA. In this
17 regard, Nash et al. (2009a) analysed the data flows within PA operations. The basic
18 idea was to capture the data flows at different planning levels that take place in crop
19 production system and to represent explicitly the domain knowledge in terms of
20 entities and their relationships.

21 In addition to data generated from PA operations, a number of FMIS have recently
22 been developed related to machinery management in an attempt to accommodate the
23 increasing amount of data generated by tractors. These data are being made available
24 through the standard ISOBUS protocol for tractors and implements. Steinberger et al.
25 (2009), considering the difficulties of data acquisition in agriculture caused by the

1 lack of compatibility between hardware and software, developed a prototype
2 implementation of an agricultural process. Specifically, agricultural process data
3 acquired from the ISOBUS were sent to a server for further analysis and subsequent
4 task formulation. To resolve compatibility problems between the devices, Nash et al.
5 (2009b) suggested the creation of geospatial web services. Recently web-based
6 applications for farm machinery have been proposed with real-time data acquisition to
7 capture both the sub-field spatial variability within field operations as well as
8 communication with autonomous mobile vehicles (Tsiropoulos et al., 2013a, 2013b).
9 In summary, FMIS should integrate PA activities into a holistic system incorporating
10 crop, soil and climatic information to allow locally based planning and management at
11 the sub-field scale.

12

13 **3.3. FMIS adoption and profitability**

14 In addition to the actual physical development of FMIS and the early introduction of
15 computers on farms, user requirements and adoption studies for FMIS were also
16 initiated. Sonka (1985) argued that the change from rigid and inflexible management
17 strategies to the flexible and adaptable management of the information age will
18 significantly enhance the potential contribution of farm computers and systems.
19 Doluschitz and Schmisser (1988) predicted that DSSs and expert systems in
20 agriculture as integrated parts of an FMIS would have a vast influence in resolving the
21 analytical shortcomings of the end user (farmer) by transforming raw data through
22 analysis and expert interpretation into useful information and finally knowledge for
23 decision making. On the other hand, Ohlmer (1991) stated that farmers tend to use
24 FMIS to execute similar management tasks and for knowledge generation as
25 previously supported by external service organizations or advisors, indicating that the

1 farm management methods in the computer software systems introduced at that time
2 were not sufficiently mature. Therefore, FMIS adoption relies not only on pure
3 technical aspects, but also, to a high degree, on the human or usability aspects of
4 information system implementation (Mackrell et al., 2009).

5 Kuhlmann and Brodersen (2001) argued that commercial software products have
6 reached a level of sophistication involving complex algorithms that can address
7 demanding planning problems. However, such complex systems present a challenge
8 in terms of acceptability and usability, making farmers revert to use of ad hoc
9 calculations using, for example, standard spreadsheet software. The authors noted
10 that, with the advent of new technologies such as PA, the amount of data collected is
11 too large to be managed by simple spreadsheet software making the case for the wider
12 adoption of more sophisticated FMIS for crop production. A recent farmers' adoption
13 study by Lawson et al. (2011) pointed out the benefits of introducing advanced FMIS
14 in relation to budgeting procedures, field planning, and paperwork for subsidy
15 applications and public authorities. The study compared FMIS adoption between
16 northern and southern European Union (EU) countries and found that Northern
17 European farmers are inclined to spend more time working with computers than their
18 Southern colleagues, probably due to the more developed and more business-oriented
19 types of farms that exist in Northern Europe.

20 A key point in FMIS development and adoption is the profitability of the system
21 (Verstegen et al., 1995). Profitability indicators are important not only to the farmers
22 who consider software investments but also to the developers who design and market
23 FMIS. The benefits of a FMIS extend from the value of the improved decision
24 making, which, however, is often difficult to quantify. For example, the benefit of
25 using an FMIS could depend on the level of the user's experience. As a special case,

1 Lewis (1998) noted that younger farmers with a relative lack of farming experience
2 can particularly benefit from using an FMIS. Moreover, Steffe (2000) argued that the
3 cost to design and set up an information system is relatively high, stressing the need
4 for the design of a dynamic and adaptable model to meet both current and future
5 demands. In addition, Steffe (2000) pointed out that the benefits of integrating PA
6 data into a general FMIS would automatically generate documentation data, reducing
7 management task time, while it would provide better management quality for
8 supplying regulatory bodies with precise site-specific information that is otherwise
9 not available.

10 In conclusion, the interaction between FMIS developers and end users (farm manager
11 and employees) should be enhanced. The interplay between the developers and end
12 users should be favoured by institutional actors such as universities and other
13 organizations, which could act as facilitators, providing training to farmers and
14 feedback to developers. Future FMIS implementation should require a minimal level
15 of operational training and must clearly show immediate benefits of its use. Improving
16 transparency for the operator/manager by providing a user-friendly interface can be a
17 first step. Self-learning and the cognition of the farm operator/manager are essential to
18 accelerate the learning process.

