ISAHP 2005, Honolulu Hawaii, July 8-10

THE ANALYTIC NETWORK PROCESS: EVALUATION AND SELECTION OF PDP SOFTWARE

James A.W. Mulebeke[1], Li Zheng

Department of Industrial Engineering, Tsinghua University, 100084 Beijing
PR China.
mlk02@mails.tsinghua.edu.cn, lzheng@mail.tsinghua.edu.cn

Keywords: Product development process software, Analytic Network Process, Benefits, Opportunities, Costs, Risks, Small-Medium sized manufacturing enterprise

Summary: *Software developers continuously enhance their offerings, often forcing an overhaul of computer systems in order to properly work the improved versions. Entrepreneurs find they have no choice but to update or replace their software. Knowing this and actually making the decision is not easy. This specific qualitative decision problem calls for a strategic solution. This paper focuses on application of the Analytic Network Process to harness the software selection problem for a small-medium sized manufacturing enterprise through objective situation analysis, a structured approach to the solution, and forward planning. Results indicate that trends are towards full blown business software solutions especially for enterprises in areas of market growth due to rapid changes in technology and competitive pressures. Application of a well defined software evaluation and management process helps provide a roadmap with the necessary information to aid management teams make sound decisions that are timely and result in financial savings.*

1. Introduction

According to a report by the MIT commission on industrial productivity, (Dertouzos, Lester, and Solow, 1989) the two major weaknesses hampering product development in America were seen as, Technical weaknesses in development and production, and failures in co-operation (lack of teamwork). Globally, the later has been dealt with to a satisfactorily adequate level for example by introduction of core teams in project management and development processes, but the former has remained a problem for many enterprises despite rapid increases in technology. Clark and Fujimoto (Clark and Fujimoto, 1991) reported that this could be associated with a number of factors like difficulty in designing for simplicity and reliability, disregarding competition, disregarding voice of customer, excessive development time, failure to incorporate quality in design phase, inadequate concentration on the product, slow decision making process and application of inappropriate technologies, the last two presenting a big dilemma. Product development is generally viewed as the process entailing from the concept, through to the design, manufacturing and finally the launch of a product. The Global business climate is such that

[1] Corresponding author

global economy causes conditions to quickly ripple through market and companies, resulting in increased pressure/motivation to improve business success, or lose. The effect is lowered tolerance for ineffective technologies with both internal and external factors (criteria) driving decisions and actions. Enterprises are seeking bottom line improvements, with economic conditions pushing technology investment decisions higher. Under such circumstances, it's imperative that manufacturing enterprises design the right product and the right development process with the right software technologies for the right people at the right time. However, seeing there are literally dozens of software solutions on the market to help automate and manage business processes, how can manufacturing enterprise managements decide on what the right software for their product development process is? How can they be certain that the selected software will perform to their expectations and those of their customers? The "How....." question could go on and on. This is a specific qualitative multicriteria decision problem that we solve in this paper by introducing the application of the ANP. The work herein focuses on mid-size business needs representing business objectives of small and medium sized manufacturing enterprises (SMMEs).

The ANP provides a general framework to deal with decisions without making assumptions about the independence of higher level elements from lower level elements and about the independence of the elements within a level. Thus the Analytical Hierarchy Process (AHP) with its dependence assumptions on clusters and elements is a special case of the ANP (Saaty, 1999). The ANP is a coupling of two parts (Saaty, 1999). The first consists of a control hierarchy or network of criteria and subcriteria that control the interactions. The second is a network of influences among the elements and clusters. The network varies from criterion to criterion and a different supermatrix of limiting influence is computed for each control criterion. Finally, each of these supermatrices is weighted by the priority of its control criterion and the results are synthesized through addition for all the control criteria.

