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Smart Project Management Information Systems (SPMIS) for Engineering Projects – Project Performance Monitoring & Reporting

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Abstract:
Engineering projects are becoming increasingly complex as projects get larger and as technology improves. Greater competition worldwide has meant that projects are delivered quicker and cheaper. This necessitates sophisticated Project Management Information System (PMIS) technologies to be adopted to improve efficiency and quality on projects. PMIS data and reports can be used to better understand the risk exposure, resource utilisation, profitability, and scheduling of a project. It also informs strategic project decisions and performance monitoring and reporting. Unfortunately, project data is often fragmented and embedded in different systems. This paper investigates several commercially available PMIS, to understand and compare the functionality of these systems. A qualitative study using semi-structured interviews was conducted with purposively selected project systems experts at twelve project-based organisations. Thematic analysis revealed what functions PMIS fulfils, how these systems are integrated and how they facilitate project monitoring and reporting. Moreover, a novel model for the basic architecture of a 'Smart' Project Management Information System (SPMIS) is proposed, which would facilitate software integration and intelligence based on identified industry needs and requirements. The model addresses the shortcomings of existing models by combining models and incorporating system intelligence i.e. the automation of certain project management activities.

Keywords:
Project Management Information System; technology; project performance; monitoring; reporting; Smart Project Management Information System; PMIS.

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1. Introduction

As global competition grows there is ever-increasing pressure on projects to deliver faster and more cost effectively, leading to the necessity to adopt new technologies. These developments will most likely influence the way projects are structured, the way in which project management is carried out and the nature of projects themselves [1]. PMIS can streamline the management of data required for project planning and performance monitoring, to increase competitiveness and the chances of project success [2]. Retnowardhani and Suroso [3] evaluated five case studies which found PMIS to have advantages such as correct decision making based on visibility of accurate project performance data and improved project performance by increasing communication through the aid of PMIS. Software can make project management easier by simplifying and/or automating the execution of various project tasks [4]. New PMIS applications enable project managers (PMs) to spend less time on repetitive rule-based tasks, enabling PM's to spend more time focusing on higher order functions such as innovation, creativity, stakeholder relations and strategy [5].

We are living in a digital era i.e. the 4th Industrial Revolution or Industry 4.0, which is characterized by businesses utilizing digitization, automation and information and communication technology in increasing measure [6]. The recent advances in the creation and storage of big data, provides the foundation to drive the implementation of new digital technologies in projects. To monitor projects, up to date and accurate project data is required. This data should be collected and presented to the project stakeholders for evaluation. The project performance data is usually summarized into a project report or on a digital dashboard. However, to generate these reports tends to be a difficult and time-consuming exercise as data is often fragmented and contained in different software applications. The rapid advances in digital technologies holds promise to create a 'Smart' PMIS (SPMIS) which can consolidate, analyze and interpret numerous data sources to assist PM's to monitor multiple, complex projects. Data is the fuel for analytics that will drive automated project management functions. Project management offices with access to data will be able to make full use of new technologies and will have a competitive advantage over companies who do not have access to data [7].

Projects are becoming increasingly technically complex with more pressure to complete the project in less time and at a reduced cost. This is mainly due to increased competition and stakeholder expectations. Engineering companies generally manage several different projects simultaneously. This makes the task of monitoring and controlling multiple projects difficult. Data from PMIS is generally fragmented because it comes from different software applications and sources. In most cases the data is captured manually, and the data is manually imported and exported between software applications. This is a laborious and time-consuming process which is prone to errors. The lack of quality live data and real-time reporting can negatively impact strategic decisions, risk exposure, resource planning, profitability, and stakeholder relations in projects. The existing commercially available PMIS systems as well as the conceptual models found in the literature do not address all of these issues in one system or conceptual model.

This is an exploratory study which investigates organizations in the construction and engineering industry as well as commercially available PMIS used in these industries. The following premises were used to formulate the research questions for the study:

The degree to which organizations can integrate project data between systems, influences the accuracy and timeliness with which the data can be pulled into project reports for decision making.

- How are companies integrating the PMIS that they use?

By understanding the methods used to monitor project performance provides guidelines for improving PMIS for project reporting.

- How are companies reporting on project performance?

By understanding how the ideal PMIS should function and the shortcomings of existing PMIS, a new conceptual model can be developed.

- What are the main characteristics of the ideal PMIS?

By understanding the functions of the different commercially available PMIS, the strengths and weaknesses of the systems can be identified, and the new conceptual model can incorporate these findings and better align the theory with the existing systems.

- How do the commercially available PMIS functions compare with each other?

The next section of the paper recalls the previous research on PMIS systems, project performance monitoring and reporting. The literature review also compares several existing PMIS conceptual models. We then describe our research methodology, which included numerous industry interviews and PMIS software investigations. We also describe our qualitative study results and discuss the implications. Finally, we propose a new conceptual model for the basic architecture of a Smart Project Management Information System (SPMIS).

2. Literature review

2.1 PMIS Definition and Functions

PMIS can be described as a computer-based information technology software system, which is used by organizations to generate, store and manage project data in pursuit of optimal project performance [7]. PMIS systems are usually made up of several different software packages which enable more efficient resource scheduling, information management and distribution, knowledge repositories and cost management systems [8]. The PMBOK Guide [8] states that, "automated gathering and reporting on key performance indicators (KPI) can be part of this system".

