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UNDERSTANDING THE INFORMATION SYSTEMS INFRASTRUCTURE OF ENGINEERING SMEs

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Abstract

It is widely accepted that information is critical for the operation and commercial success of any organisation. For engineering SMEs, which are highly dependent upon the effective management of information and knowledge to gain competitive advantage, this is a particularly important issue. One of the critical components for improving information management within an organisation is the development and implementation of an integrated information systems infrastructure. This is an infrastructure which supports not only the business processes but also the activities of design and manufacture, and can considerably improve the responsiveness of the organisation and also significantly reduce internal waste. However, the creation of an integrated infrastructure is rarely achieved. This is generally because of a lack of understanding of the functional requirements of the organisation and the relationships between the various elements of the infrastructure. To address these issues, this paper presents the results of an in depth study of the information systems infrastructure of ten engineering SMEs. From this study, a generalised model of the functional elements of the infrastructure is developed. This provides a unique reference model against which SMEs can compare and contrast their current infrastructure, and elicit the understanding necessary to develop and plan a more integrated infrastructure to better support the organisation.

Keywords: Software, design information, manufacturing information, information management, communication

1. Introduction

Information and systems for its management are an essential and integral part of the resources and infrastructure of any organisation. Information is critical for the undertaking of many business processes, the production and delivery of products and services, and the support of an organisation's core competencies [1]. To support the management of this wide variety of important information, academia and industry have researched and developed a large number of systems. These information systems incorporate tools, techniques, procedures and methods which are based on standard languages, recommended processes and accepted practices. The overall aim is to improve the availability, accessibility and visualisation of information and also where appropriate automate routine information based operations.

As previously stated, information is necessary for a wide range of functions. This is particularly the case for engineering organisations where a wealth of information is also necessary for processes of design and manufacture. As a consequence of this variety and diversity many separate information systems have been created. These include finance systems, payroll systems, document management and product data management systems etc. Furthermore, these systems have, in the past, been developed in relative isolation of one another and as a result are frequently unable to perform in an integrated manner. The major

efforts for the creation of an integrated system or unified information systems infrastructure have been in the area of MRP and ERP systems. These implementations often require significant business process realignment, high levels of invest in the latest hardware technologies and systems architecture, and significant training and learning for the organisation. For these reasons, the uptake of such systems has been more prolific in larger organisations.

In contrast to this, many small medium-sized enterprises (SMEs) cannot implement and manage such large-scale solutions. If only because of their limited resources and their often unique business processes. In general, the IS/IT resources of SMEs and in particular, engineering organisations, have evolved incrementally overtime to meet the parallel needs of accounting and manufacturing, and changes in the level of business activity. In many cases, there is no evidence of a formal strategy relating to IS/IT. System elements are acquired and implemented on an ad hoc basis often driven by necessity rather than planning. This lack of planning frequently results in new elements which only replace a current problem with a new less well understood problem.

Poorly functioning information systems can have a significant impact on the responsiveness of the organisation and hence performance. For example, engineering organisations need to be able to provide accurate, competitively priced quotations for new systems which can be produced within the capabilities and current capacity of the organisation and that generate an appropriate contribution to profit. In addition to the above, a poorly functioning information systems infrastructure can result in a significant amount of internal waste. This waste typically manifests itself in the form of time spent on information intensive activities. Such as finding information, manually transferring information between systems and verifying information or updating information.

In order to address these issues there is a need for improved planning and strategic development of the information infrastructure of engineering SMEs. A critical element in undertaking this activity is the generation of a fundamental understanding of the existing information systems infrastructure and the evaluation of its performance. The subject of assessing and evaluating information systems has received some attention [2, 3]. The techniques that have resulted from this previous work have been important for the development and implementation of more effective IS strategies within large organisation. However, this is generally ineffectively carried out or not undertaken at all in SMEs; as managers consider it takes too long and perceive little or no added-value arising from the process [4]. Assessing the benefits of IS/IT is also difficult due to the often long-term and intangible benefits [5].

To address this important issue, the work reported in this paper investigates the information systems infrastructures currently implemented in a range of engineering SMEs. This includes the functional elements of the information systems infrastructure necessary to support business processes and the core activities of design and manufacture. From this understanding, a generalised model of the information systems infrastructure in an engineering SME is established and an understanding of the relationships between the various elements is developed.

