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The Definition of an Assessment Framework for Information Systems Issues for Agile Manufacturing

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***Abstract* - Information systems are identified as enablers of agile manufacturing. Despite the continuous utilisation of IT/IS applications, there is growing evidence that information technology/systems do not deliver their expected benefits. In this work we investigated three main issues related to information systems: competitive bases-general goals, development and infrastructure. We tested our approach with information gathered from 14 manufacturing companies based in the UK. The results of this work make it possible to link information systems to other dimensions of agility like competitive bases and agility attributes to define an assessment framework.**

I. Introduction

Manufacturing organisations are facing an ever increasing change in their business environment. These changes are represented by an increase in competition, changes in customer requirements, changing business objectives to mention just a few. In order to cope with these challenges, manufacturing organisations must become agile. Agility means the capability of operating profitability in a competitive environment of continually and unpredictably, changing customer requirements [1]. The current literature identifies information systems as enablers of the concept of agile manufacturing [1], [2], [3]. Moreover, the introduction of new tools in information systems enables the execution of new ways of work not experienced before (e.g. concurrent design operations). Authors agree that information systems lend competitive advantage to organisations, describing some characteristics of information systems to support the challenges facing manufacturing organisations [4]. On the other hand, parallel to the development of sophisticated information systems, we find the problem of information systems evaluation [5]. The literature shows few examples of the evaluation of information systems in manufacturing. In fact, different researchers follow different approaches in evaluating manufacturing information systems. Some of them evaluate the benefits of information systems in the entire organisation [6], others, like Kelley [7], measured the productivity achieved through the introduction of automated devices focusing on the upgraded process instead of the company as a whole. If examples of information systems evaluation in manufacturing are few, the allusion of practical guidelines for information systems requirements, specifications and assessment to support agility are seldom mentioned in the literature, making imperative the development of practical guidelines for today's manufacturing needs of the organisation.

To ensure the success of information systems in supporting agile manufacturing it is necessary to define a set of requirements. Dove [8] was the first researcher to address the importance of information systems as a critical business practice for agility. However, little empirical research is available in the literature on identifying information systems properties to support agile practices. This work addresses the current development of information systems in a study that included 14 manufacturing organisations and the importance of agility issues in information systems to support the development of business operations. The framework of our study is presented in figure 1.

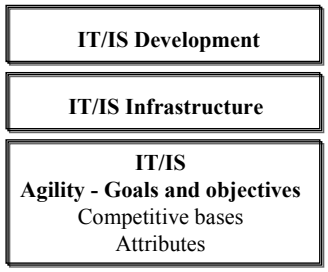

Fig. 1 The Basic Framework for IS evaluation for agility.

This framework identifies first the evolution and development of information systems with its related infrastructure, followed by the identification of a series of competitive bases and attributes in a single company.

II. Information Systems and Manufacturing

The importance of information systems in manufacturing is growing continuously. Billions of dollars are spent in infrastructure (systems related to e-commerce, internet), planning (ERP –Enterprise Resource Planning, APS – Advanced Planning and Scheduling) and execution (systems that manage company's transactions).

The classification of information systems for this work is based on the evolution experienced by manufacturing information systems over the last few years. The main characteristic of this evolution is the growing complexity of information systems to support new ways of collaboration. Table I represents this progression based on a classification presented by the Next Generation Manufacturing Project [9].

TABLE I
INFORMATION SYSTEMS EVOLUTION

Stage	Information Systems Applications for Manufacturing
1	MRP, manufacturing operations, material handling.
2	MRPII, financial and planning modules to assist manufacturing operations.
3	CIM, EDI, intelligent scheduling, integrate different internal and external activities of the company.
4	ERP, Enterprise integration, systems that address not only the information needs of manufacturing but also the information needs of the enterprise.
5	E-commerce, active agents, systems that addresses the needs of customers and suppliers.

The description of the current state of development of an information systems structure, is the first step in the identification process of agility issues that affect other dimensions linked to the operation of the organisation.