In general, there can be several control criteria or subcriteria, that enable us to study all the influences in a complete analysis of a decision problem and some may have different merits (Saaty, 2004) i.e., benefits (B), opportunities (O), costs (C) and risks (R). For each control criterion of the BOCR, one derives priorities for alternatives of a decision with all the significant influences that cause some alternatives to have higher priority than others. One then combines the weights of the alternatives according to the weights of the BOCR assessed in terms of strategic criteria. Strategic criteria are very basic criteria used by individuals and groups to assess whether they should make any of the daily decisions they face in their daily operations (Saaty, 2004). Strategic criteria don't depend on any particular decision for their priorities but are assessed in terms of the goals and values of the individual or organization. Finally one rates (not compares) the top ranked alternative for each BOCR and uses the resulting weights to combine the values of each alternatives for the four merits and obtain the final answer in the form of priorities whose relative values are important for choosing the best alternative, sensitivity analysis, and resource allocation (Saaty, 2004). From the rating, one obtains normalized respective weights, b, o, c, and r. and computes the total outcome bB+oO-cC-rR for each alternative. Note in evaluating the benefits or opportunities one responds to the question of dominance: which alternative contributes the most benefits (opportunities), whereas for costs or risks one responds to the question which alternative costs (is subject to greater risks) more, which is opposite in sense to the benefits and opportunities and must be subtracted from them.

The ANP includes four axioms. Informally, they are concerned with reciprocal relation, comparison of homogeneous elements, hierarchic and systems dependence, and expectations about the validity of the rank and value of the outcome and their dependence on the structure used and its extension. The

formalism of introducing the axioms would lead us far afield in this paper; however, the reader should like to consult work by Saaty (Saaty, 1994; Saaty, 2001) for a full description and results derived from the axioms.
The rest of this paper deals with the application of ANP in a small–medium size manufacturing enterprise (SMME) to solve a specific PDP software evaluation and selection problem.

2. The Decision to Acquire PDP software by SMME

The analysis in this section focuses on determining an optimal decision for a small-medium sized manufacturing enterprise (SMME) regarding the selection of PDP software. ANP is applied to the problem, analyzed through a control system of benefits, opportunities, costs, and risks for each of which priorities are developed through the rating approach of the AHP. The decision to upgrade, acquire new or replace business software has to be based on proven data. These facts are drawn through objective situation analysis, a structured approach to the solution, and forward planning, all of which are constituted in the ANP.
Under the BOCR models, there are different clusters defined that interact with respect to control hierarchy established. The control hierarchy consists of economic and technology enhancement factors applicable to each of the BOCR models.
Although the clusters and the specific elements assigned to each network vary due to their interactions, the following two general definitions do apply to all.

Alternative Decisions: This cluster includes potential decisions for the SMME PDP software evaluation and selection problem. Among the lot, we selected these seven possible decision alternatives from which a SMME could select a/or possible PDP software. The selection was based on various criteria the most outstanding being functionality. Including their respective vendors, the PDP software alternatives are: Pro/Engineer by Parametric Technology Corporation (PTC) and Solid Edge by Unigraphics solutions (UGS). These belong to computer aided design (CAD) software category. Mastercam by Mastercam Inc. This belongs to the computer aided manufacturing (CAM) software category. Windchill by PTC and Teamcenter by UGS. These belong to the product lifecycle management (PLM) software category. Finally, ANSYS by Ansys Inc, and Moldflow by Moldflow Inc., belonging to the computer aided engineering (CAE) category. These seven alternatives all have the potential for leveraging automation and hence causing substantial improvements of enterprise development processes. The alternatives were obtained through a focus group brain storming session consisting of five participants. A pairwise t-test done on the ages and years of experience (with software) of the participants resulted in a P value < 0.0001 (note that $P \leq 0.05$), Difference in means of -24.50, a 95% confidence interval of -28 to -21, $t = 18.0128$, $df = 5$ and standard error of diff. = 1.360. We can thus conclude from the P value that the treatment was statistically significant and also scientifically significant from the confidence interval.

Control Network: This cluster includes control criteria that serve as a basis for making pairwise comparisons about influence. For each of these control criteria, one obtains priorities from a limit supermatrix and then combines the several sets of priorities by weighting them by priorities of the control criteria to obtain an overall outcome. The control criteria included in this network are:

Economic and Technology Enhancement, these two forming subnets. The goal of any economy is to enhance economic development whereas the goal for Technology enhancement would naturally be automation of all business processes.