PMIS was introduced to the market in the late 1970's, created by companies such as Oracle, Artemis and Scitor Corporation [9]. However, it was only in the late eighties and the nineties that project management software was more widely used as more and more people started using personal computers. During this time both the software and the techniques for managing projects developed rapidly [9]. Over the last decade PMIS have changed considerably, driven by the advances in new technology and the need for better systems. PMIS have evolved from systems that only manage project scheduling and resources, to comprehensive systems that support many of the other project management functions at a project as well as project portfolio level [2].

The PMBOK Guide [8] provides the following categories and functions of PMIS:

- Scheduling software – assists with planning mapping out project timelines by providing tasks with start and finish dates and provides the links between the tasks. These are commonly known as Gantt charts. The software greatly enhances the speed to create as well as update these charts.
- Cost Control Software – assists with project cost control and includes spread sheets, statistical analysis and simulation tools which can make it easier to estimate costs and evaluate cost estimate alternatives.
- Resource Management Software – assists to optimize resource utilization and highlight where resources are constrained, the software can help manage resource groups, track resource loading, record time sheets and associated resource costs.
- Information (document) Management – assists with project communication enabling stakeholders to source and share documents in a timely way. These systems can be in the form of specialized project information portals, web interfaces, collaborative work management tools and dashboards.

2.2 PMIS project monitoring and reporting

The PMBOK Guide [8] explains that one of the benefits of project monitoring is to allow stakeholders to know the current state of the project in relation to cost and schedule. The actual measurements or observations of project activities is called work performance data. This typically includes percentage work completed, start and finish dates of activities, number of change requests, actual costs, and durations. This data is collected from the different processes or business areas in the project, throughout the lifecycle of the project. The interpretation of the data provides insight into the condition of the project and enables the stakeholders to take corrective or preventative action.

Project performance monitoring has been extensively covered in the existing literature [10].Głodziński [11] developed a conceptual framework to highlight the complexities around project performance drivers, including the interdependency between project performance and project management performance. The research provides a new framework for evaluating project performance by evaluating both the quantitative and qualitative aspects of project performance. The quantitative measures are defined as financial performance which includes all financial data related to income and expenditure. The qualitative project performance measures include aspects like quality and stakeholder satisfaction. The qualitative and quantitative information are combined to produce project performance reports. Díez Silva et al. [10] provide a comprehensive list of the most common project performance measures found in the literature as shown in Table 1.

Table 1. Categories for measuring performance in project management literature [10]

#	**Category**
1	Time
2	Cost
3	Quality
4	Customer satisfaction
5	Organizational – management
6	Staff
7	Efficiency
8	Scope
9	Communication
10	Changes
11	Effort
12	Profitability / Benefits
13	Contracts/ Procurement
14	Risks
15	Safety & Health
16	Conflicts / Arguments
17	Environment
18	Urgency
19	Commitment
20	Successful implementation
21	Relevance / reassessment
22	Diffusion

Several techniques can be used to analyze data, for example cost benefit analysis, earned value analysis, trend analysis and variance analysis. Project performance is usually measured against a project baseline, which is put in place during project initiation [12]. Typically, time, resource, cost and technical variances are measured, however it is cost and schedule variance which is most often analyzed [8]. Project data is communicated in the form of status reports or progress reports. The reports are usually illustrated with charts, trend lines, graphs, color signals and additional written commentary on project performance and risks is often provided. The project data which is used to compile project reports is often stored in a PMIS.

2.3 Documents and data

Documents can be defined as a set of data or meta data. A document carries information that can be shared and stored. In the case of electronic documents, documents are any source of data which is stored in a database. Some of the document types that exist in a project environment include quotations, invoices, meeting minutes, drawings, forms, emails, specifications, and test results [13]. Many different types of data can be generated by PMIS, including project management data, system management data, model data and meta data. Each of these data types can be broken down further into smaller parts or subsets, each type of data has its own attributes. These attributes typically include start and finish times, duration, and status [14].

Digital documents allow many advantages over other types of documents because each instance of data movement leaves a trace. Most project documents are in a digital format and the generation, sharing and modification of documents is almost all done by computers and computer networks. The traces that these documents leave can be exploited to measure and analyze the activities in an organization or project. Document creation and evolution within projects can reflect or indicate the performance of an enterprise or project. Documentation and project performance are also closely linked; therefore, project performance can be monitored by tracking documents [13].

2.4 PMIS software & evaluation

Kostalova et al. [4] compare different PMIS on the market including several freeware software packages. The software review includes Project Libre, Gantter and Easy Project as well as licensed software such as Microsoft Project and Primavera. Freeware cloud-based tools offer limited functionality and are only suitable for small or simple projects. The more sophisticated software has financial limitations and demands extensive training to use these software applications [4].

Rautenbach and Schutte [15] developed a software application to help organizations select PMIS based on several evaluation criteria broken down into three main criteria as listed below. The tool was tested by several experts and the constancy ratio of the outputs from the different experts were all found to be consistent.

PMIS functional criteria include:

- Integration management;
- Scope management;
- Cost management;
- Time management;
- Quality management;
- HR management;
- Communication management;
- Risk management;
- Procurement management.

Criteria specific to each organization include:

- Perceived usefulness;
- Perceived ease of use.

Software acquisition criteria include:

- Software cost;
- Maintenance and support;
- Implementation and training.

Jaafarit and Manivong [16] also reviewed existing PMIS systems. Their sample consisted of 24 PMIS systems, half of which were commercially available at the time and the other half were in house propriety software applications. They used a scoring system where they scored the software applications against the ideal project management system. The results show that the top scoring software applications fall short of the ideal project management system, the ideal system would result in a score of 100, however the best scoring system only received a score of 39 [16].