19

20 **3.4. FMIS development trends**

21 The FMIS field is developing rapidly to produce new and useful tools for the
22 agricultural community to meet market demands. A recent study by Wageningen
23 University, aimed at presenting the current situation of FMIS and the use of data
24 standards, provided an overview of all the functionalities used and data standards
25 offered by applications in the market through the creation of a reference model

1 (Robbmond and Kruize, 2011; Kruize et al., 2013). Key points included the
2 importance of a common data exchange between the FMIS and external actors, such
3 as agricultural input suppliers, processors, data providers, and governmental offices.
4 Moreover, wide use of the Internet has presented new possibilities and challenges,
5 namely, to fulfil the increasing needs of farmers and agricultural advisers for time-
6 critical, up-to-date, and precise information as part of farm management. Web
7 applications support data collection from distributed sources and integrate the results
8 into personalised web graphical user interfaces with embedded graphics, expert
9 interpretations, and links (Jensen et al., 2000; Engel et al., 2003; Thomson and
10 Willoughby, 2004; Plénet et al., 2009). In addition, recent developments in computer
11 technology along with advances in the hardware and software capabilities of mobile
12 phones providing wireless Internet access have enabled real-time data recording and
13 fuelled the interest for ‘on the go’ information in the field (Hearn and Bange, 2002;
14 Karetos et al., 2007; Kitchen, 2008; Peets et al., 2012). Web applications have
15 proven to be a very powerful tool, particularly for less experienced users. Recent
16 designs and prototypes using cloud computing and the future internet generic enablers
17 for inclusion in FMIS have recently been proposed by Kaloxyllos et al. (2012, 2014).

18

19 Key points from the academic analysis include that FMIS architectures have been
20 proposed to cover a range of farm activities and functions. The focus has been on the
21 farm manager as the main decision maker and main actor. FMIS is trying to cover
22 very complex systems with all possible interrelationships of data gathering on the
23 farm, revealing the need for more holistic approaches. In this complex setting,
24 establishing industry-wide data exchange protocols becomes pivotal in facilitating
25 integration between different FMIS modules that handle specific tasks. Although

1 some have pursued this goal (e.g. the creation of the ISOBUS protocol), the level of
2 integration still remains inadequate. The development of standards for data exchange
3 should be coupled with current definition of FMIS architectures to improve
4 transparency for the operator/manager by providing not only user-friendly interfaces,
5 but also reliable data structures and data manipulation procedures.

6

7 A general understanding of FMIS evolution and the current development level of
8 commercial solutions is still lacking. Therefore, to provide an overview on how
9 research in this field has been implemented in practice, the second part of this study
10 tries to decompose the current functions provided by commercial FMIS and identifies
11 potential improvements.

12

13 **4. Targeted review of commercial FMIS applications**

14

15 **4.1. Review of commercial FMIS applications**

16 Figure 2 illustrates the distribution of the 11 defined FMIS functions indicating how
17 frequently these functions are appear in the studied vendor applications and which
18 functions are most useful to the farmers. The functions most frequently found in the
19 software applications included field operations management (63%), reporting (57%),
20 finance (45%), site-specific management (40%), inventory management (38%),
21 machinery management (28%), and human resource management (25%).
22 Additionally, less frequently used functions included traceability (19%), quality
23 assurance (19%), sales (18%), and best practices (16%). It is evident that functions
24 that support operations and finance management of farm enterprises are used more
25 frequently, together with reporting, as an integral element of the FMIS. The high rate

1 of site-specific functions, however, reveals the vendors' understanding that PA
2 techniques pertaining to the rational use of inputs to both reduce production costs and
3 support environmental protection will eventually be part of mainstream agriculture.
4 The analysis clearly demonstrated that traceability is still in its infancy in commercial
5 FMIS, as well as best practice functions, which are directly related to food quality and
6 could be used to differentiate and enhance the value of farm products, as well as
7 improve competitiveness (Canavari et al., 2010). Moreover, sales components within
8 FMIS for farmers are still very scarce, since usually farmers do not selling directly to
9 end users. However, one of the strategies of the EU Directorate-General for
10 Agriculture and Rural Development through the new Common Agricultural Policy is
11 to facilitate direct sales between farmers and consumers and therefore more FMIS
12 solutions in this domain may be introduced in coming years.