2. Engineering SMEs

The reliance of organisations on information and the importance of effectively managing it within engineering organisations have been highlighted. One of the key reasons for this is the substantial amount and wide variety of information and information types necessary to

undertake the activities of design and manufacture, and support a product over its lifetime. For example, within engineering organisations information relating to, or represented by, CAD files, documents, emails, correspondence, suppliers literature, analysis models, service reports, meeting records, manufacturing schedules, lead time, procurement information and attendance all need to be managed. Some of this information is very structured and held in formal information systems. These may include product data management (PDM) or customer relations management (CRM) systems. In contrast, some of the information is less structured and as a result is managed by less formal means such as log books, spreadsheets and service reports. For the purpose of this study only the formal structured information systems are considered.

The dependency of engineering organisations on information is particularly the case for machinery manufacturers operating in the Advanced Engineering [6] sectors. This includes organisations manufacturing processing, packaging, pharmaceutical, food technology and measurement equipment who deal with a large number of individual customers and a wide variety of suppliers. These organisations are highly dependent upon systematic knowledge based resources to achieve and sustain competitive advantage [7]. Such organisations can be thought of as knowledge based engineering SMEs and it is this important class of organisation that is considered in this work.

3. Research Methodology

In order to inform a general model of the information systems infrastructure of an engineering SME ten organisations have been investigated in some detail. These organisations were based in the South West of the UK and selected using the formal definition of an SME; 'an organisation with a workforce of up to 250 employees and, or a turnover of less than £28 million' [8]. In particular, a range of organisations was selected to provide a series of enterprises distributed over the bounds of the criteria which define an SME. Turnover against the number of employees for each organisation is shown in figure 1.

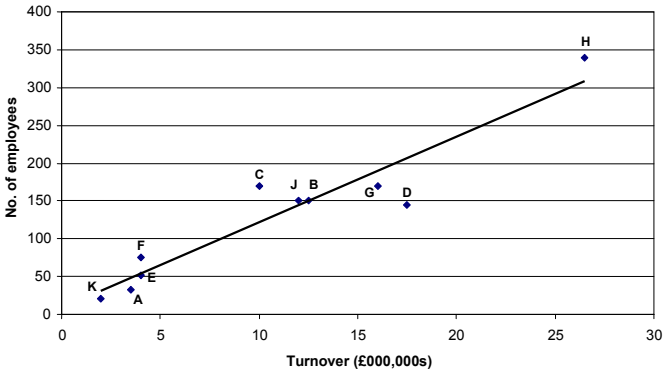

Figure 1 Turnover against number of employees

Empirical data was collected by virtue of two approaches. The first of these involved a detailed audit of the various elements of the IT/IS infrastructure. This included computing equipment and all software. The results of the audit were then used to undertake semi-structured discussions with senior personnel to explore the functions of the various elements of the information systems infrastructure and establish the relationships between them.

4. Information systems in engineering SMEs

As previously stated the information systems of ten engineering organisations were studied in some detail. The approach taken in this work was to establish and audit the various functional elements of the information systems infrastructure rather than purely identifying different computer based systems within the organisations. These functional elements do not have to be supported by, or limited to, a particular computer based system. However, it will be seen that particular elements are frequently supported by a single dedicated system.

4.1 The key functional elements

The study identified twelve key functional elements of the total information systems infrastructure which are necessary to support the business processes of an engineering SME and the activities of design and manufacture. These elements are those identified by, and implemented within, the various organisations. The twelve elements and their respective function(s) are summarised in figure 2. These elements can also be grouped under four business functions: production and planning, design and manufacture, finance and administration, and sales.

	Business function	***Functional element***	***Core purpose / function***
1	*Production and planning*	**Materials / Manufacturing Resource Planning**	Managing and monitoring stores, purchasing, procurement and logistics
2		**Job Management System**	Management and monitoring of where work is in production and the status of particular projects
3		**Manufacturing**	Scheduling of component manufacture and monitoring of process status and capacity
4	*Design and Manufacture*	**Computer-Aided Design**	2D drafting and 3D modelling software
5		**Product Data Management**	Managing CAD models and assemblies (2D and 3D) and other documents which relate to specific projects
6		**Computer Numerically Controlled**	Control of manufacturing equipment
7	*Finance and administration*	**Personnel**	Records of employees, their contact details and training status / proficiency
8		**Time and Attendance**	Monitoring employees' time at work and also monitoring manufacturing and production times for particular operations and jobs
9		**Payroll**	Control payments to employees and subcontractors
10		**Accounting**	Preparation and management of budgets, job costing, monitoring costs and cash flow
11		**Quotations and Reporting**	Preparation and production of management accounts, budgets, forecasts and costs
12	*Sales*	**Customer Relationship Management**	Management of customer and supplier information. Often including all correspondence and records of contact