2.5 Smart project management information systems (SPMIS)

The concept of a SPMIS was introduced by Jaafarit and Manivong [16]. Their research describes an advanced PMIS to support more complex projects. They use the word smart to highlight additional system intelligence when compared to existing systems on the market. The authors provide some valuable insight on SPMIS. They emphasize that the system should have live real time data which is easily accessible to the project stakeholders. The system should be flexible and able to accept different types of data and information sets. Moreover, it should be extensive in terms of the different functions that the software can perform and intelligent in its analysis and overview capabilities over the project lifecycle. When reviewing the PMIS systems of the day, they stated that micro computers were not powerful enough to create and run a SPMIS. They also noted that most of the PMIS on the market are not designed to "facilitate proactive project management, or even provide integrated evaluation of traditional areas such as cost, time and risks or handle information management, a function which the authors view as an essential, integral part of project management"[16].

Similarly, Braglia and Frosolini [17] proposed an information control tower model which emphasized a PMIS that integrates multiple complex projects into one digital platform. The study found that the platform saved time, reduced errors, and rework and improved document management and overall communication amongst the team members [17].

2.6 Conceptual models

Over the past few decades PMIS have evolved from single project management systems to dynamic multifunctional and multi-project systems that are no longer limited to only project planning and cost control functionality [18]. Several authors have provided models which conceptualize these multifunctional systems. The development of project management theory is beneficial as it can be applied by project managers and organizations for managing projects [19]. Four existing conceptual models [16, 17, 20, 21] are reviewed to gain a better understanding of the basic architecture, functionality, and system characteristics of SPMIS. The focus of these four models are summarized in Table 2. Each model has some unique features as well as common features which are listed in Table 3.

Table 2. Existing conceptual models

Authors	**Model description**	**Main emphasis of model**
Jaafarit & Manivong, 1998[16]	Broad Concept Architecture of the SPMIS	System should handle hard and soft project management functions over the entire lifecycle of the project.
Braglia & Frosolini, 2014[17]	Control Tower Application Model	System is characterized by a central control tower, which interfaces with other databases and systems from the different functional areas of the organization and other organizations.
El-Omari & Moselhi, 2011[20]	Proposed PMIS Architecture – Automated Data Acquisition from Job Sites	System emphasizes automated data acquisition from job sites into a centralized database.
Zamani et al., 2017[21]	PMIS – The Interplay Between Communication, Information & Intelligence	System emphasizes an internet-based system which functions over the entire lifecycle of the project, with integral links between communication information and intelligence.

Table 3. Existing conceptual models' characteristics

Main system characteristics	Jaafarit & Manivong, 1998[16]	Braglia & Frosolini, 2014[17]	El-Omari & Moselhi, 2011[20]	Zamani et al., 2017[21]	Total
Centralized data base			✓	✓	**3**
Real-time data	✓	✓	✓	✓	**4**
Project portfolio management		✓			**1**
Automated data inputting			✓		**1**
Intelligence, decision making, future forecasting & scenario planning	✓	✓	✓	✓	**4**
Compatible with other software	✓	✓	✓	✓	**4**
Easy access to information	✓	✓	✓	✓	**4**
Project reporting/tailored information outputs	✓	✓	✓	✓	**4**

2.7 Literature review synopsis

The PMBOK Guide [8] provides substantial theoretical knowledge on how projects are monitored and the role of PMIS in projects. The PMBOK Guide [8] does not advocate or rank existing PMIS in the market nor does it refer to intelligent PMIS systems. It also does not address how project reports, containing extensive data from projects, are generated and presented to stakeholders.

Project performance is well documented in terms of both quantitative and qualitative project performance measures [10]. However, the literature does not provide solutions on how organizations can efficiently create and manage all the performance data and easily integrate it into project reports.

Four different conceptual PMIS models are identified in the literature. There is no distinct or unified conceptual model for the architecture of an advanced PMIS. The existing models have similarities, however, these models also differ quite substantially. Therefore, the opportunity exists to provide a more unified model which combines common as well as unique characteristics of the existing models.

Kostalova et al. [4] compare the capabilities of the different applications by means of a check box table, while Jaafarit and Manivong [16] use a scoring system. Primavera is the only application tested by both authors. Unfortunately, Kostalova et al. [4] PMIS review methods are poorly defined, while Jaafarit and Manivong [16] PMIS scoring results are no longer relevant as most of the software that was reviewed is no longer commercially available.

The literature review revealed the need for a more up to date PMIS investigation of the latest commercially available software applications. The literature review also identified that a more unified conceptual model of advanced SPMIS is required, which has the potential to solve the problem of fragmented data sources from different PMIS in projects. According to Brynjolfsson et al. [22] from MIT, "one thing we've learned about digital progress is never say never. Like many other observers, we have been surprised over, and over again as digital technologies demonstrate skills and abilities straight out of science fiction. In fact, the boundary between uniquely human creativity and machine capabilities continues to change."

3. Research methodology

The research includes two main approaches; semi-structured industry interviews and PMIS software review as shown in Figure 1. The two approaches were used to gain knowledge to develop a new SPMIS conceptual model.