13

14

Figure 2

15

16 Finally, the analysis showed that, regarding the prevailing platforms, 75% of
17 applications are computer based, with 10% of which are only operating on mobile
18 applications (tablets and smartphones), 9% are web-based applications, and 6% are
19 both mobile and web-based applications (Figure 3). This indicates that most FMIS
20 applications are standalone computer software applications that do not require Internet
21 access. The very limited introduction of web-based applications in commercial FMIS
22 is presumably due to the fact that farm managers are used to having sole access to the
23 data. Additional, the limited introduction of mobile applications could be explained by
24 limited wireless data access in urban farm areas. This reasoning was supported by a
25 survey of Danish and US Corn Belt farmers findings (Fountas et al., 2005), where

1 indications were that 81% of the Danish and 78% of the US respondents preferred to
2 store the data themselves. Moreover, 88% of the US respondents preferred not to store
3 the data in a shared Internet-based database explaining the reluctance of software
4 vendors to push in this direction, which further emphasize the importance of farm data
5 ownership. Nevertheless, the introduction of tablets and smartphones is expected to
6 increase dramatically in the near future. In general, no sustained relation between
7 available functions and type of hardware platform was found.

8

9 Figure 3

10

11 **4.2. Clustering analysis**

12 The cluster analysis outlined a solution with four-clusters, in which the complete
13 solutions from software houses are grouped according to the coverage provided to the
14 functions. In other words, the clustering procedure grouped in the same cluster the
15 systems which largely support the same set of functions. The spider diagrams of
16 Figure 4 show the results of the clustering analysis: each single diagram presents the
17 coverage of functions by the systems grouped in that cluster.

18

19 Figure 4

20

21 Showing the percentage of solutions in each cluster which have a particular function,
22 Figure 5 presents the same information, but in relative terms, making possible
23 comparisons between clusters.

24

25 Figure 5

1

2 Cluster 1 was called *basic systems* and groups 15 FMIS (21%) devoted to a limited set
3 of functions, especially finance and reporting. These functions constitute the core of
4 the FMIS and mainly support traditional farm management, without giving any
5 support to specific activities.

6 Cluster 2 collects *sales-oriented systems* and comprises 13 FMIS (29%), including all
7 sales and marketing, inventory management, and finance functions. These systems
8 cover the product management of a company but, surprisingly, the majority of them
9 also include functions for human resource management. This extension could be
10 related to the necessity of providing a full product, which requires the inclusion of the
11 costing of human labour.

12 Cluster 3 refers to 21 *site-specific systems* (18%), comprising a homogeneous group
13 of systems designed for site-specific purposes (precision agriculture) in addition to
14 functions for field operations management. About 60% of these also offer reporting
15 functions of which more than 30% offer services on mobile platforms. These features
16 are coherent with the site-specific functions, which require direct in-field data
17 collection and operations management.

18 Cluster 4 comprises 24 FMIS (33%) *complete systems*, which involve the widest
19 range of functions. A number of these functions are also covered by the other three
20 clusters, such as reporting and field operations management. Some other functions,
21 such as inventory management, are offered by only one or two of the other three
22 clusters.

23 Interestingly, cluster 4 shows the highest percentage of web-based and mobile
24 functions, slightly distancing the other clusters. Moreover, this cluster offers two
25 functions that are weakly supported by the other clusters: quality assurance and best

1 practice estimate functions. Both of these are complex functions requiring the
2 coexistence of multiple other functions: For example, to define best practices, historic
3 data related to inventory, field operations, and machines are needed to compare yearly
4 yields and define possible alternatives. Most of the FMIS in this cluster include a site-
5 specific module, showing that such functionality advances the complement of existing
6 services. Surprisingly, only 20% of the systems in this cluster include a sales module,
7 probably because this function is conveyed by external systems that are not integrated
8 in the FMIS.

9 The matrix in Figure 6 presents the four clusters positioned along two dimensions: the
10 support of site-specific activities and the inventory function. We selected these two
11 functions because they require more advanced algorithms and sub-functions to be
12 offered by a FMIS and they pave the way for the development of more complex
13 systems. Inventory management is necessary to support the introduction of still more
14 complex and complementary functions as traceability and quality assurance, while
15 site-specific features enable the use of DSSs with best practice estimation, which are
16 unique functions of cluster 4.

17

18

Figure 6

19

20 As an overview of the commercial FMIS analysis, a limited presence of functions for
21 traceability, quality assurance, and best practice was observed. This could be
22 explained by the greater degree of complexity in data processing and interpretation of
23 the results in an automated manner. Therefore, these systems need to be considered as
24 an essential area for future development in FMIS. Moreover, future developments
25 should also address the low penetration of FMIS covering sales by holistic systems as

1 in cluster 4, especially since customer relationship management systems are becoming
2 pervasive.

3 In conclusion, new complete commercial FMIS based on the integration of inventory
4 management and PA (site-specific) functionalities should include traceability, quality
5 assurance, and best practice estimate functions in the immediate future. The
6 integration of customer relationship management systems in the subsequent years will
7 enable the support of sophisticated decision support functionalities.