III. Information Systems Structure to Support Agile Manufacturing

The information systems characteristics in agility are based on a set of issues identified by Dove et al. [4], Boar [10] and the NGMP[9]. They cover the utilisation of information technology components to solve unique business needs in an overall corporate structure. These issues are classified as proactive and reactive. Being proactive means the ability to predict business trends. On the other hand, reactive means the power to react to changes in the business environment.

Proactive issues refer to those capabilities that are at the very focus of today's competitiveness. These issues include:

1. Creation. Designing an infrastructure of global interaction standards that permits unique local solutions.
2. Augmentation. Improving the standards without impacting operational applications.
3. Comparison. Watching developments in information technology applications.
4. Migration. Anticipating future electronic interactions with customers and suppliers.
5. Modification. Adding new standards to the infrastructure without conflict with other existing implementations.

Reactive issues are identified as those characteristics necessary to have at an entry level in any industry. These issues include:

6. Correction. Fixing an infrastructure that is overly restrictive.
7. Variation. Accommodating variations to the infrastructure standards for unique requirements.
8. Expansion. Expanding the internal user community and number of supported business units.
9. Reconfiguration. Moving unique solutions from one business unit to another.

Fourteen manufacturing organisations were asked to identify their information systems applications according to table 1. Respondents occupy positions in manufacturing management, people that are users of information systems applications to support the company's operations. Asking the final user to evaluate the information system structure gives the opportunity to know how well information systems help him/her to accomplish his/her daily activities.

The respondents were asked to give their assessment to a set of nine statements based on the nine issues described above using a 5-point Likert scale, where 1 stands for completely disagree, 2 for not completely disagree, 3 for not agree or disagree 4 for not completely agree and 5 for completely agree. The following statements represent the nine issues of information systems infrastructure asked of the companies.

1. Information technology in the enterprise provides an environment that promotes the development of customised solutions based on unique business needs.
2. The information systems infrastructure ensures continued viability as components are improved, added or removed.
3. The organisation constantly monitors developments in information systems in our industry and bechmarks it against other industries.
4. Our information technology infrastructure anticipates future electronic interactions with customers and suppliers.
5. New standards can be upgraded or modified to the information systems infrastructure without breaking other applications.

6 In case of problem, fixings to the information systems infrastructure are in short periods of time.

7 It is possible to make variations to the information systems standards in order to accommodate unique requirements.

8 The information systems function is in constant expansion to support all business units and user community.

9 Our information systems infrastructure supports the portability of solutions from one business unit to another.

IV. The Definition of the Characteristics of Information Systems for Agility.

The companies that took part in this work come from different business backgrounds. In fact there were three companies from the automotive sector, three from aerospace, four from electronics and semiconductors and four from general manufacturing (ceramics and plastics). At first sight it appears that the nature of the business determines the complexity of the information required by the organisation. Nevertheless, the heterogeneity of the companies surveyed gives the opportunity to appreciate in a wider context the

utilisation of information systems to the concepts introduced in the previous section.

A. *Information Systems Development*

The purpose of this section is to ascertain the current development of the companies according to the evolution of information systems in manufacturing. The first question addressed the development of information systems in manufacturing organisations. The respondents were asked to identify the current development of their information systems function within their organisation based on the evolution of information systems presented in table I.

The results of information systems development in manufacturing organisations show that MRP and MRP_{II} modules are still the most common information systems applications in manufacturing. Surprisingly for us, six of the 14 companies surveyed identified the presence of E-commerce and active agents applications in their information systems infrastructure, taking in consideration that in the utilisation of these applications manufacturing organisations lag behind the financial and services sectors. The results are shown in figure 2.