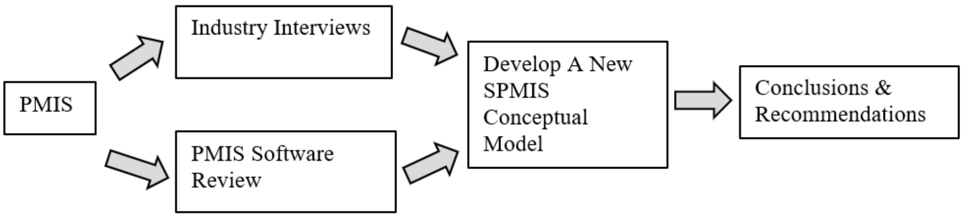

Figure. 1. Research design schematic

3.1 Industry interviews

Guest and Johnson [23] suggest that at least twelve in-depth interviews should be completed where the aim is to understand commonalities between similar types of groups. According to this recommendation and the time constraints of this study, thirteen interviews were completed. The research participants were purposefully chosen from different project-based organisations for the qualitative study. Research participant 10 and 11 were from the same organisation. The selected project-based organisations were all within the South African engineering and construction sector. The selected organisations all manage multiple projects varying in size from smaller feasibility studies to very large engineering and construction projects. Organisations which handle large projects were purposively chosen because more sophisticated software is required to handle the size and complexity of these projects [11].

The designation of the chosen research participants included senior project managers, senior project controllers or director level employees in the organisations. They had job descriptions which included managing, monitoring or controlling multiple large engineering and construction projects.

The semi-structured interview consisted of 25 questions. Further follow-on questions were used in some instances to prompt more feedback regarding certain topics. Each interview took approximately 40-60 minutes, it was voice recorded, transcribed and then coded in Atlas.ti using thematic analysis. The demographics of the research participants and their project-based organisations are provided in Table 4.

Table 4. Participant demographics

Interview	Job title	Industry	No of projects in progress	Project size in Rands [1US$=15 Rand]	Project duration range
1	Projects director	Construction management - retail & warehousing	30	500K-1G	0.5 - 24 months
2	Senior project manager	Construction management - retail, hospitals, hotels, industrial	50	1M-500M	4 - 24 months
3	Program manager	EPCM - Energy, oil & gas	10-12	10M-2.5G	12 - 120 months
4	Head of projects	Scientific & engineering construction projects	7	2G-3G	60 - 96 months

Interview	**Job title**	**Industry**	**No of projects in progress**	**Project size in Rands** [1US$=15 Rand]	**Project duration range**
5	Projects director	EPCM - Mining & mineral processing	10-20	2M-150M	4 -15 months
6	Program manager	EPCM -Water treatment & plant manufacturing	4-5	1M-400M	3 - 96 months
7	Capital planning manager (PMO office)	Mining, mineral processing, schools & hospitals	137	100K-5M	2 - 36 months
8	Senior project manager (Director)	EPCM - Ferro alloy & energy	3	100M-1.5G	16 - 22 months
9	Chief Executive Officer (CEO)	Construction & fabrication of building glass & aluminium facades	25	1M-120M	6 - 18 months
10	Project services hub leader	EPCM - Construction duplexes, simplexes, low cost housing, water & transport infrastructure	1200 (Southern Africa)	500K-1G	1.5 - 72 months
11	Digital practice leader	EPCM - Construction duplexes, simplexes, low cost housing, water & transport infrastructure	1200 (Southern Africa)	500K-1G	1.5 - 72 months
12	Project controls manager	EPCM - Base metals, pyromet & hydromet	600 (Africa, Europe Middle East)	2M-10G	6 - 36 months
13	Contracts director	Construction/building of commercial, industrial and retail buildings	25	100M-500M	12 – 24 months

* K=Thousand M=Million G=Billion

3.2 Software review

An internet search on Capterra, a software review website, revealed that there are at least 500 commercially available software applications that can be used for supporting project management [24]. Therefore, it was not practical to review every commercially available PMIS. Rather the results from a survey by Ilyas, Hassan and Khalifa [25] of approximately 25 project managers in the construction and energy/oil industry in Europe, the Middle East and Africa (EMEA) was used together with the findings from this research to determine a shortlist of five different PMIS to be reviewed in this study, as listed below [25]. Each PMIS was investigated by interviewing software sales consultants, reading product brochures, assessing website content and watching software demonstration videos online.

- CCS Candy;
- MS Projects;
- Primavera;
- Aconex;
- Trimble (Project Sight).

Table 5 lists the main functions of five commercially available PMIS. A scoring matrix which is adapted from Kostalova [4] includes some additional project functions which were used to score the PMIS.

Table 5. PMIS Software Review Matrix

PMIS FUNCTIONS	MS Project Online	Oracle/Primavera	CCS	Oracle/Aconex	Trimble
1. WBS & Gantt chart	✓	✓	✓		
2. CPM (critical path method)	✓	✓	✓		
3. Time sheet system	✓	✓			
4. Task management (social collaboration)		✓		✓	✓
5. Cost and financial control	✓	✓	✓		✓
6. Risk management		✓			
7. Document management		✓		✓	✓
8. Field management		✓		✓	✓
9. Automated data inputs (from field instruments)					
10. Resource levelling or histogram	✓	✓	✓		
11. Project performance data reporting/dashboards	✓	✓	✓	✓	✓
12. Workflow management				✓	✓
13. Customisable project reports	✓	✓	✓	✓	✓
14. Live data reporting/cloud based	✓	✓	✓	✓	✓
15. Project portfolio management (ppm)	✓	✓			
16. Ability to use data from past projects					
17. Compatible with other software applications	✓	✓	✓	✓	✓
18. What if analysis (scenario planning)	✓	✓	✓		
19. Earned value and s-curves	✓	✓	✓		
20. BIM & drawing mark-up interface			✓	✓	✓
SCORE :	12	15	11	9	10

The research results show that according to the criteria in Table 5. Primavera has the most PMIS functions based on the study sample. However, the other applications are not too far behind. Each software application has strengths and weaknesses when compared to the other applications, these are listed in Table 6.