2.1 Benefits to SMME

2.1.1 Economic Benefits subnet

Increased market share

This cluster considers elements that will impact the enterprises' relationships with customers. The elements in this cluster are the following:

- Credibility: Win trust worthiness of customers in terms of product quality, transactions, on time delivery and so on.
- Influence: Be able to influence dealings among customers, decision makers and stake holders in general
- Reputation: Achieve global recognition from customers and competitors.

Maximize profitability

This cluster describes factors that will hoist enterprise revenue, cut expenses, and accelerate return on investments. The elements include:

- Fast time to market: Deliver products to the market at the stipulated time, accommodate innovation, customization and high productivity
- Costs saving: Savings on manual documentation, paperwork, analysis, etc.
- Return on investments (ROI): Facilitate quick return on investments.

2.1.2 Technology Enhancement Benefits subnet

Technology experts

This cluster describes increase in knowledge, know how, and skills that come with application of new technology. The elements here are:

- Expertise: By introducing new technology, the staff would learn new skills /expertise
- Experience: Increase the level of exposure and experience of personnel.

Growth in Technology capability

This cluster describes the growth of the technology level of the enterprise into a multi-purpose sophisticated system with regard to functionality. The elements in this cluster are:

- High: Customizable software systems offering robust customization and integration tools. These could be installed and implemented with assistance generally in 6-12 months.
- Medium: Configurable systems that offer more customizable and integration tools. These are generally installed /implemented with assistance generally in 3-6 months.
- Low: Generally off-the-shelf solutions, with limited customization and integration tools. They are installed /implemented without assistance generally in 1-3 months.

Technology advancement

This cluster considers factors associated with automation of business processes. The elements include:

- Support: Myriad emerging and existing transport and communications protocols, and security standards and mechanisms.
- Global interconnectivity: Upgrade connectivity to trading partners, e-commerce, integrate flow management and secure transport of electronic data, documents and information. Offer central reusable repository for customers, profiles, and processes.
- Scheduling of resources: Labor, tools, work centers and machines, and preventive maintenance capabilities.
- Integration and automation: Discrete bill of material structure and routing definitions, CAD integration, outside processing (subcontracted operations), engineering change control, work order creation, material issues, labor entry, real-time shop floor control and more.
- Material planning: Materials planning requirements, sales forecasting, and inventory replenishment.
- Batch process features: Such as formula definition, compliance management, laboratory management and quality control, etc.

2.2 Opportunities for SMME

2.2.1 Economic Opportunities subnet

Competitive advantage

Under this cluster, we consider factors that would hoist the competitive advantage of the enterprise. The elements herein include fast time to market (ability to deliver quality transactions and products on time with reduced lifecycles), motivated workforce, and direct link with customers.

Better Image

New software would most probably better the image of the enterprise through better satisfaction of old customers and thus attraction of new customers. The respective elements of this cluster thus are new customers and Satisfy old customers better.

Growth

This cluster refers to market growth and the possibilities of a new line of business. The elements in this cluster include new product line and Market growth.

Savings

Basically refers to savings with regard to finances and reduced expenditure. The single element in this cluster is Time and Money.

2.2.2 Technology Enhancement Opportunities subnet

Technology base

This cluster describes factors that promote technology platforms and possibilities for technology integration and advancement. The elements in this cluster include:

– Improved visibility through the hub: Establish central point of management, monitor and track transactions in real time, Minimize critical errors as they occur.
– Automation: Automate product definition, processes and transactions.

Reduced operations management
Possibly all the business processes related to production would at one time get automated. The elements in this cluster include less or improved scheduling and improved production management techniques

Growth
We refer to growth potential of software−opportunity for technology expansion and new product lines due to market growth. The elements in this cluster are:
– Off-the-shelf: Limited customization
– Configurable: More customization and integration tools
– Customizable: Robust customization and integration tools.