8

9 **5. Discussion and future perspectives**

10

11 This study focused on crop production, and as such, applications for greenhouses
12 were not considered due to their higher level of technological maturity. However, it is
13 recognized that there are benefits to be gained from FMIS and DSS development in
14 greenhouses in terms of efficient information handling and decision modelling (e.g.
15 Taragola and Gelb, 2004). Additionally, simulation models representing wide
16 application domains in crop production were not included, since these systems are
17 currently mainly used within the scientific community and have not yet been
18 commercialized. However, due to their solid scientific background and the increasing
19 complexity of crop production, such models are expected to be implemented in the
20 near future.

21 Results show that current research is focused on developing sophisticated systems and
22 merging complex biological, physical, and chemical processes in crop production
23 together with an increased level of awareness of environmental protection, food safety
24 and quality. Moreover, current research try to accommodate the advent of PA through,
25 for example, new spatial and temporal functionalities although key aspects like

1 interoperability and data standardisation is still missing. As for the compliance with
2 national and international standards for food safety and quality, and environmental
3 protection, automated systems in this area is still missing and only preliminary
4 research attempts are available. This will require designing FMIS complying with
5 these new requirements, as presented in the FutureFarm project (Sorensen et al.,
6 2010a, 2010b). All in all, the increasing need for European farmers to demonstrate
7 compliance to the auditing authorities will increase the need to implement FMIS aided
8 by automated data collection.

9 The analysis of commercial software solutions revealed that current solutions mostly
10 targeted everyday farm office tasks related to financial management and reporting
11 (cluster 1) and, most specifically, those related to sales, inventory, and field
12 operations management (cluster 2). Functions related to traceability, quality
13 assurance, and best practice estimates are still in their infancy in most commercial
14 applications. The support of PA technologies is limited to a very small group of
15 systems (cluster 3) devoted primarily to field operations management. Furthermore,
16 the group of systems that cover wider sets of functionalities (cluster 4) lacks basic
17 sales functions.

18 It was observed that the FMIS architectures that were designed by academics in the
19 1980s have to a large extent become mainstream commercial applications today.
20 Therefore, the more complex FMIS (for example in the case of PA) that are currently
21 being designed by researchers around the world should be expected to move into
22 commercialization in the coming decades. Nevertheless, it is to be noted that future
23 drivers will probably focus on Internet connectivity, the Internet of things, and cloud
24 computing (e.g. Pesonen et al., 2008; Kaloxylos et al., 2012). Future FMIS
25 developments must emphasize closer cooperation between academia and software

1 developers. Studies have shown the effectiveness of such cooperation through a user-
2 centric and near-practice development process (Pesonen et al., 2008).

3 In general terms, it can be concluded that, despite the considerable efforts of
4 developers, FMIS still remain at the periphery of agricultural technology and has yet
5 to serve its intended purpose as a mainstream knowledge transfer tool or an innovative
6 aid supporting effective decision making in agricultural production (Parker, 1999;
7 Lawson et al., 2011).

8 A crucial aspect of FMIS is the knowledge management within the decision processes
9 in the form of dedicated DSS. The development of knowledge-based system in the
10 farming sector requires key components, supported by Internet of things, data
11 acquisition systems, machine-to-machine communications, effective management of
12 geospatial and temporal data, traceability systems along the supply chain, and ICT-
13 supported stakeholder collaboration. The process of building knowledge-based
14 systems for agriculture will be supported and supplemented by industrial
15 developments (Lewis, 1998). Special attention should also be given to interoperability
16 and the availability of standardized formats used on defined data infrastructure
17 elements in the agrifood sector, advanced by, organizations such as the Open
18 Geospatial Consortium (OGC).

19 As was recently documented by Lawson et al. (2011), farmers who use FMIS are
20 benefiting from them, since these systems have had a major impact on crop
21 management and have provided objective standards. However, functional
22 improvements are still needed to facilitate wider acceptance within the farming
23 community.

24

25 **6. Conclusions**

1

2 This paper presented a targeted review of the state of the art in Farm Management
3 Information Systems (FMIS) from both an academic and commercial perspective. The
4 academic analysis covered mainly the areas of systems architecture, applications,
5 FMIS in Precision Agriculture (PA) and future trends, while the commercial analysis
6 included 141 FMIS packages focused on crop production in open-fields. Results
7 indicated that on the question of academic research and its ability to accommodate
8 advanced systems like PA, academic research tend to analyse more complex systems,
9 capturing new trends involving spatial and temporal management, as well as
10 distributed system involving internet of things, future internet and web services. As
11 regards the commercial applications, these tend to focus on solving daily farm tasks
12 and aim to generate income for the farmers through better resource management and
13 field operations planning. In terms of the commercial applications being able to adopt
14 the innovations from research, this is the case to a large extent but it is foreseen that
15 software vendors must put extended efforts on adopting the more advanced systems
16 and closely cooperate with academia in order to accommodate the requirements from,
17 for example, PA.