Table 6. PMIS strengths & weaknesses

Software Application	Core Strengths	Weaknesses
MS Projects	▪ Scheduling ▪ Cost effective ▪ Easy to use ▪ Most widely used in industry	▪ Cost management ▪ Risk management ▪ BIM and drawing interface ▪ Field management
Primavera	▪ Scheduling ▪ Resource management ▪ Portfolio management ▪ Risk analyses	▪ Cost management ▪ Workflow management ▪ BIM and drawing interface
CCS	▪ Cost management ▪ Scheduling ▪ Earned value integrator	▪ Portfolio management ▪ Document management ▪ BIM and drawing interface
Aconex	▪ Document management ▪ Workflow management ▪ Field management ▪ BIM and drawing interface	▪ Scheduling ▪ Cost management
Trimble	▪ Cost management ▪ Document management ▪ Workflow management ▪ Field management ▪ BIM and drawing interface	▪ Scheduling ▪ Portfolio management

None of the PMIS used machine learning based on historical project data or had automated data capturing. These shortcomings remain major challenges as well as opportunities for future development.

4. Results

4.1 PMIS utilization

The research results indicated in Table 7 show that many different PMIS applications are used to fulfil multiple project functions. For example, research participant 4 makes use of Primavera for project schedule management, resource management and time sheets. The results also show that the organisations do not use each PMIS application to their full functionality. For example, research participant 3 makes use of an enterprise resource planning (ERP) software called IFS for time sheets rather than using Primavera. Research participant 3 described the organisations approach to software selection as the “best of breed”, for each project management function, where they use the strengths or core functions from different PMIS applications on the market.

Table 7. Utilization of PMIS software

Inter-view	Project Cost Management	Time Sheets	Project Resource Management & Histograms	Document Management & Workflow Management	Project Schedule Management	Drawing & BIM Software
1	MS Excel	None	None	Windows Server Based	MS Project	None
2	PPO	PPO	None	PPO	MS Project	
3	IFS	IFS	Primavera	Aconex & M-Files	Primavera	Autodesk Revit
4	Great Plains	Primavera	Primavera	EB, Google Drive	Primavera	
5	Cispro	SDK	MS Project	DR Pro, Windows, done manually	MS Project, CCS Candy	Autodesk, Smart Plant, Aveva
6	Envisage	Clock o Fi	Asana	EB	MS Project	
7	Prism, SAP, Excel	Saeco	None	Standard Windows Server	MS Project	Autodesk, Pro-Engineer
8	CCS Candy	None	None	Solidworks	MS Projects	
9	MS Excel, Pastel & V6	MS Excel	CCS Candy	Wownet, MS Team Member	MS Projects, CCS Candy	Bentley/Navisworks
10&11	BST Global, Revit, Builder	BST	MS Excel	Share Point, BIM 360	MS Projects	
12	SAP, Trimble, CCS Candy	SAP bolt on, custom built tool	SAP bolt on, custom built tool	Livelink	Primavera & MS Projects	Solidworks/Revit
13	CCS Candy, BuildSmart	SAS (custom in house system)	SAS (custom in house system)	Docwise	CCS Candy	

*MS=Microsoft PPO=Project Portfolio Office CCS=Construction Computer Software

4.2 PMIS integration

The results show that no project management functional area stands in isolation, all the functions worked together to ensure successful project implementation. Therefore, when data is located in different PMIS applications, organisations find it challenging to integrate data across systems. The data is either integrated manually, requiring user interface, or it is automated through the software. The integration enhances the software's capability and provides better information to the users.

In table 8 summarised feedback from the interviews, show that the greater the number of projects being handled by an organisation the more sophisticated the software application needs to be to manage the large amount of data generated. This claim is substantiated by research participants 10, 11 and 12 who's organisations have built a centralised database system to deal with this problem. These organisations were then able to build earned value tools as well as reporting and dashboarding tools from the database. These findings support the new SPMIS conceptual model which is presented in this research.