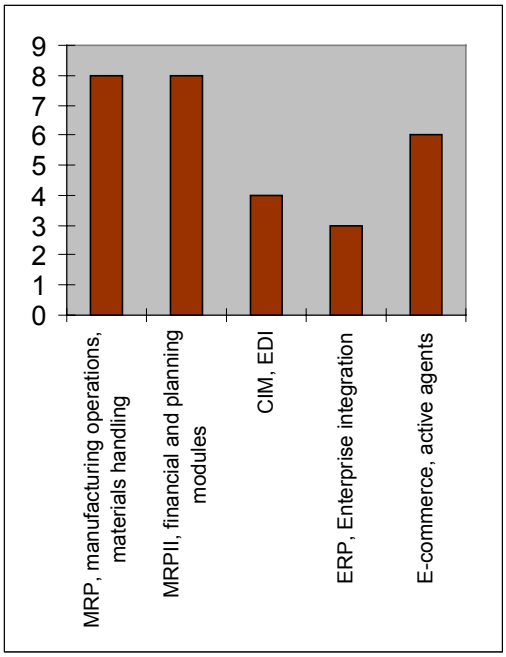

Fig. 2. Information systems development in surveyed companies.

Each bar represents the number of companies that identified the utilisation of a specific application within their information systems infrastructure (i.e. eight companies of the total of 14 identified the utilisation of MRP and MRP_{II} applications, three companies of a total of 14 work with applications identified with ERP). From the automotive companies of our sample, all of them identified the utilisation of e-commerce to support activities with customers and suppliers.

B. *Information Systems Structure*

In this section we used Kendall's tau-b to find if there is any correlation present between the issues presented in section III. Table II presents the most significant correlation factors identified using Kendall's tau-b.

TABLE II
KENDALL'S TAU-B RESULTS

Creation	Augmentation	0.654
Comparison	Migration	0.626
Migration	Modification	0.696
Correction	Variation	0.567
Correction	Expansion	0.519

The correlation coefficients found in this section reveal the close association of developing information systems for agile manufacturing, used to integrate business units and anticipate future business needs. It seems that all respondents agreed that a proactive policy, creation and augmentation showed correlation based on the results of our case study companies. Moreover, respondents clearly identified reactive statements very similar amongst them, showing correlation for correction, variation and expansion.

An analysis of the answers given to the questionnaire shows that augmentation and creation are the most important issues for information systems infrastructure to support agility. The results of this analysis are shown in table III.

TABLE III
INFRASTRUCTURE ISSUES MEAN

Statement	Mean
Augmentation	4.076
Creation	4
Migration	3.769
Reconfiguration	3.615
Comparison	3.461
Correction	3.307
Modification	3.230
Variation	3.153
Expansion	3

Moreover, the results of the three automotive companies that have implemented E-commerce modules within their IS infrastructure gave the highest scores to the properties of augmentation and creation (mean of 4.33). According to a report from the UK Department of Trade and Industry the automotive sector has been identified as a sector subject to increasing competition at national and international levels. Semiconductors and electronics which have implemented MRP_{II} and E-commerce modules identified creation and augmentation (mean of 4.0 and 3.75 respectively). Aerospace industries (currently working with ERP modules) identified Reconfiguration as the most important issue (mean of 4.33). General manufacturers (two of them working with e-commerce applications) identified creation and augmentation (mean of 4.0).

According to our results, the most important characteristics for an information systems infrastructure in terms of agility include augmentation and creation.

V. Building Suitable Framework for IS Assessment in Terms of Agility.

Once the characteristics for development and infrastructure have been determined the next step is the identification of supported characteristics in terms of agility. The framework introduced in this work tries to answer how to bring together issues that are related specifically to the characteristics of information systems to a more global assessment that includes intangible issues such as competitive bases. The framework identifies the current development of information systems within the organisation with the assessment of information systems issues to support agility.

The scope of information systems for agile manufacturing affects all the operations of the enterprise. Two dimensions that affect manufacturing enterprises are competitive bases and agility attributes [11], [12]. For our particular interests, figure 3 depicts how these elements relate to the concept of agility and information systems. Competitive bases constitute the top goals for agility, information systems and attributes.

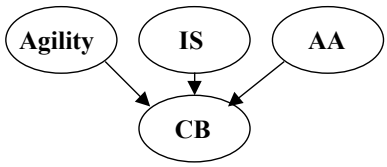

Figure 3. Competitive bases, agility, information systems and attributes.