2.3 Costs for SMME

2.3.1 Economic Costs Subnet

Training
The acquisition of new software would require the staff to be made proficient with specialized instruction and practice. This cluster only contains the Human resource element.

Acquisition and Implementation
This cluster refers costs that would vary depending on whether the enterprise thinks they need new software, upgrade the existing one or do not need software at all, formulating the respective elements.

2.3.2 Technology enhancement Costs Subnet

Technical costs
The elements in this cluster constitute costs like maintenance, integration and testing, data conversion and analysis, and process rework.

Labor
The elements in this cluster include costs due to redundant stuff, hiring new stuff and consultations.

Growth
These are costs associated with technology growth. The elements in this cluster are off-shelf, configurable and customizable.

2.4 Risks for SMME

2.4.1 Economic Risks subnet

Bankruptcy

– Costs of producing results: This cluster describes failure of the software to produce the desired results due to erroneous results, malfunctions, or delayed results (elements). This has bad financial implications and could lead to bankruptcy to the extremes.

Loss

– Skilled personnel: Redundancy caused by automation replacing manual.
– Financial: Costs incurred by firing workers and hiring workers depending on the functionality of the software.

2.4.2 Technology Enhancement Risks Subnet

Insufficient functionality

The elements in this cluster include:

– Unfeatured product features: Failure to cope with feature set and capabilities of product
– Performance and quality: Failure to achieve functionality and quality of products
– Testability: High complexity of testing product (features and functionality)
– Reuse: Integration and use of software assets from a previously developed system
– Obsolescence: Low or no growth potential of software leading to obsolescence just after acquisition

Requirements

These are conditions or capabilities that are necessary for a software system to meet its objectives. The elements in this cluster include:

– Instability or incompleteness: Is the information stable or varying?
– Clarity: Comprehensiveness of requirements
– Feasibility: Failure to handle possible difficulties that may suddenly arise
– Tracking: Visibility of requirements during a project

Vendor stability

This cluster describes a situation where the service provider is not in position to offer support or upgrades for the software product. The elements in this cluster include unstable vendor and discontinued solution (as a result of small vendor being bought out by larger vendor)

Non Integral solution

The elements in this cluster are:

– Software inability to fit business: Failure for connectivity among components, systems etc.
– Hardware constraints: limitations of hardware speed, size, availability and functionality to meet product requirements.
– Non amalgamative: Lack of synchronization of data, failure to keep registry information up-to-date, failure to integrate with other systems, workflow, information repository, and ability to synchronize

and syndicate information to a variety of destinations in multiple formats.

– Unsupported Technology Platforms: Software interfaces not amalgamable with existing technology.
– Irrelevant functionality: Obtain a software system for which much of the functionality is wasted on the shelf and just the smaller part of its functionality applicable.

3 ANP Procedure

In order to rate the BOCR in the decision the SMME management team would have to make regarding PDP software selection, we set the goal (overall objective) which is selection of PDP software and the following five strategic criteria.

1) Customer attraction and relationship management. The enterprise would like to attract new customers and at the same time create a lasting relationship with both the old and new customers. Focus is on feedback from customers, so as to offer them fast and better product solutions, support and maintenance.

2) Global trade mark. The enterprise would like to make quality unique products that will become global name brands.

3) Complex customized products. Customer requirements evolve and so do products. The enterprise would like to keep upbeat with the technology capability to respond to these evolutions.

4) Competitive advantage. The enterprise would like increased in market share and be able to compete for customers in this global economic era.

5) Profitability. The bottom line for any business is to make profits from the products and services they offer to the market. They need to make high quality products at a reasonable cost and be able to attract as many customers as they possibly can.

The analysis was done using the ANP in a BOCR model. The general structure of the analysis with respect to the goal is shown in Figure 1.