Table 8. Research participants' comments on PMIS integration

Partici-pant	Research Participants Summarised Comments
1	**MS Excel – MS Project –** "Information is entered manually in the master schedule based on progress from the Quantity Surveyor and other contractors monthly. "
2	**PPO** – "Project cost management, timesheets and document management and workflows are integrated into one system. The integration of schedule and costs are not done in this organisation." **PPO – Autodesk –** "Drawings are uploaded manually into the system."
3	**Primavera** – **"**Project resource management and project schedule are integrated across projects to provide resource histograms. Organization had an application programming interface (API) developed to link the enterprise resource planning (ERP) IFS cost management system to the Primavera schedules, however this created a lot of friction because the planners schedule updates were dominating the information on the cost control system." **IFS – "**Time sheets are integrated with the project cost management sheets." **Primavera - IFS –** "Reverted to having separate systems with manual entry of data between the two systems. Primavera does have its own cost control capability, however IFS is the main company asset, and a substantial investment has been made implementing the system which has a time component capability which the organisation then reverted to." **Aconex – Autodesk – "**Documents are uploaded from Autodesk into Aconex, where they are distributed."
4	**Primavera** – **"**Project resource management and project schedule are integrated across projects to provide resource histograms." **Primavera – Great Plains** – "The progress information and time sheets are fed manually to Great Plains. Participant acknowledged that it could be done better, they are investigating ERP's systems which can do better integration."
5	**SDK-CISPRO – "**Timesheet data from SDK is imported into Cispro cost control software. However, this is a manual process where data is first exported into Excel, where macros are written to import into Cispro. Once data has been imported it must be checked manually to confirm that the data has synced correctly." **MS Projects – "**Data from separate project schedules is collected and then a new schedule is manually developed to understand how the projects overlap at an organisational level." **MS Projects/CCS** – **Bentley/Navisworks – "**In some cases the schedule is linked to the 3D model. This allows you to build construction sequence animation videos. You first need to code each section in the model and group it together, you need to make sure all your coding is correct and it's a complicated procedure, so it is not being utilised on all projects, only where the effort is justified." **MS Projects – Bentley – Cispro –** "In some cases a link is set up where the model can download a bill of quantities (BOQ) based on the progress which can then be manually integrated into the cost reports."
6	**Clock o Fi - Envisage** – "Time sheet data entered manually into the ERP system."
7	**Excel – Prism – "**Base line budget done in Excel and uploaded into Prism." **Saeco – SAP – "**Time sheet directly integrated with cost control system which is SAP." **MS Projects – Prism** – "MS Projects integrates the project schedule into Prism. The schedules sit on the server and are manually uploaded into Prism." **Prism – SAP** – "The project cost sheets in Prism are integrated with SAP, there is a SQL database so there is a live link."
8	**MS Projects** – **CCS Candy** – "MS Project schedules get uploaded into cost control software." **Solid Works** – "Integrates the 3D models with project documentation and workflows."
9	**MS Excel – Pastel** – "Time sheet hours captured in excel against certain cost codes. This information is then manually fed back into Pastel." **CCS Candy** – "Integrates the schedules with resources to do resource management, however the organisation reverted to Excel because the person with the skills to operate the system left the organisation."

Partici-pant	Research Participants Summarised Comments
10&11	**Digital Work Space (Share Point) –** "The organisation developed a digital cloud based workspace, where the different software applications could be easily accessed in one location by clicking on the different project functions which includes an approvals portal, WBS breakdown development portal, the project cost and pricing management portal, the project schedule portal and the business intelligence portal where the data can be pulled into various project performance dashboards. The organisation is also working on integrating BIM360 and ProjectWise into the platform digital workspace, to have full integration and accessibility across all functional areas."
	BST Global – Project Time Sheets – "Are directly linked in the software to the project cost control sheets at a task or activity level."
	BST Global – MS Projects Online – "The different task 'percentage complete' values are manually exported into BST to determine forecasts and earned value measurements."
	MS Projects - Navis Works – "The schedule is linked to Navis Works to create 3D animations of construction sequence. This is not a seamless process so if the model changes the schedule doesn't update automatically. Difficulty in translating schedule to actual site construction sequence."
	Autodesk/Bentley – Cost & Pricing Tool – "The bill of materials which comes from the 3D design models is exported manually into the cost and pricing tool."
12	**Note:** The organisation developed a cloud-based structured query language (SQL) database which, enables data sharing and visibility across all the applications to facilitate extracting data for project reporting, including a custom-built earned value tool. The tool takes the timesheets, schedule, documentation and drawing progress information and automatically correlates it to the project cost codes with SAP to calculate earned value and project performance indices.
	CCS Candy – Trimble – "Budget estimates are done in CCS and budget costs are then manually exported into Trimble to establish the baseline costs."
	SAP – **Trimble** – "Trimble only captures SAP manhour costs as a cost account."
	SAP – **Custom resource tool** – "Pulls data from SAP and into custom built resource tool which compares actual hours versus planned hours."
	MS Projects/Primavera – Navis works – "Integrates schedule with a 3D model, to create 3D simulations of construction sequence."
13	**CCS - BuildSmart –** "CCS captures revenue, budgets, and schedule, BuildSmart captures costs of procurement, BuildSmart is integrated into CCS to compare revenue vs cost. Ledger numbers need to line up on the two software systems to enable integration and do proper comparisons to calculate margins."
	SAS (Internal custom-built tool) – "Integrates time sheets and resource management."

Data generated from PMIS is used by the organisations, to support monitoring and reporting of projects. The research results for project performance monitoring is summarized in Table 9.

Table 9. Project performance monitoring and reporting

Method	Explanation
Fundamental understanding of the project	There is a need to be able to determine if the data received is correct. People can manipulate data to hide things and there is the need to know how to identify erroneous information. There is a need to understand the information behind the data, like the organization's strategic objectives for the project, or where things have gone off track, to really be able to make sense of the data.
Project performance reviews	Regular meetings are required to monitor and control projects. Meetings are an effective way to collectively review project performance data and for managers to get deeper insight on project performance. Typically, project teams meet weekly and senior management or

Method	Explanation
	executives meet monthly to review project performance data.
Project performance measures	The results show that the top three performance measures used by organizations for reporting are, cost, schedule and risks/issues. Other common measures are health and safety (H&S), earned value measurements, forecast 'schedule to complete' and forecast 'cost to complete'.
Project reporting	The results show that project performance data is collected from project managers, contractors, site teams, cost controllers, planners, photos, drone footage as well as from the PMIS. The data is often pulled together into an MS Excel, MS Word or MS Power Point document to compile monthly project reports. Generally, reports contain graphs and colors to illustrate the data. Reports are typically created for management executives or clients.

4.3 The "ideal" SPMIS

This section investigates several of the most important characteristics for the ideal SPMIS based on information obtained from the research participants. The characteristics for the "ideal" system are summarised in the Table 10.