18 Key research representing areas for further development and improvement for
19 currently available academic and commercial applications include improvements in
20 technology, adaptation motives, hindrances, specific new functionalities and, greater
21 emphasis on software design governed by usability and human–computer interaction.
22 In this respect, the diffusion of information management as business innovation in the
23 farming community could benefit from the comprehensive research developed in the
24 last decades on the adoption of ICT and e-commerce among both consumers and
25 small businesses.

1 This study has provided a stepping stone for further development of FMIS. In the
2 past, a key issue was the adoption of farm computers, but this has advanced to include
3 more sophisticated information and communication solutions suitable for PA. The
4 evolution of FMIS must take into account the human-related nature of business
5 processes, specifically for marketing/sales and supply chain functions, where the
6 social aspects have greater relevance. This awareness is necessary to ensure the
7 required advancement from the basic use of farm data recording and processing
8 systems to the adoption of a sophisticated FMIS that truly supports the farm
9 manager's decision making process.

10 The results of this research provides FMIS software developers and vendors with a
11 comprehensive overview of the state of the art of FMIS applications, including
12 updated knowledge of FMIS packages on the market, while farm managers and
13 service providers can gain an overview of the available FMIS that can meet their
14 needs. Importantly, the results identified new functionalities like distributed
15 management systems that must in the near future be implemented in FMIS if the
16 farming community is to fully embrace possibilities and the benefits of PA.

17

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12

1 **Table captions**

2

3 Table 1. FMIS functions included in the commercial software

4

5 Table 2. Countries of origin for the commercial Farm Management Information

6 Systems

1 **Figure captions**

2

3 Figure 1. Conceptual outline of precision agriculture FMIS

4

5 Figure 2. Distribution of defined functions in the FMIS (numbers indicate the FMIS in
6 each function)

7

8 Figure 3. Prevailing platforms of the studied applications

9

10 Figure 4. Results of the cluster analysis showing the number of systems supporting a
11 specific function, in each cluster

12

13 Figure 5. Results of the cluster analysis showing the percentage of systems supporting
14 a specific function, in each cluster

15

16 Figure 6. Cluster categories

Table 1

Table 1.

Countries	Number of commercial solutions	Number of vendors
Europe	61	31
France ^a	10	6
Germany ^b	16	4
Italy ^c	16	10
United Kingdom	19	11
North America	67	38
United States	63	34
Canada	4	4
Australia	13	6
Total	141	75

^a in French; ^b in German; ^c in Italian

Table 2

Table 2.

Function title	Function description
Field Operations Management	Includes the recording of farm activities. This function also helps the farmer to optimize crop production by planning future activities and observing the actual execution of planned tasks. Furthermore, preventive measures may be initiated based on the monitored data.
Best Practice (Including Yield Estimation)	Includes production tasks and methods related to applying best practices according to agricultural standards (e.g. organic standards, integrated crop management requirements). A yield estimate is feasible through the comparison of actual demands and alternative possibilities, given hypothetical scenarios of best practices.
Finance	Includes the estimation of the cost of every farm activity, input–outputs calculations, labour requirements, and so on, per unit area. Projected and actual costs are also compared and input into the final evaluation of the farm’s economic viability.
Inventory	Includes the monitoring and management of all production materials, equipment, chemicals, fertilizers, and seeding and planting materials. The quantities are adjusted according to the farmer’s plans and customer orders. A traceability record is also an important feature of this function.
Traceability	Includes crop recall, using an ID labelling system to control the produce of each production section. Traceability records related to the use of materials, employees, and equipment can be easily archived for rapid recall.
Reporting	Generally includes the creation of farming reports, such as planning and management, work progress, work sheets and instructions, orders purchases cost reporting, and plant information.

Site Specific	Includes the mapping of the features of the field. The analysis of the collected data can be used as a guide for applying inputs with variable rates. The goal of this function is to reduce or optimize input and increase output.
Sales	Includes the management of orders, the packing management and accounting systems, and the transfer of expenses between enterprises, charges for services, and the costing system for labour, supplies, and equipment charge-outs.
Machinery Management	Includes the details of equipment usage, the average cost per work-hour or per unit area. It also includes fleet management and logistics.
Human Resource Management	Includes employee management, including, for example, the availability of employees in time and space. The goal is the rapid, structured handling of issues concerning employees, such as work times, payment, qualifications, training, performance, and expertise.
Quality Assurance	Includes process monitoring and the production evaluation according to current legislative standards.