The agility dimensions cover six competitive bases (speed, proactivity, quality, cost, innovation and flexibility) [11]. A description of them is given:

- Speed: concept-to-cash time or the time it takes to respond to perceived customer needs.
- Flexibility: the ability to adapt to variable customer requirements.
- Innovation: succesful exploration of new ideas for products, services and procedures.
- Proactivity: the ability to influence and predict market trends.
- Quality: products and services that satisfy customer expectations over their life-times.
- Cost: the expense of resources required to produce goods or services to satisfy a market need which are lower than those of the competition.

A set of 32 agility attributes identified in the literature of agile manufacturing [11], [13] were gathered in five groupings. These include: Organisation commitment to integration and co-operation -A1-, Culture of quality and responsiveness -A2-, State of technology to enhance flexibility and operations performance -A3-, Organisation commitment towards change -A4- and Education and welfare of human resources -A5-. Table IV, presents the attributes and groupings.

TABLE IV
Agile Attributes and Five Groupings

Organisation commitment to integration and cooperation - A1
Multi-venturing capabilities - A11
Encouragement of teaming with other customers – A12
Rapid formation of partnerships – A13
Strategic customer relationships – A14
Close supplier relationships – A15
Trust based customer and supplier relationships – A16
Enterprise integration – A17
Cross-functional teaming – A18
Concurrent execution of business activities – A19

Culture of quality and responsiveness – A2
Quality over product life – A21
Addition of value to products –A22
First time right designs – A23
Satisfaction of customer requirements – A24
Rapid development cycles – A25
Rapid response to changing market requirements – A26
Frequent new product innovation – A27
Customer-driven innovations – A28

State of technology to enhance flexibility and operations performance – A3
Technology awareness – A31
Leader in the use of current technology – A32
Using skill and knowledge enhancing technologies – A33
Use flexible production technology – A34
Open information environment – A35

Organisation commitment towards change – A4
Continuous improvement – A41
Embracing a culture of change – A42
Descentralisation of authority – A43
Learning organisation – A44
Bespoke business practice and structure – A45

Education and welfare of human resources – A5
Employee satisfaction – A51
Multi-skilled and flexible workforce – A52
Continuous training and development for Personnel – A53
Workforce skill upgrade – A54
Workforce empowerment – A55

Given this scheme, we focused in defining a general function for agility as presented in (1).

$$CB = f_{CB}\left(\sum_{i=1}^{n} A_{1n} + \sum_{i=1}^{n} A_{2n} + \sum_{i=1}^{n} A_{3n} + \sum_{i=1}^{n} A_{4n} + \sum_{i=1}^{n} A_{5n} \right) \quad (1)$$

Where $\sum_{i=1}^{n} A_{1n}$ is the sum of all the significant coefficients of the attributes identified for that competitive basis in grouping A1 , and so on for A2, A3, A4 and A5. CB is any of the six competitive bases we have defined for our model, S_{CB} –Speed-, F_{CB} –Flexibility-, P_{CB} –Proactivity-, I_{CB} –Innovation-, Q_{CB} –Quality- and C_{CB} –Cost-. The idea behind this approach is to identify the importance of

competitive bases with the concept of agility and information systems. These competitive bases constitute the goals-benefits of information systems. By identifying a number it may be possible to determine the most important competitive basis for a specific organisation.

The nature of the issues introduced in this section is intangible, so it is very difficult to define a specific measure for them. Moreover, the definition of an agility function for competitive bases and agility attributes by conventional methods is impossible. The most adequate way to define a function that includes the relationships between the issues of competitive bases and agility attributes in terms of agility and information systems is one that gives them weights. The definition of weights is fuzzy by nature. A membership function for agility is one that takes values from 0 to 1, making it necessary to define a scale of grades. The scale of grades is used to simplify operations and it is similar to others used in methodologies to evaluate tangible and intangible issues. This scale is shown in figure 4 and is utilised to identify the importance of competitive bases and attributes for a specific organisation with a specific information systems infrastructure. The fuzzy language values used to derive their fuzzy numbers are presented in table V.