Figure 2 Functional elements of the IS infrastructure of engineering SMEs

The range of computer based systems implemented to support these twelve functions are shown in figure 3. This also shows the relative levels of implementation for these twelve functional elements. These levels range from 40% to 100% of the total possible elements with an average level of 70%.

	Functional elements of the information systems infrastructure														
Organisation	Planning & Production			Design & Manufacture			Finance & Administration					Sales	No. of elements	Percentage implementation	No. of different systems
	MRP	JMS	Manufacturing	CAD	PDM	CNC	Personnel	Time & Attendance	Payroll	Accounts	Quotations / reporting	CRM			
A		Navison		AutoCAD 97, 2000, 2002, LT					Sage	Sage Line 50	Navison (Now use Excel & Access)	Goldmine	6	50.0	6
B	Visual		Visual	AutoCAD 13, AutoCAD LT, Solidworks	SmartTeam V5		MS Excel		External	Visual	MS Access	MS Access	9	75.0	7
C	Swift - Industry 2000	Swift - Industry 2000		AutoCAD 13 &14, SolidWorks, Raddraft	PDMWorks		Vizual Systems - Personnel Manager		Teamsprint	Sage Line 50	Crystal / Seagate		8	66.7	7
D	SYSPRO	SYSPRO / MS Excel	SYSPRO/T-cards	AutoDESK Inventor, AUTOCAD 2000			MS Excel	MitreFinch	SYSPRO	SYSPRO	SQL Reporting, MS .NET bespoke	SYSPRO	10	83.3	7
E	MS Excel	MS Excel		Mech Desktop 3 & 4, Inventor & Auto CAD 14	MS Excel	Fanuc Mastercam		Timelink	ACCESS accounts	Crystal / Seagate	MS Excel	MS Access	10	83.3	10
F	MS Excel	Workticket	Scan Data	Artios CAD	MS Excel	ELCEDE	MS Excel	Timeware	ACCESS accounts	ACCESS accounts	Adobe & MS Excel	MS Excel	12	100.0	11
G	SYSPRO	SYSPRO		AutoCAD 14	MS Access			Dataware	Equator / VAX	SYSPRO	Crystal / Seagate	MS Access	9	75.0	7
H	MFG Pro		MFG Pro	Catia V5	TeamPDM			Dataware	Pegasus	MFG Pro	MFG Pro	Goldmine	9	75.0	6
J	MS Access / Project		MS Access	AutoCad / Inventor					Sage Line 100	Sage Line 100			5	41.7	5
K		JobShop	JobShop	AutoCad 14		XYZ (BOB-CAD)			Sage Line 50	Sage Line 50			6	50.0	4
												Average	8.4	70	7

Figure 3 Functional elements of the information systems infrastructure across engineering SMEs

For the majority of functional elements their purpose or function can be clearly identified. However, the distinction between certain elements is more difficult where production and planning related components are considered. In particular, MRP, JMS and Manufacturing elements. Whilst all organisations possess at least one of these functional elements, only three organisations identify all three individual elements as components of their total infrastructure.

Notwithstanding this, nine organisations identify two of these elements as separate components of their infrastructure.

One of the reasons for this functional overlap or apparent duplication between elements of the information systems infrastructure is the relationship between the various functions. Very often the computer based system implemented to deal with a particular function is capable of dealing with related groups of functions, such as those associated with production and planning. As a result of this, organisations and users frequently classify a particular computer based systems and its entire functional capability as a single element of the infrastructure. For example, in the case of planning or production, two thirds of the organisations where two functional elements can be identified, use only as single computer based system to perform both functions. This inability to differentiate between computer based systems and the various elements of functionality can significantly frustrate the capacity to plan and develop the information systems infrastructure.

In addition to the close relationship between elements of production and planning, there is also a natural overlap between accounts and payroll. For example, in five out of the ten organisations the same computer based system is used to perform both functions. It is also interesting to note that one organisation out sources the payroll function, which is an interesting development given that this requires data for over 150 employees to be transferred externally on a weekly basis.