Table 10. Characteristics of the ideal SPMIS

Characteristic	Description
Increasing efficiency and time savings	The system should save the user time so that minimal man-hours are required to manage the system. There is no question that the data generated from PMIS is useful to the organization however it is always a time versus benefit trade-off. The research results show that some organizations purposely choose not to use sophisticated systems due to the time involved to operate them. System functionality is not always the problem but rather the time required to use the systems. Upload and download speeds were also mentioned as a problem.
Accessibility to project information	The system should have all the information in one place which is easy to store and retrieve. The system should provide easy access to good information so that people are empowered to make informed decisions on projects.
Automated data capturing and validation	The system should be able to either capture data automatically or automatically validate any of the data being captured or fed into the system. The systems are only as good as the quality of the data being fed into them. Data capture should be made as easy and seamless as possible, as data capture remains a problematic area in projects due to the human factor where data may be manipulated or entered incorrectly.
Flexibility & adaptability	The reporting system should be easily adaptable to present different information to different stakeholders, even to the extent where the same data can be customized and presented in different formats like tables or graphs. The system should be adaptable to organizational business processes as well as to each project's diverse requirements. Software should also be adaptable as the project is executed and requirements change.
Simplicity of system	The system should be simple enough to be used by the wider organization and not only by specialists who are trained in each specific software application. An integrated system is required, that everyone can interpret. Software functionality is often not the problem but rather the availability of expertise required to use the software to its full functionality.
Intelligence	The quality, quantity and the format of data are three important factors that will enable machine learning in projects. This data can be leveraged through machine learning to monitor the performance of projects as well as automate many project management functions. The challenge however lies in the SPMIS having enough intelligence to understand the complexities of each project, and to let the system operate autonomously with limited human interaction.

4.4 SPMIS conceptual model

A new proposed conceptual model is presented in Figure 2, which was developed using the findings from this research.