Figure 1
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Figure 1

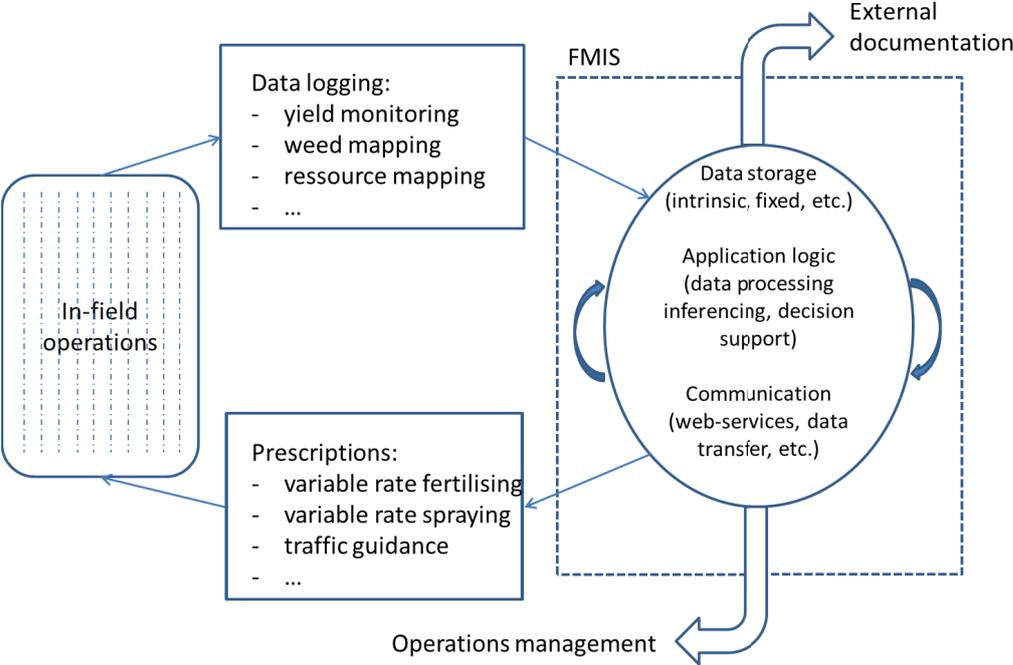


Figure 2
[Click here to download Figure: Figure 2-revised.docx](#)