Although there are overlaps between functional elements of the information systems infrastructure the results of the study reveal that a large number of these different functional elements are clearly identifiable. In particular, for six of the ten organisations it is possible to identify at least nine different functional elements. Furthermore, in the case of two of these organisations ten separate elements can be identified, whilst for one organisation all twelve elements can be identified. In fact, the average number of functional elements of an information systems infrastructure is just over eight, which arguably requires a large number of different computer based systems in order to fulfil these requirements.

4.2 Computer based systems

In the process of establishing the functional elements of the information systems infrastructure the range of computer based systems implemented within each organisation was evaluated. The various computer based systems (software tools) necessary to perform the different functional elements within each organisation are shown in figure 3. This reveals that two of the organisations maintain as many as ten or more different computer based systems in order to fulfil the various functional elements. In fact, the organisation where twelve separate functional elements can be identified implements eleven different computer based systems. In general, the average number of different computer based information systems maintained by an organisation is seven, covering planning and production, design and manufacture, finance and administration, and sales.

The study also highlights three core functional elements and associated computer based systems which are implemented across all the organisations. These are accounts, payroll and CAD and represent the minimum set of information systems necessary to operate and support an engineering SME. These three elements are perhaps unsurprising given that there are legal and statutory requirements governing accounting and payroll, and the fact that CAD systems are now a prerequisite for the design and production of any engineering system.

The information provided by the participants also suggests that many organisations are dropping specialist software in favour of simpler systems created in-house using desktop office software, and in particular, Microsoft Office and Adobe. The most common functional

elements of the information systems infrastructure which are fulfilled by such applications are quotations and reporting, and then Customer Relationship Management (CRM) followed by personnel and product data management. All of which lend themselves to spreadsheets, relational databases and linked reports (linked reports use technologies such as Microsoft Object Linking and Embedding to dynamically link data and objects across different files. One of the reasons for the widespread use of Office applications is the relatively low cost combined with the increasing level of functionality provided by general office applications. Furthermore, generic templates for supporting various business functions are freely available and can be easily altered by proficient users, and therefore do not require expensive customization by a third party.

As previously mentioned, engineering organisations can maintain up to eleven different computer based systems to deal with all the various functional elements. The reasons for this variety and diversity, which often address only a specific element of the IS infrastructure, can be attributed to a number of factors;

- the typically incremental evolution of the information systems infrastructure,
- the relatively isolated development of computer based systems by vendors,
- the often high cost of new implementation
- the organisational structure.

In particular, the traditional organisational structure of engineering SMEs can lead to two potential issues; key decision makers can posses a limited view of their department or their organisation's activities, the perceived viewed of many departments that their systems are largely independent and intended solely to support their activities and processes. It is therefore particularly important to establish and understand the dependencies and relationships between the elements of the IS infrastructure within these organisations.

4.3 Information and functional dependencies

As has been previously discussed twelve key functional elements of the information systems infrastructure of engineering SMEs have been identified. In addition to understanding each of these elements, described in section 4.1, it is also important to understand their relationships. More specifically, this work deals with information dependencies and functional relationships. This includes overlaps in terms of functionality where one or more elements and associated computer based systems may be used to achieve a specific function or purpose, and dependencies were common information (data) is produced by, or required by, a number of different elements. These dependencies were explored during the semi-structured interviews with personnel at each organisation.

The key elements of the information systems infrastructure and the various relationships are represented graphically in figure 5. In particular, two elements of the IS infrastructure; Quotation and Reporting, and Accounting require or utilise information from a large number of other elements. For example, Quotation and Reporting systems typically require or use information from eight different elements and their associated computer based systems; MRP, JMS, Manufacturing, Time & Attendance, Payroll, Personnel, CRM and PDM elements. Accountancy functions may also be dependent upon these elements with the exception of PDM.

When considering the entire information systems infrastructure nine key dependencies have been identified. These critical relationships or dependencies (A to I) are summarised in figure 4 and highlighted in figure 5. Although the dependencies are relatively high level they

establish the links between functional elements which ultimately need to be satisfied or handled by the various computer based systems implemented to perform the individual functions. In particular the underlying nature of these dependencies leads to two important considerations; procedures for automatic information exchange between computer based systems, and the use of a common representation for information elements where information form different systems needs to be combined and manipulated for a specific purpose.

