An information systems assessment framework for agile manufacturing.

Adrian E. Coronado M.
Department of Systems Engineering
Brunel University, Cleveland Road
Uxbridge, Middlesex UB8 3PH, UK

Abstract.

Turmoil in the business environment is driving manufacturing companies to become agile. Agility means the capability of operating profitably in a competitive environment of continuous and unpredictable changes with information systems regarded as one of its main enablers. The research presented in this work focuses on the assessment of information systems to support agile manufacturing. The assessment framework is constructed upon a series of competitive bases (six) and agility attributes (32) identified in the literature. Other issues included cover the characteristics of the business environment and the evolution/development and infrastructure of information systems. The framework is validated through a survey research instrument and the responses analysed with statistical tests (descriptive statistics, factor analysis, linear regression and reliability). The results of the statistical analysis enabled us to determine the attributes identified as predictors for the set of questions linking information systems and agile manufacturing. Due to the fuzzy nature of assessment of information systems, the complete framework can be presented as a hierarchy where techniques like AHP and fuzzy language sets are applicable.

The findings will enable the researchers to clearly identify the trends adopted by manufacturing companies in the utilisation of information systems to gain competitive edge in support of the concept of agile manufacturing.

Introduction.

Information systems have become the backbone of manufacturing organisations, supporting most of their operations and procedures. As information technology/systems get more complex, enabling new forms of work never experienced before like the virtual enterprise or collaborative work, new developments in information systems assessment are required to support the changing business conditions faced by manufacturing organisations. Furthermore, manufacturing enterprise operations are becoming more information intensive, thus requiring sophisticated information systems.

In order to survive in a business environment in continuous change, organisations must become agile. The aim of agile manufacturing is to give organisations the capability to survive and prosper in an environment of continuous and unpredictably change driven by customer-designed products and services [1], [2]. The success in the implementation of agility in manufacturing organisations depends on a number of different enablers. Information systems are among those enablers addressed in the literature [3], making imperative the definition of an adequate evaluation framework. In the literature, the definition of information systems to support the concept of agility is very superficial, so a deep understanding of the concept is required to design assessment models of information systems that satisfy the needs of organisations in competitive business environments.

In agility, the central contribution of the technology would be the acquisition, management, communication and reuse of information. Most companies turn to new technologies, in particular Information Systems (IS) that will provide them with a competitive edge, or that will allow them to become agile [4].

Evaluation is a widely recognised problem inherent to the continuous use of information systems in manufacturing. From a general point of view, evaluation of information systems has kept the attention of practitioners, researchers and academics for more than two decades [5], [6]. Evaluation tries to ascertain the perceived benefits of information technology/information systems to an organisation. The problem of evaluation of information systems has kept the attention of researchers and practitioners for the last two decades. Myers et al. [5] defined a set of information systems success dimensions and measures based on the DeLone and McLean [7] model. In their paper they defined measures for the organisational level such as: cost savings, improved customer satisfaction, improved productivity, ROI (return on investment) and increased data availability. Smithson and Hirscheim [6] defined different measures such as system usage, cost-benefit analysis, critical success factors, user satisfaction, gap analysis, risk analysis, resource utilisation, economic analysis and organisational behaviour to measure the effectiveness of information systems. A typical approach to the assessment of information systems classifies the benefits of information systems in manufacturing organisations in strategic, tactical and operational. Although, the literature in information systems is extensive in defining different evaluation methods and guidelines, few examples in the literature are focused on the evaluation of IS in manufacturing organisations. Kelley [8] measured the productivity achieved through the introduction of IT, others [9] have focused on investment justification of MRP_{II} systems.

It is not the intention of this work to focus on a specific software-application to support the concept of agility. This work focuses on information systems as a general function within the organisation. It is the purpose of this work to give practical guidelines for the assessment of information systems in the context of agility, to evaluate current systems or support the justification of future investments on IT/IS.

Objectives.

The objectives of this research cover the definition of practical guidelines for the evaluation of information systems in manufacturing organisations to support the concept of agile manufacturing. Those guidelines will define a set of agility attributes supported by IS, and the identification of competitive bases to achieve competitive edge. The guidelines of our framework will give organisations the possibility to use them as an instrument to determine the characteristics of their information systems infrastructure in terms of agility. One motivation for this research is the continuous perception that information systems fail to deliver expected benefits.