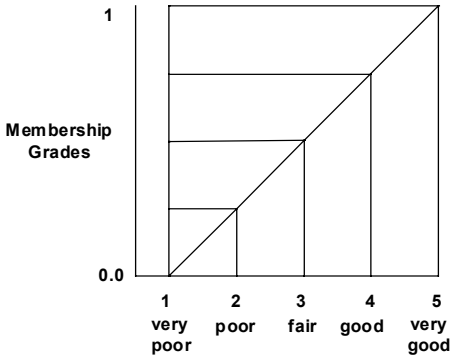

Figure 4 Agility assessment curve

TABLE V
LINGUISTIC VALUES REFERENCES

Linguistic values	Mean of fuzzy numbers
Completely Disagree (very poor)	0
Disagree (poor)	0.25
Fair	0.5
Agree (good)	0.75
Completely Agree (very good)	1

This is in complete agreement with the theory of fuzzy logic where a fuzzy set is a number $\mu_A(X) \in [0,1]$. Using the values presented in table V, we can construct an evaluation matrix to identify the most important competitive bases. To facilitate our task we have adapted a model developed by Cheng et al [14]. This method eliminates the utilisation of a scale of values that range from 1 to 9 using traditional AHP [15] or the utilisation of fuzzy numbers in complex matrices [16].

In this work the same companies of the previous section were asked to assess the importance of each competitive basis to information systems and the concept of agility. Furthermore, the companies were asked to assess the importance of each agile attribute in terms of competitive bases. We have used the above approach to identify the most important competitive basis of one of the organisations that answered our questionnaire.

We start constructing and evaluation matrix,. where S denotes the elements under assessment (CB, competitive bases) X_j denotes the criteria with which performances are measured (agility, information systems and agility attributes A1, A2, A3, A4 and A5) and X_{ij} denotes the performance score of element Si with respect to criteria X_j.

$$\begin{array}{c} \\ S_1 \\ \vdots \\ S_i \\ \vdots \\ S_m \end{array} \begin{pmatrix} X_1 & & X_j & & X_n \\ X_{11}/t_1 & \dots & X_{1j}/t_j & \dots & X_{1n}/t_n \\ \vdots & & \vdots & & \vdots \\ X_{i1}/t_1 & \dots & X_{ij}/t_j & \dots & X_{in}/t_n \\ \vdots & & \vdots & & \vdots \\ X_{m1}/t_1 & \dots & X_{mj}/t_j & \dots & X_{mn}/t_n \end{pmatrix}$$

$$= \begin{pmatrix} \mu_1(X_1) & \dots & \mu_1(X_1) & \dots & \mu_1(X_n) \\ \vdots & & \vdots & & \vdots \\ \mu_i(X_1) & \dots & \mu_i(X_j) & \dots & \mu_i(X_n) \\ \vdots & & \vdots & & \vdots \\ \mu_m(X_1) & \dots & \mu_m(X_j) & \dots & \mu_m(X_n) \end{pmatrix}$$

Once this is done, we normalise all total scores for every element of the criteria. Then we apply a power of dilation/concentration depending on the importance of each element of the criteria. The power of dilation is determined by a linguistic hedge or modifier; an operation that modifies the meaning of a term –fuzzy set-. Power of dilation is shown in (2) and power of concentration in (3).

$$\mu\text{con}(u) = (\mu A(u))^n; \text{ where } n > 1 \quad (2)$$

$$\mu\text{dil}(u) = (\mu A(u))^{1/n}, \text{ where } n > 1 \quad (3)$$

After applying the power of dilation/concentration the most important competitive base is determined by maximising the minimum membership value over all the elements of the criteria using (4).

$$\mu_A(xi) = \max_i(\min_j \mu_{ij}) \quad (4)$$

Using this approach we are able to identify the most important competitive basis in a specific manufacturing organisation. As a numerical example of this method we employed the answers given to us by a leading aerospace organisation –currently working with an ERP application- to identify the most important competitive bases for the company in terms of agility, information systems and attributes for agility. It is important to note that the aerospace industry has very long lead-times and product development. In this case the person answering the questionnaire identified. The following values:

Agility

S_{CB}	F_{CB}	I_{CB}	P_{CB}	Q_{CB}	C_{CB}
0.5	0.75	0.75	0.5	0.75	0.75

Information Systems

S_{CB}	F_{CB}	I_{CB}	P_{CB}	Q_{CB}	C_{CB}
0.75	0.25	0.5	0.25	0.25	0

The complete evaluation matrix –including the values for the groupings of agility attributes- for the aerospace company is shown in table VI (see appendix). The normalised matrix is shown in table VII of the appendix. Since in our study we wish to recognise agility and information systems as very important issues we gave them a power of concentration of 1.5 [14]. The resultant matrix is shown in table VIII of the appendix.