	Information Systems	***Dependency***
A	**CNC and CAD**	Creation and exchange of machining instructions
B	**CAD and PDM**	Management and organisation of part drawings and documentation
C	**MRP and PDM**	Creation, management and completion of Bills of Materials
D	**Manufacture, MRP and JMS**	Scheduling and monitoring of production
E	**Manufacture, MRP and JMS and Accounting**	Costing and variance analysis of manufactured components
F	**JMS and Time & Attendance**	Monitoring and analysing time spent on manufacturing activities for particular jobs
G	**Time & Attendance and Payroll**	Calculating payment for employees
H	**Payroll and Personnel**	Personal information necessary for payment
I	**CRM, Quotation and Reporting, and Accounting**	Provision of accurate quotes for particular customers

Figure 4 Key dependencies between elements of the IS infrastructure

4.4 A model of information systems infrastructure in engineering SMEs

In the previous section, what can be thought of as the 'internal' elements of the information systems infrastructure are dealt with. These internal elements are implemented within and used by the organisation. However, it is also important to consider external elements. For the purpose of this work, external systems are defined as those which are maintained by a particular organisation but either relate to, or are implemented for, another organisation. For engineering SMEs these external organisations typically include suppliers and customers.

From the results of the study a number of external elements and internal systems which possess an external interface can be identified. These include Email systems, the Internet, Electronic Catalogues, MRP systems, Extranets and Electronic Data Interchange. These elements are also shown in figure 5. A number of these elements have been previously defined in section 3 and their inclusion as external is merely enabled by computer software and hardware which allows access to elements of the internal information systems infrastructure. However, Catalogues, Product Configurators and Extranets can be considered as separate elements of the total IS infrastructure. Electronic catalogues [9] and product configurators [10] are becoming increasingly common as organisations try to rationalise product ranges and smooth production runs. These systems typically represent the current range of products and possible configurations, and often require information from the PDM system and often MRP system, particularly if current stock levels are included. Extranets and EDI systems incorporate some similar functionality to the electronic catalogue but may also include stock levels and lead times. Furthermore, these elements often provide customer specific information such as production progress and anticipated delivery times. These

systems therefore frequently require or use information managed by the MRP system and JMS.