Our research questions are focused to determine:
- The characteristics of the business environment for the automotive, aerospace, semiconductors and general manufacturing sectors.
- The current development of information systems in surveyed companies and the characteristics of their infrastructure in terms of agility.
- The relationship between attributes, competitive bases for agility and information systems. What are the most important competitive bases and attributes supporting the concept of agility and supported by the information systems infrastructure?
- Identification of metrics for assessment.
- Identification of an index for agility.
- Deep analysis on metrics to register evaluation.

Agile manufacturing is an extensive and new area of research. Because there are few examples in our field of study, one of our research aims is to help to build up the theory in the field of information systems for agile manufacturing. In fact, very little research has been done in the area of information systems to support agility.

The final stage of the research contemplates the design of a multiple case-study that will help to get a deeper knowledge of some aspects addressed in our study such as the metrics of productivity, cashflow, ROI and throughput.

Research Methodology.

The initial task in our research was a comprehensive and extensive literature survey of agile manufacturing, its characteristics, enablers, facilitators and integrators. During this task it was possible to observe that many authors agree that information systems are basic enablers of the concept of agility, but many of them do not mention or give a deep explanation of the characteristics of information systems to support the concept of agility. Moreover the definition of information systems for agility is a very superficial concept in the literature.

The framework defined in this work is based on a set of six competitive bases that include speed, quality, flexibility, innovation, pro-activity and cost (profitability) widely addressed in the literature [10]. A definition of these competitive bases is given below:
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: successful 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 lifetimes.
Cost: The expense of resources required to produce goods or services to satisfy a market need.

Furthermore, the framework identifies thirty-two agile manufacturing attributes from the most representative works identified in the literature. Five groupings were created to facilitate the manipulation of these attributes. They include: a) organisation commitment to integration and co-operation (A1), b) culture of quality and responsiveness (A2), c) state of technology to enhance flexibility and operations performance (A3) and d) organisation commitment towards change (A4) and e) education and welfare of human resources (A5). The list containing the agility attributes is shown in table 1.

Organisation commitment to integration and cooperation - A1	**State of technology to enhance flexibility and operations performance – A3**
Multi-venturing capabilities - A11	Technology awareness – A31
Encouragement of teaming with other customers – A12	Leader in the use of current technology – A32
Rapid formation of partnerships – A13	Using skill and knowledge enhancing technologies – A33
Strategic customer relationships – A14	Use flexible production technology – A34
Close supplier relationships – A15	Open information environment – A35
Trust based customer and supplier relationships – A16	
Enterprise integration – A17	**Organisation commitment towards change – A4**
Cross-functional teaming – A18	Continuous improvement – A41
Concurrent execution of business activities – A19	Embracing a culture of change – A42
	Descentralisation of authority – A43
Culture of quality and responsiveness – A2	Learning organisation – A44
Quality over product life – A21	Bespoke business practice and structure – A45
Addition of value to products –A23	
First time right designs – A24	**Education and welfare of human resources – A5**
Satisfaction of customer requirements – A25	Employee satisfaction – A51
Rapid development cycles – A26	Multi-skilled and flexible workforce – A52
Rapid response to changing market requirements – A27	Continuous training and development for Personnel – A53
Frequent new product innovation – A28	Workforce skill upgrade – A54
Customer-driven innovations – A29	Workforce empowerment – A55

Table 1. Identified attributes for agile manufacturing.

In addition, four manufacturing metrics were added to the model including throughput, productivity, ROI and cash flow.

The definition of our model lies on the main issues identified after an extensive literature review of the concept of agile manufacturing and information systems evaluation. The initial framework brings elements that are source of competitive edge (competitive bases) and a series of characteristics of agile organisations (agility attributes). It is important to remark that these attributes represent tangible and intangible aspects of agility.