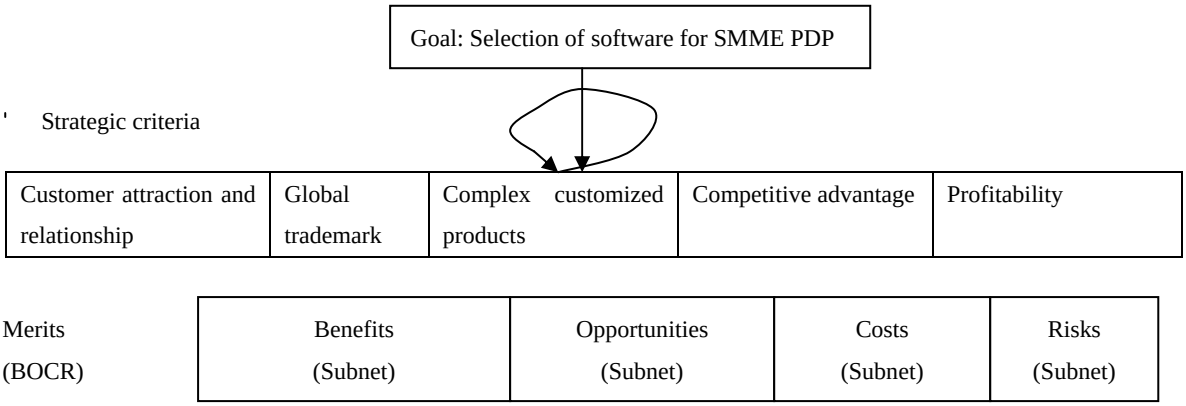

Figure 1 General structure of ANP analysis with respect to the goal

The Benefits subnet is shown in detail in Figures 2 and 3 for exemplification. The subnets for the OCR were dealt with similarly.

The final synthesis for the alternatives for each merit is shown in Table 1. Note that Teamcenter is the ideal choice for opportunities and costs. Windchill has the largest priority value for benefits, while Solid Edge has the largest priority value for risks.

Table 2 shows the priorities of the intensities in ideal form, normalized by dividing each by the largest.