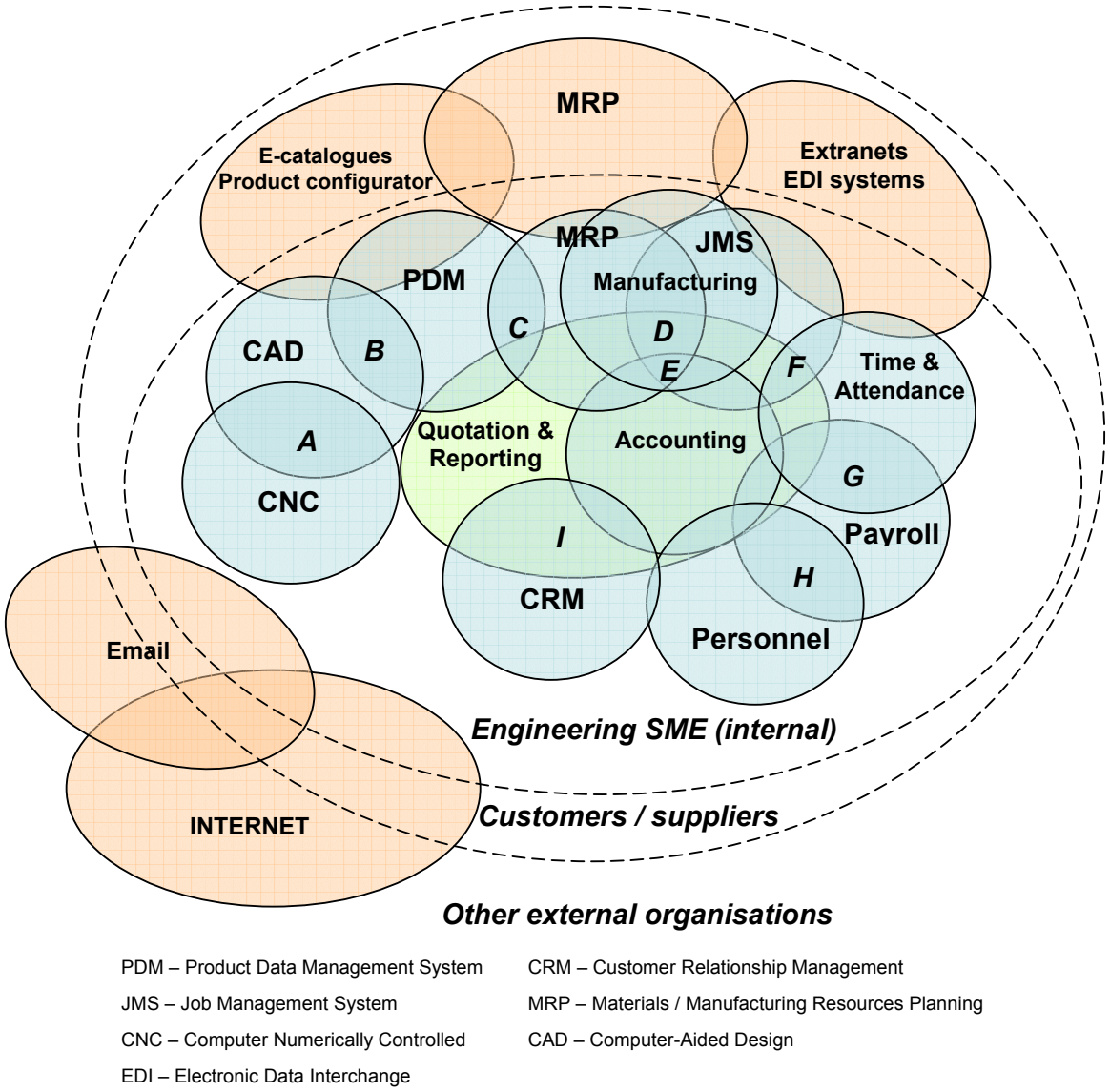

Figure 5 A generalised model of the functional elements of information systems in engineering SMEs

This generalised model represents an understanding and unified view of the full range of functional elements of an information systems infrastructure for engineering SMEs. The model also highlights the large number of relationships between the various elements, which need to be supported if the information systems infrastructure is to operate in an integrated manner. Such a fundamental understanding is essential for the effective planning and development of the information systems infrastructure for this class of organisation. The unified view helps to overcome the issues associated with organisational structure by providing an understanding of wide range of systems and relationships between them. In particular organisations can identify elements that may be required and elicit an understanding of the interactions and relationships which would need to be satisfied for the successful integration of additional elements into the infrastructure. The model also provides important

functional requirements for the evaluation and selection of computer based systems offered by vendors, and may also be considered to help inform the future development of these computer based systems.

5. Conclusions

This paper discusses the importance of the efficient and effective management of information within engineering organisations, and highlights the critical role of information systems in achieving this. It is also shown that whilst there is a significant amount of support for large organisations, SMEs have been comparatively neglected. To address this issue, the information systems infrastructures of ten engineering SMEs have been investigated in some detail. The study reveals twelve key functional elements of the information systems infrastructure which support the business processes and the design and manufacturing activities of engineering SMEs. These twelve elements are used as the basis for developing a generalised model of the information systems infrastructure of engineering SMEs. It also highlights the minimum set of elements necessary for basic operation. This minimum set of elements includes accounting, payroll and CAD, which is perhaps unsurprising given the statutory requirements governing accounting and payroll, and that CAD systems are a prerequisite for the production of any engineering system or product.

The various functional elements will ultimately be performed by a number of computer based systems and as such an understanding of the functional elements is essential for effectively generating the requirements for the computer based systems. Importantly, the study also establishes and characterises the various dependencies between the functional elements. Once again it is desirable that these dependencies be supported by the various computer based tools, in order to reduce waste and improve the responsiveness of the organisation.

The general model provides an understanding and a unified view of the various functional elements of the information systems infrastructure and their relationships. An understanding of the information systems infrastructure at an organisational level is central to the development and implementation of a more unified and integrated infrastructure which ultimately better support the needs of the engineering SMEs. In particular organisations can identify elements that may be required and elicit an understanding of the interactions and relationships which would need to be satisfied for the successful integration of additional elements into the infrastructure. The model also provides important functional requirements for the evaluation and selection of computer based systems offered by vendors, and may also be considered to help inform the future development of these computer based systems. This can also be used as a reference model for organisations to audit their systems and processes.

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