Another part of our work involves the study of the characteristics of the information systems infrastructure to support the concept of agility. Dove et al. [11] were the first researchers to determine a series of issues for an information systems infrastructure to support agility. Nine elements were identified to carry out this approach:

1. Creation. IT/IS in the enterprise provides an environment that promotes the development of customised solutions based on unique business needs.
2. Augmentation. The IT/IS infrastructure ensures continued viability as components are improved, added or removed.
3. Comparison. The organisation constantly monitors developments in IT/IS in our industry and benchmarks it against other industries.
4. Migration. Our IT/IS infrastructure anticipates future electronic interactions with customers and suppliers.
5. Modification. New standards can be upgraded or modified to the IT/IS infrastructure without breaking other applications.
6. Correction. In case of problem, fixings to the IT/IS infrastructure are in shorts periods of time.
7. Variation. It is possible to make variations to the IT/IS standards in order to accommodate unique requirements.
8. Expansion. The IT/IS function is in constant expansion to support all business units and user community.
9. Reconfiguration. Our IT/IS infrastructure supports the portability of solutions from one business unit to another.

A classification based on the evolution/development of information systems based on a report by the Next Generation Manufacturing Project [12] was introduced in order to identify the current trends by manufacturing organisation to acquire new technology. Table 2 presents this 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.

Table 2. Information Systems Evolution.

The business environment section asks questions about market growth, forecast, leadership, innovation and planning. These are the main issues behind driving a company to become agile.

To test the structure introduced in our model, it was necessary to design a survey instrument in order to gather data from manufacturing companies. Moreover, we are interested in identifying those competitive bases important in terms of agile manufacturing and information systems.

A pilot survey was conducted to test the structure of the survey instrument. The questionnaire of the pilot survey was sent to 28 manufacturing companies in the UK. The feedback received on it enabled us to make corrections to the model, reword some questions and identify correlation between the different attributes and competitive bases. The respondents were asked to answer the questionnaire using a 5-point Likert scale, where 1 stands for completely disagree, 2 for disagree, 3 for not agree or disagree, 4 for agree and 5 for completely agree (see table 2).

1 completely disagree	2 disagree	3 not agree or disagree	4 agree	5 completely agree

Table 3. Likert evaluation scale.

Once corrections were made, the modified questionnaire was sent to a large number of manufacturing companies in the UK, covering the aerospace, automotive, semiconductors and general manufacturing sectors. The targeted respondents of the questionnaire included the managing director or the information technology director. According to an 1997 inform from the UK's Department of Trade and Industry, the automotive, semiconductors and aerospace are sectors subject to tough competition in their respective business environments.

Survey research is the most adequate technique to accomplish empirical analysis due to the lack of theory available in our fields of study.

The accomplishment of the survey research enabled us to determine:

1. The conditions of the business environment in the four manufacturing sectors targeted.
2. The development and adoption of information systems present in surveyed companies.
3. The underlying factors for each of the sections of the questionnaire, using factor analysis (principal components analysis and maximum likelihood) in order to identify those issues that are predictors using linear regression.

The results allowed us to reduce the size of the questionnaire in order to launch a new survey instrument focusing only in the most relevant issues.

Another method that will help us to choose a suitable arrangement of agility attributes, competitive bases and metrics is the utilisation of AHP (Analytical Hierarchical Process) [13]. This technique seems adequate according to the scheme proposed in our research, where the thirty-two agility attributes determine each of the six competitive bases defined in our work. The hierarchy is presented in figure 1. In this case we are not depending only in the results of statistical analysis, moreover we are using these tools to provide an alternate method for our work. A fuzzy logic approach has been included to this section. Fuzzy logic provides a simple way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information. Fuzzy linguistic variables are the same type of variables used to define each competitive basis and attributes. A fusion of these techniques will make possible to obtain an agility index.

The agility index will give managing directors and information technology directors the possibility to better assess the implementation of agility policies and to identify the areas where their information systems infrastructure supports agility.