According to these results Innovation is the most important competitive basis behind the operation of information systems and agility from the point of view of our studied aerospace company. The maximum value for the minimum of each competitive basis is for Innovation with 0.080. If we identify the maximum, the value is 0.229 for Innovation. These results can be used later to benchmark companies in the same industry.

The use of this approach enables us to determine a number -agility index- for a specific competitive basis matching the requirements for agility and information systems and of course, the attributes required for agility.

It is, hence, possible to appreciate that creation and augmentation are part of the information systems function directly related to competitive bases.

The adoption of the scheme introduced in this work can be used to make better decision on the information systems function in order to improve the overall performance of the organisation.

VI. Summary and Conclusions

The information systems development and infrastructure and their support to competitive bases were the components introduced in this work. The support to the concept of agility by development and infrastructure, enabled us to identify in our case study that organisations with better developed information systems are committed to creating and improving current operations by using such technologies. The approach was complemented with the utilisation of fuzzy language variables to determine the most important competitive basis for a specific organisation in terms of agility, information systems and attributes.

The results of the questionnaire employed for this case study cannot be considered as statistically valid, but they give valuable indications for the preparation of adequate assessment models on information systems for organisations in competitive business environments.

The development of assessment tools of information systems for manufacturing would require the consideration of some of the concepts introduced in this work. The concept of agility is changing the way manufacturing organisations conduct their businesses.

A clear understanding of the issues introduced in this work would give practitioners and researchers the opportunity to develop information systems assessment tools suitable for present and future conditions in manufacturing..

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APPENDIX.

TABLE VI
AEROSPACE COMPANY MATRIX

CB	Agility	IS	A1	A2	A3	A4	A5
Speed	0.5	0.75	4.75	4.0	2.5	1.75	2.5
Flexibility	0.75	0.25	4.0	3.5	1.5	2.5	2.5
Innovation	0.75	0.5	4.5	4.5	2.75	2.5	3.5
Proactivity	0.5	0.25	5.5	4.0	3.25	3.25	2.5
Quality	0.75	0.25	4.0	3.5	2.75	2	2
Cost	0.75	0	4.5	3.75	4.25	2.25	2.25

TABLE VI
AEROSPACE COMPANY NORMALISED MATRIX

CB	Agility	IS	A1	A2	A3	A4	A5
Speed	0.125	0.375	0.174	0.107	0.147	0.122	0.163
Flexibility	0.187	0.125	0.146	0.150	0.088	0.175	0.163
Innovation	0.187	0.25	0.165	0.198	0.161	0.175	0.229
Proactivity	0.125	0.125	0.201	0.172	0.191	0.228	0.163
Quality	0.187	0.125	0.146	0.150	0.161	0.140	0.131
Cost	0.187	0	0.165	0.161	0.25	0.157	0.147

TABLE VIII
AEROSPACE COMPANY MATRIX AFTER APPLYING POWER OF CONCENTRATION

CB	Agility	IS	A1	A2	A3	A4	A5
Speed	0.044	0.185	0.174	0.107	0.147	0.122	0.163
Flexibility	0.080	0.044	0.146	0.150	0.088	0.175	0.163
Innovation	0.080	0.125	0.165	0.198	0.161	0.175	0.229
Proactivity	0.044	0.044	0.201	0.172	0.191	0.228	0.163
Quality	0.080	0.044	0.146	0.150	0.161	0.140	0.131
Cost	0.080	0	0.165	0.161	0.25	0.157	0.147