Figure 2

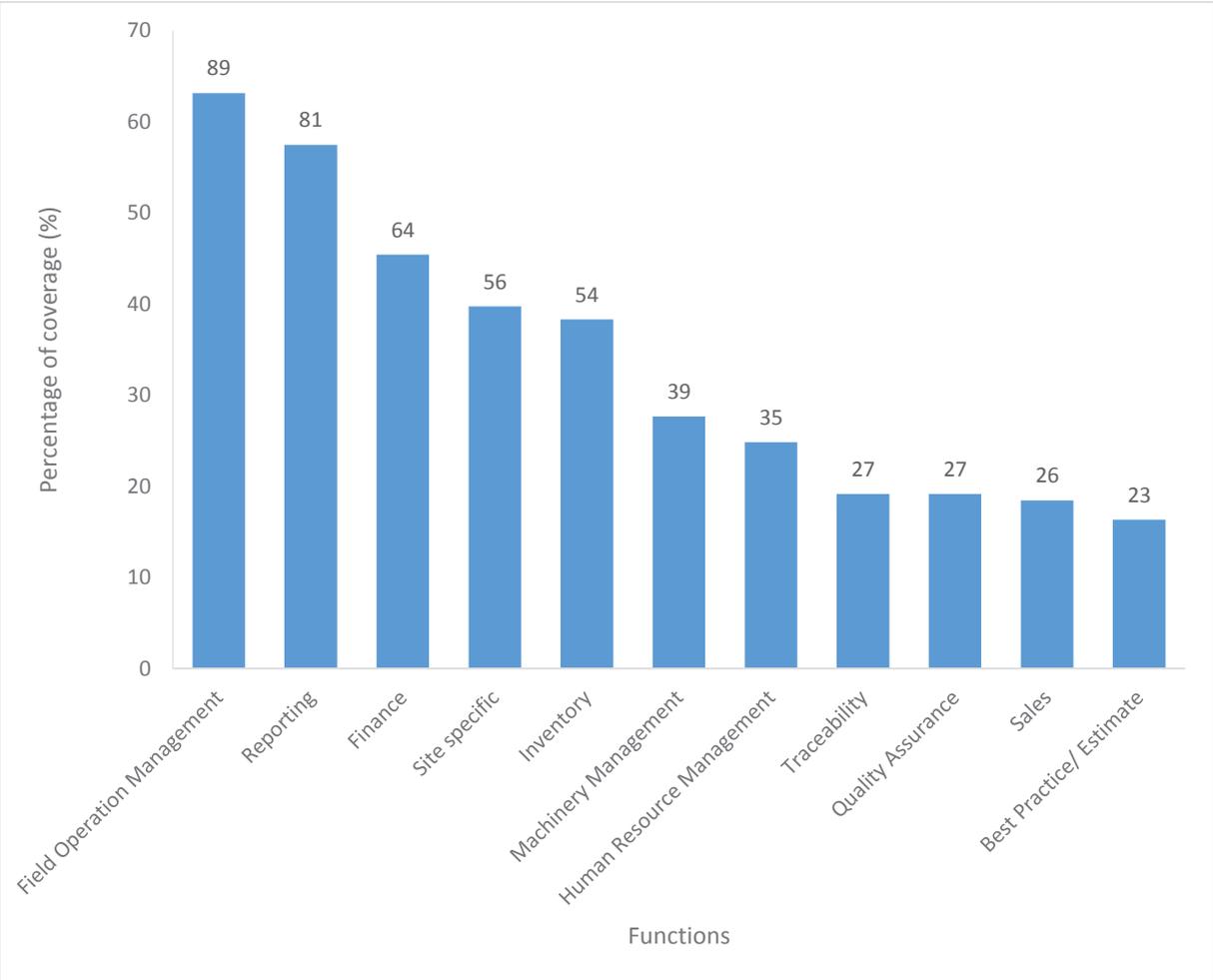


Figure 3
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Figure 3

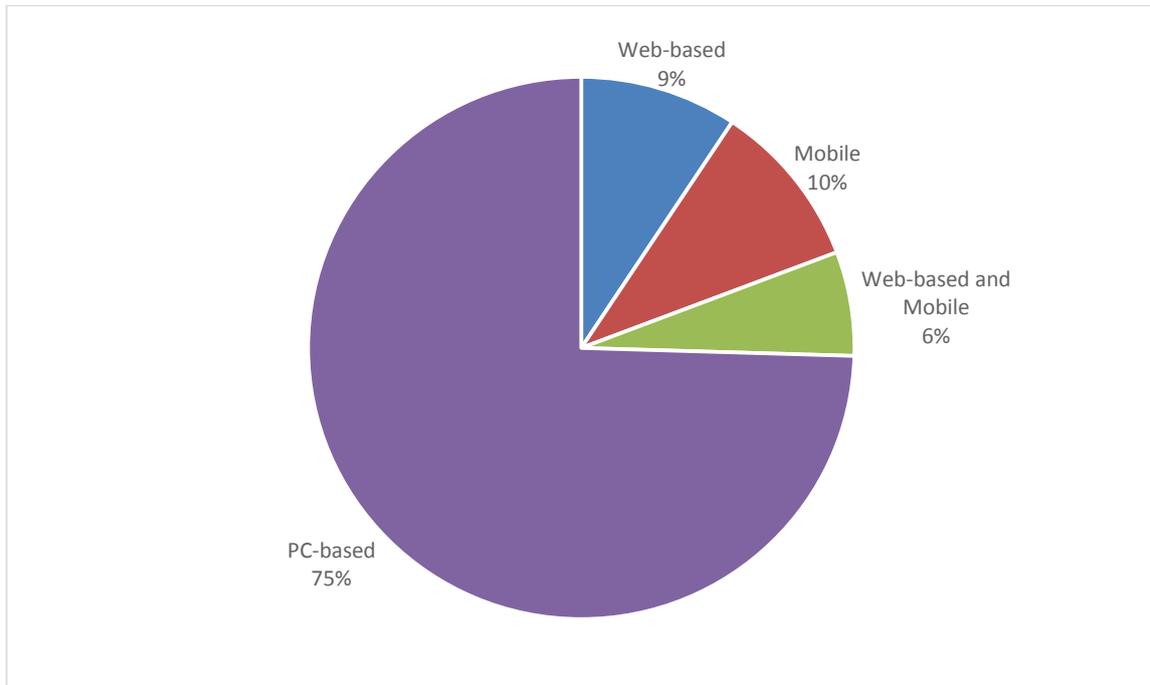
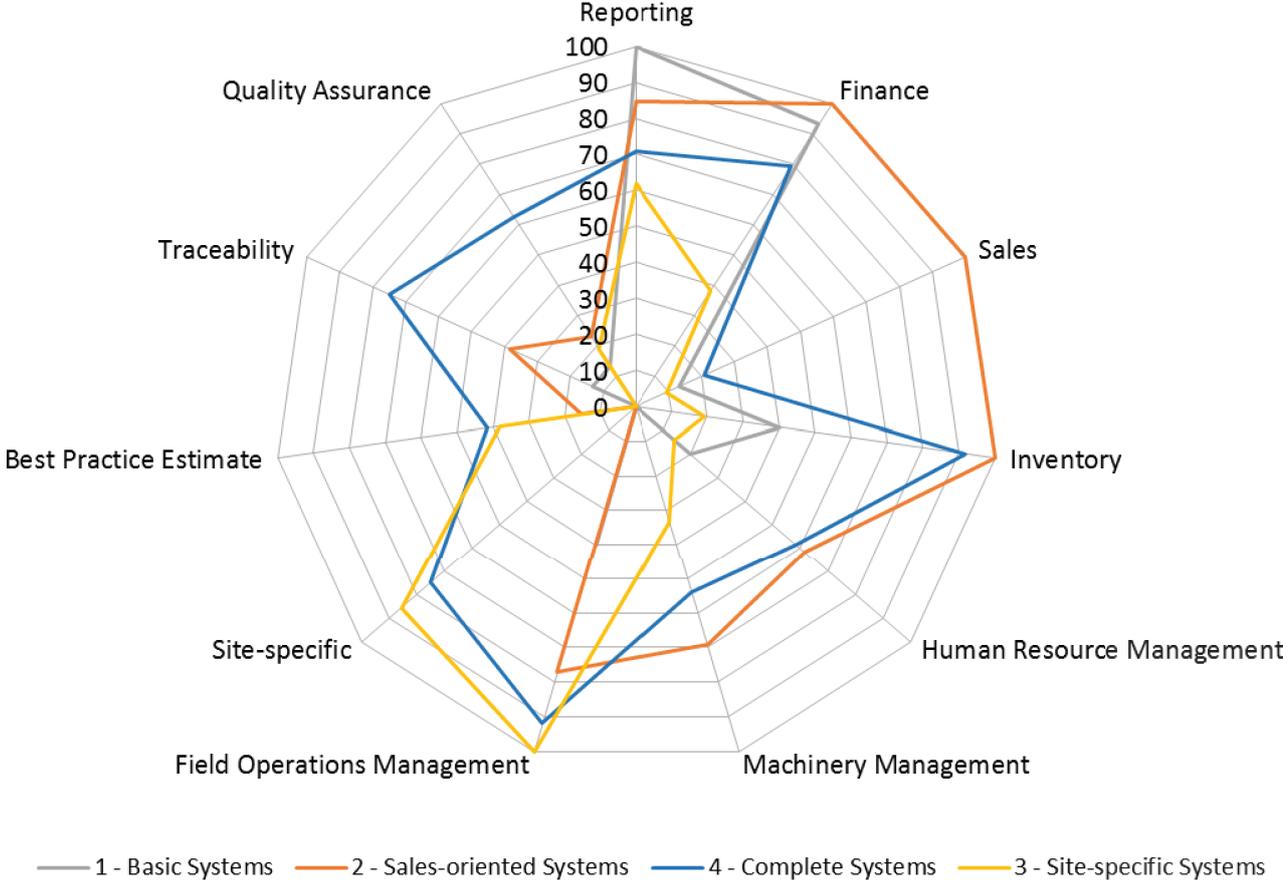