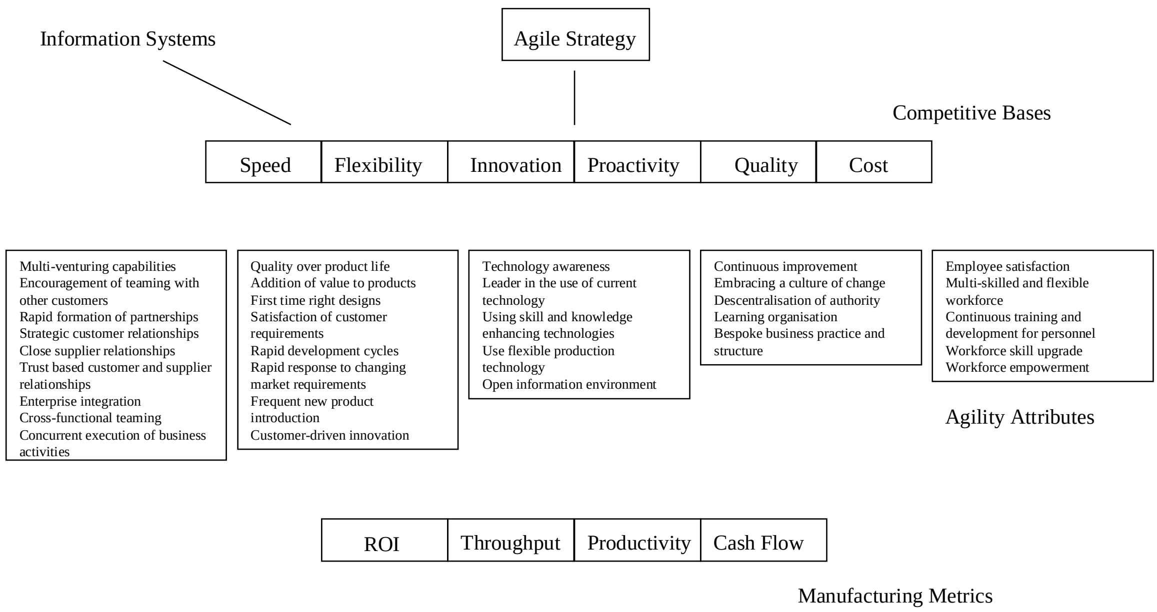

Figure1. AHP general framework.

The process of assigning values using a Likert scale is fuzzy by nature. This process is depicted in figure 2. Table 2 shows its linguistic values references.

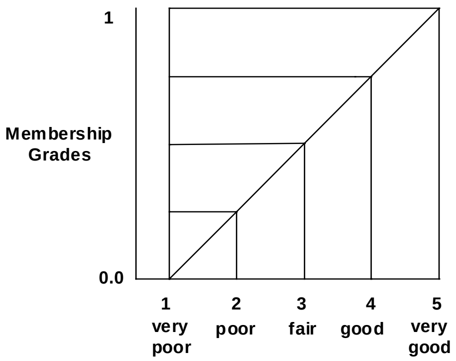

Figure 2 Agility assessment curve

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

Table 4. Linguistic Values References

Based on figure 2 and table 4, a fuzzy set is a number given by $\mu_A(X) \in [0,1]$.

Current status of our work.

At this time, we have finished the analysis of the responses received to the questionnaire mailed out last January. The statistical analysis was accomplished using SPSS 9.0, enabling us to reduce the number of attributes for each section and prepare a new questionnaire.

After examining the results of the survey, it was possible to determine that flexibility (mean 4.28) is the most important issue in terms of agility. In terms of information systems speed (mean 3.89) was identified as the most important one. These results were confirmed with the utilisation of factor analysis and linear regression tests.

Regarding the information systems infrastructure, the statistical analysis shows that augmentation, creation and migration were identified as the more important characteristics. Business environment responses show that most of the surveyed companies agree that it is necessary to be a technology leader to succeed in their industries (mean 4.51), followed by the need to introduce new products (mean 3.75).

The reduction of attributes for each section was supported by the utilisation of factor analysis, using principal component criteria and linear regression analysis. Moreover, the structure of the questions was analysed using reliability tests (Cronbach's alpha).

A model defined by Cheng [14] and adapted to our framework promises to be helpful to determine an agility index based on fuzzy language sets and the analytic hierarchy process.

Finally, the utilisation of a framework proposed in this paper will give practitioners and researchers the opportunity to evaluate the information systems function from an agile manufacturing perspective.

Identification of the target audience and beneficiaries of the thesis.