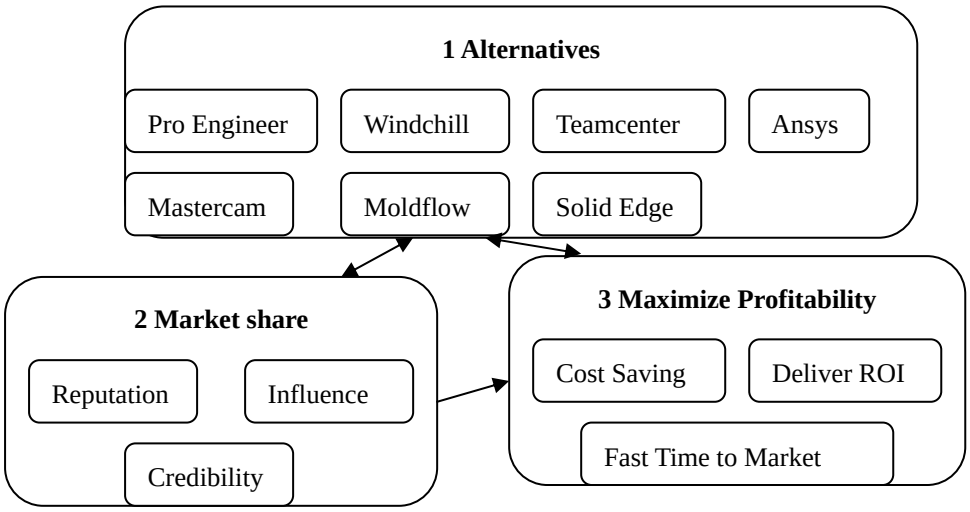

Figure 2 Economic Benefits Subnet

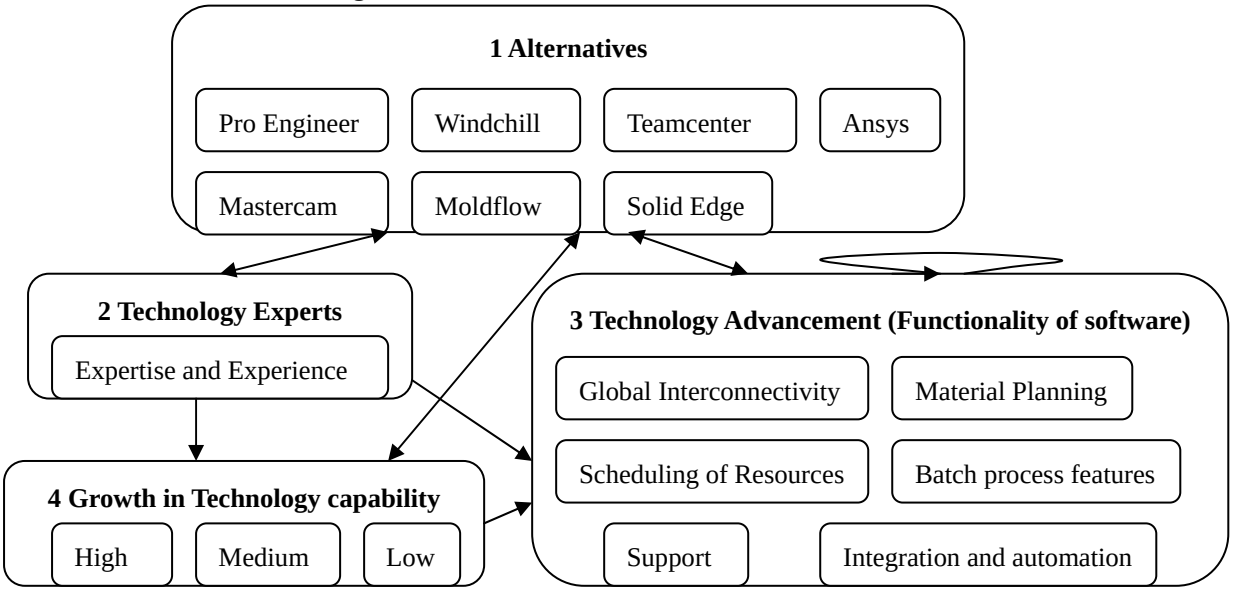

Figure 3 Technology Enhancements Benefits Subnet

These priorities were pairwise compared for preference and the same intensities derived by making general pairwise comparisons in a manner similar to all criteria. The BOCR were then rated by taking the alternative with the highest priority for each (Table 1) and then selecting the appropriate intensity for it (Table 2) for each strategic criterion. The overall weighted outcome normalized is shown on the left in Table 3. Using these normalized values for the BOCR, the final ranking of the alternatives is shown in Table 4. All computations and analysis with respect to the above ANP application are done using the Superdecisions software (*www.superdecisions.com*) which implements the ANP for the PC. Note that Windchill has the highest priority value among the software alternatives for the SMME.

4 Discussion and Conclusion

From the ANP analysis, we deduce that Windchill has the highest priority value among the software

Table 1 Synthesized Alternatives for B, O, C and R in ideal form

Values of Alternatives for BOCR	Benefits(B)	Opportunities (O)	Costs (C)	Risks (R)
Ansys	0.257	0.437	0.524	0.739
Mastercam	0.276	0.464	0.678	0.773
Moldflow	0.138	0.304	0.583	0.933
Pro Engineer	0.504	0.658	0.724	0.657
Solid Edge	0.147	0.281	0.578	1
Teamcenter	1	0.970	1	0.666
Windchill	0.999	1	0.997	0.617

Table 2 Intensity values (Ideal form) for rating B, O, C and R

High	Medium	Low
1	0.335	0.15

Table 3 Rating of BOCR with respect to strategic criteria

Strategic criteria	Priority (Normalized)	Competitive advantage (0.252)	Complex customized products (0.134)	Customer attraction & relationship mgt. (0.223)	Global Trademark (0.125)	Profitability (0.265)
Benefits	0.439 (b=0.259)	High	High	High	High	High
Opportunities	0.337 (o=0.199)	High	High	Medium	Medium	High
Costs	0.147 (c=0.087)	Medium	Medium	Medium	Medium	Medium
Risks	0.077 (r=0.045)	Low	Medium	Low	Low	Low