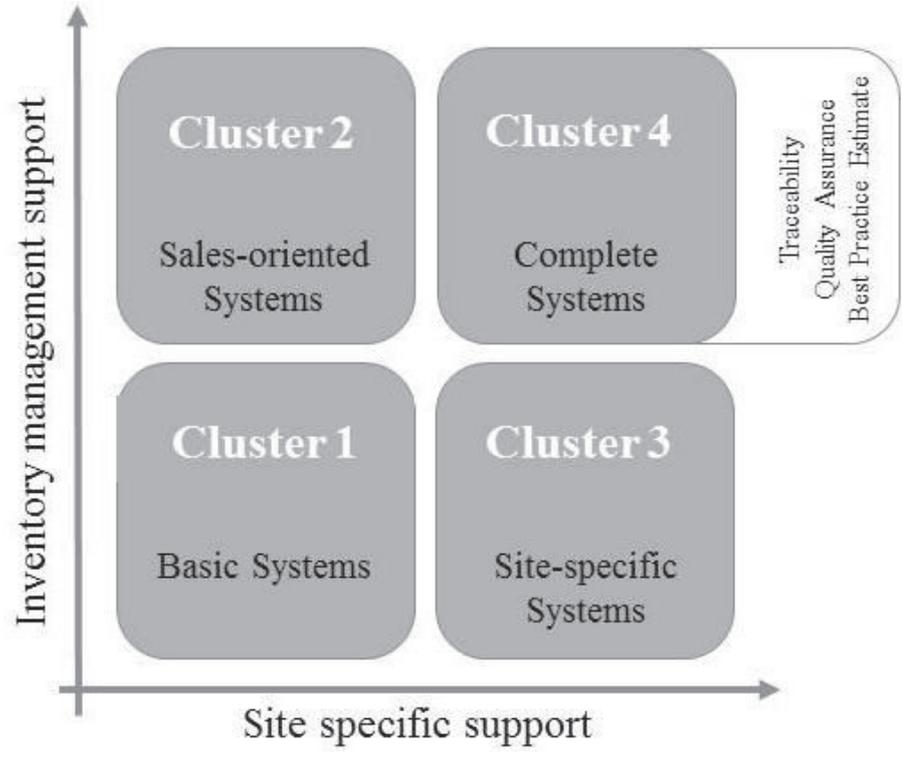
Figure 5
[Click here to download Figure: Figure 5-revised_II.docx](#)

Figure 5.



1 Figure 6

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