The main beneficiaries of this work are the academic community in the field of information systems. Practitioners and consultants may find the results interesting, specially for those working in the development of new projects for organisations in competitive business environments. As technology continuous to bring new ways of collaboration not experienced before, our defined framework will give them an adequate background to better determine requirements in order to ensure that the information systems function delivers all its expected benefits.

Innovative contribution of the thesis to the existing state of the art.

The innovative contribution of the thesis lies on the definition of practical guidelines to the assessment of information systems in manufacturing enterprises. The assessment covers specific attributes of agile manufacturing. This work is intended to contribute to the theory-building process in the fields of agility and information systems.

Conclusions and further work.

Current work involves the definition of fuzzy sets for the utilisation of fuzzy logic in order to define in other ways, the attributes required to support the concept of agility.

A new questionnaire, product of applying a meticulous statistical analysis is ready to be sent to a new set of companies in the aerospace and automotive sectors.

The results of the second survey will give us the opportunity to design a multiple case study that will enable us to finish our research. Aspects to be addressed in the case-study cover a deep study of the following performance metrics:
Cashflow, includes operating activities –cash inflows and outflows-, cash collection from customers, among many others.
Productivity, usually is the measure of outputs divided by inputs. Including diverse possible outputs and inputs.
Throughput, and average throughput rate is the Average number of units produced per time
Return on Investment,
Return on Investment ROI, determined by issues such as net profit, investment, etc.

The development and conclusion of this work will help organisations –in this particular case manufacturers- to clearly identify the conditions where information systems can help them to achieve competitive advantage in the context of agility. The practical guidelines of this work will help them to get the most from their systems and prepare themselves to implement advanced information systems that will expand the collaboration between customers and suppliers.

References

[1] Goldman S., Nagel R. and Preiss K. (1995). Agile competitors and Virtual Organisations, Van Nostrand Reinhold, New York.

[2] Gunneson A., 1997, Transitioning to Agility. Addison Wesley, Reading MA

[3] Gunasekaran A., 1998, Agile Manufacturing: enablers and an implementation framework. International Journal of Production Research, 36, 1223-1247.

[4] Reich Y, Konda S, Subrahmanian E, Cunningham D, Dutoit A, Patrick R, Thomas M, Westerberg A and the n-dim group (1999). Building Agility for Developing Agile Design Information Systems. Research in Engineering Design, 11**,** 67-83.

[5] Myers B., Kappelman L. and Prybutok V., 1997, A Comprehensive Model for Assessing the Quality and Productivity of the Information Systems Function: Towards a Contingency Theory for Information Systems Assessment. North Texas University Information Systems Research Centre.

[6] Smithson S. and Hirschheim R. 1998, Analysing information systems evaluation: another look at an old problem, European Journal of Information Systems, Vol 7, 158-174.

[7] DeLone W. and McLean E., 1992, Information Systems Success – The Quest for the Dependent Variable. The Institute of Management Sciences, Information Systems Research, 3, No. 1, 60-95.

[8] Kelley M., 1994, Productivity and information technology. The elusive connection. Management Science, Vol. 40, No. 11, 1405-1425.

[9] Ezingeard J.N., Irani Z. and Race P., 1998, Assessing the value and cost implications of manufacturing information and data systems: an empirical study. European Journal of Information Systems, Vol. 7, 252-260.

[10] Yusuf Y.Y., Sarhadi M., Gunasekaran A., 1999, Agile manufacturing: the drivers , concepts and attributes. International Journal of Production Economics, Vol. 62, 33-43.

[11] Dove R., Hartmann S., Benson S., 1996, An agile enterprise reference model with a case study of Remmele Engineering, an Agility Forum Project. Project report, Paradigm Shift International.

[12] Next Generation Manufacturing Project, 1997. U.S. Department of Energy, Vol II Imperatives for Next Generation Manufacturing.

[13] Saaty T., The Analytical Hierarchical Process, New York. McGraw-Hill, 1980.

[14] Cheng C.L. , Yang K.L. and Hwang C.H., Evaluating attack helicopters by AHP based on linguistic variable weight, European Journal of Operational Research, vol. 116, no. 2, 423-435, 1999.