Table 4 Final Ranking of alternatives (Normalized form)

Alternatives	Final Ranking (bB+oO-cC-rR)
Ansys	0.078
Mastercam	0.074
Moldflow	0.011
Pro Engineer	0.168
Solid Edge	0.007
Teamcenter	0.033
Windchill	0.335

alternatives followed by Teamcenter and Pro Engineer in that order**.** A sensitivity analysis revealed that the results obtained were insensitive to perturbations in the inputs' priorities hence stable and reliable. However, we discovered closeness between Teamcenter and Windchill with regard to their priorities for the BOCR. Both Windchill and Teamcenter are PLM solutions and clearly not point solutions in a way the last generation of systems used to be (e.g. CAD, CAM, PDM, office suite etc.) but rather integrate these systems to form full blown business solutions. Many SMMEs remain relatively small and may never require full blown business solutions, however, trends in growth markets (like China and Africa) are forcing enterprises to adapt aggressive business plans and compete or die. Such enterprises should like to select a business system that can grow with the company both in terms of transaction volume and increased functionality, thus justifying the ANP results. By selecting a scalable solution the

business can extend their investment for several years while avoiding unnecessary costs to implement a new solution. With ANP all these issues and more were cozily incorporated into the final decision through analysis of criteria and/or subcriteria of the BOCR control system. In relation to real time data, research by CIMdata Inc for 2004 forecast the application and investment of PLM in enterprise PDPs to grow at a compound annual growth rate (CAGR) of 15% as compared to the point solutions with 4.5% for the next five years. We confidently infer that the final decision outcome from the ANP analysis is substantial, reasonable and conclusive.

The process of evaluating and selecting software is continuous because software applications are often due for upgrade and more so no single software solution is enough to solve all SMME problems and hence have to be beefed up through integration with other solutions. More over, companies always out grow software as a result of business expansion and/or Technology obsolescence. ANP was found to be a simple comprehensive and adaptable decision support tool to deal with this recurring situation. ANP facilitates strategic planning through which control and improvement of changes can be done as they happen rather than leaving them to the influence of external forces. The application of the ANP involves capturing information from various factions of the enterprise like Accounting, Sales and Marketing, R&D, Engineering and Human resource. This capturing of information is adaptable to knowledge management that is essential in aligning business objectives for strategizing technology. SMME managements can relate evolution of market trends to evolution of software technology hence the opportunity for breakthrough products (the right technology for the right product and right development process).

We conclude that application of a well defined software evaluation and management process like the ANP helps provide a roadmap with the necessary information so that manufacturing enterprise management teams and decision makers can make sound business and technical decisions that benefit both them and stakeholders, leveraging enterprise competitive advantage. Knowledge of company requirements, appropriate software, and calculated present and future costs, are all important factors in determining the final software business decision.

References

1. Dertouzos, M.L, Lester, R.K. and Solow, R.M. (1989) *Made in America- Regaining the productive edge*, Cambridge, MA: MIT press
2. Clark, K.B. and Fujimoto, T. (1991) *Product development performance: Strategy, organization and management in the world auto industry*, Boston: Harvard Business school Press
3. Saaty, T.L. (1999) “Fundamentals of the Analytic Network Process,” *Proceedings of the Fifth International symposium of the Analytic Hierarchy Process*, Kobe, Japan, August 12-14
4. Saaty, T.L. (2004) “Fundamentals of the Analytic Network Process-Multiple Networks with Benefits, Costs, Opportunities and Risks,” *Systems Science and Systems Engineering*, 13(3), 348-379
5. Saaty, T.L. (1994) *Fundamentals of Decision Making and Priority Theory*, 4922 Ellsworth Ave., Pittsburgh, PA: RWS Publications
6. Saaty T.L., (2001) *Decision making with dependence and feedback: The Analytic Network process*, Second Edition, Pittsburgh, PA: RWS Publications