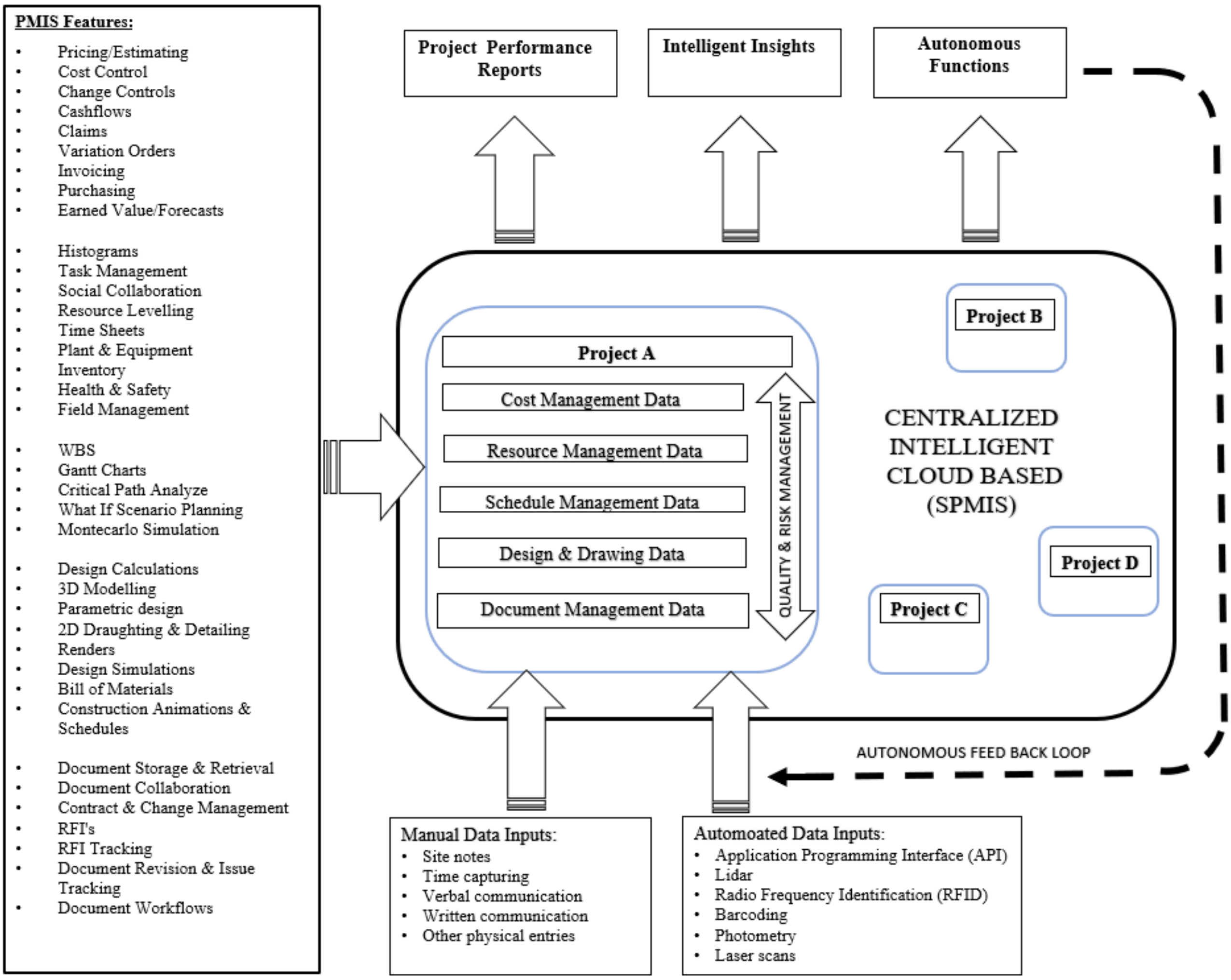

Figure. 2. New proposed SPMIS conceptual model basic architecture

The various PMIS functions are listed in the left-hand column in Figure 2. These functions can be completed by multiple PMIS applications and are categorized into five main categories, namely, cost management, resource management, schedule management, design and drawing, and document management. These categories are aligned with The PMBOK Guide [8]. Except for the category of design and drawings, it was evident from the research that the project organisations who completed engineering in house made use of sophisticated 3D design software which was integral to their operations. These systems often had additional functionality known as building information modelling (BIM) allowing real time data sharing and collaboration over the life cycle of the project. The BIM systems can have a time dimension (4D) and a cost dimension (5D) as well as other relevant project data linked to the model as part of the BIM integrated project delivery approach [26].

The conceptual model is designed to be flexible whereby different software applications can be used for individual projects, depending on the project's requirements. The results from the industry interviews show that typically quality management and risk management are not separate PMIS applications, but rather that use of PMIS helps improve quality and reduce risk. For example, document and workflow PMIS can improve quality on projects by ensuring that documents are reviewed and approved and then distributed to the correct people on the project team. The same could be said for risk management, using PMIS to support and improve the management of projects across the different functional areas naturally leads to risk mitigation.

The sources of data are fed either manually or automatically into the system. Manual data entry requires a user interface to capture and enter data while automated data capture is data that is fed into the system without requiring any external human input. One example could include 3D laser scans that sync with design models and automatically update the project schedules. The autonomous feedback loop should have the intelligence to automatically manage project data and automatically complete administrative tasks to maximise the utilization efficiency of project resources. The autonomous interaction via feedback loop and the automated data entry is unique to the new proposed SPMIS model as well as the emphasis on project reporting at a project and multi project level.

The heart of the SPMIS is the centralized cloud-based data management system. Where data from multiple projects can be fed into the system. The centralized SPMIS is built on the fundamentals of artificial intelligence, which uses artificial neural networks and machine learning algorithms to detect patterns in project performance data and provides these insights to the project stakeholders. The SPMIS should handle many different types of data and make all data easily accessible and visible in one location. Finally, the system should present data as project reports in ways that are meaningful and easy to interpret like graphs, charts, and diagrams to help project stakeholders make more informed decisions while monitoring project performance.

5. Conclusions and recommendations

5.1 Conclusions

The study indicates that there are many different types of PMIS, which fulfil or support various project functions. There is no single application which caters for all the required project functions, nor is there one PMIS solution that fits all types of projects. Most of the organizations' sampled selected PMIS based on the system that they felt best served their needs in each functional area. This is supported by Rautenbach and Schutte [15], who recognized the challenge of PMIS selection and developed a software selection tool to help organizations select the best suited PMIS. Many organizations integrate data manually across applications which is time consuming and open to data manipulation or misalignment. The organizations who manage many large projects use centralized PMIS systems like MS Share Point. The concept of the centralized data management system in this research is aligned with the conceptual models proposed bay El-Omari and Moselhi [20] and Zamani et al. [21].

The research indicates that PMIS functionality is not the real problem but rather the amount of time and skills required to operate the systems and keep the data up to date. In some cases, the effort required to use these systems outweighs the benefits realized from them. There is high variability of PMIS utilization in industry (based on the industry interviews) this may be due to the limited sample size.

It is recommended that larger sample sizes be utilized in future studies and that these studies should primarily focus on large organizations managing mega projects.

The research highlighted the link between project performance monitoring and PMIS integration, as integrated systems help break down information silos and improve the quality and efficiency of project reporting. The finding that organizations produce monthly project reports, containing mainly scheduling, cost, risk and earned value project performance data supports the literature [10].

The research indicates that MS Projects is the most used software application for project scheduling. This corroborates the findings of Kostalova et al. [4] and Raymond and Bergeron [27]. The results show that Primavera has the most functionality and advanced features, these findings are supported by the Kostalova et al. [4], who came to the same conclusion after doing a similar study. Primavera's strengths include its well-developed project portfolio capabilities where resources can be managed and levelled across multiple projects.

Ultimately a new conceptual model for a SPMIS was developed based on the literature review, industry interviews and PMIS software review. The new model is unique in that it covers more PMIS features than the existing models and includes an automated feedback loop for improving the utilization efficiency of project resources. The model is limited in that it only provides a basic architecture, the complexities of incorporating the many qualitative aspects of project performance and success factors are not incorporated into the model like environmental management and stakeholder relations.

5.2 Recommendations

The pace of digital technological progress is advancing rapidly, driven by the demand from industry as well as governments for better PMIS. Therefore, it is recommended that the model be tested as new PMIS technological breakthroughs occur. The most promising areas for breakthrough technologies lies in the application of AI in PMIS as well as automated data capturing from job sites. The application of these technologies would remove some of the major obstacles that are experienced with current day PMIS. Firstly, AI could be used to process the vast amounts of data generated during a project, identify patterns and anomalies in projects which cannot be comprehended by human cognition. Then it could communicate this information back to project stakeholders and team members, providing insight and actions to follow. This tool could be used by project managers to optimise the allocation of scare resources in the most efficient way. Secondly, new computer vision or scanning technologies could be used to monitor and assess site progress and feed this data automatically into the SPMIS. It is recommended that further study be done in these areas as they relate to practical implementation and integration into the SPMIS.

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