EVALUATION OF VALUE STREAM MAPPING IN MANUFACTURING SYSTEMS REDESIGNING

Ibon Serrano, Carlos Ochoa Laburu, Rodolfo de Castro

EVALUATION OF VALUE STREAM MAPPING IN MANUFACTURING SYSTEMS REDESIGNING

Journal:	*International Journal of Production Research*
Manuscript ID:	TPRS-2006-IJPR-0690.R1
Manuscript Type:	Original Manuscript
Date Submitted by the Author:	15-Dec-2006
Complete List of Authors:	Serrano, Ibon; Mondragon University, Industrial Management Department Ochoa Laburu, Carlos; University of the Basque Country, Business Organization Department De Castro, Rodolfo; Universitat de Girona, Business Organization, Management and Product Design
Keywords:	MANUFACTURING SYSTEMS, LEAN MANUFACTURING
Keywords (user):	VALUE STREAM MAPPING, CASE STUDY

Title: **EVALUATION OF VALUE STREAM MAPPING IN MANUFACTURING SYSTEMS REDESIGNING**

Authors:

Ibon Serrano. Lecturer in Mondragon University. His main research field is focused in the manufacturing systems design and improvement.
Industrial Management Department. Mondragon University
Mondragon, Gipuzkoa (Spain).
iserrano@eps.mondragon.edu

Carlos Ochoa. MSc,. Professor in the University of the Basque Country. His research is mainly oriented to Production and Operations Management.
Business Organization Department. Polytechnic University College. University of the Basque Country, San Sebastián, Gipuzkoa (Spain).
oepoclac@sp.ehu.es

Rodolfo de Castro. PhD, Professor in the University of Girona. His research is focused on Lean Thinking in Production and Operations Management and in Supply Chain Management.
Business Organization, Management and Product Design Department. University of Girona, Girona (Spain)
rudi.castro@udg.es

Corresponding Autor,
Rodolfo de Castro. rudi.castro@udg.es

Universitat de Girona. Campus Montilivi. Edifici P-i

17071 - Girona (Spain)

Tel 972 418 872

Fax 972 418 399

TITLE: EVALUATION OF VALUE STREAM MAPPING IN MANUFACTURING SYSTEM REDESIGN

Keywords: Value Stream Mapping, lean production, manufacturing system redesign, case study.

Abstract

The Value Stream Mapping (VSM) technique, developed within the lean production paradigm, was presented as an innovative graphic technique to help practitioners redesign production systems. This paper presents the results of a project whose main purpose is to evaluate the real applicability of VSM to redesign disconnected flow lines based on manufacturing environments with a diversity of logistical problems. The research was developed using multiple case study methodology in six industrial companies. The experiences have served to highlight the following results: 1) the validity of VSM as a redesign tool is confirmed; 2) resources required for the application process are established; and 3) the differences between theoretical concepts proposed by VSM and their real world practical applications are indicated and analysed.

These results have led to conclusions relating to: 1) communication solutions for practitioners to obtain maximum efficiency when using VSM; and 2) definitions of theoretical development points for VSM to become a reference among redesign techniques.

1. INTRODUCTION

Manufacturing companies need to redefine and redesign their production systems in response to the competitiveness demanded by the challenges of present markets (European Commission 2004, Modarres et al. 2005). Therefore, it is necessary to have practical models that will support the manufacturing system redesign process. This need for practical techniques is recognised in the business sector as well as in academic literature on the subject.

A survey conducted in January 2004 by the Lean Enterprise Institute of 999 industrial companies belonging to the Lean Community (Marchwinski 2004) highlighted the need for these tools in the industrial sector, and provided a powerful argument in their favour.

As for the academic sector, calls for the development of adequate techniques have come from different areas. Hunt et al. (2004) highlight the need for new curricula in the production sector to include efficient means of designing advanced manufacturing systems. On the other hand, Seth et al. (2005) emphasise the urgent need for new techniques to achieve more productive environments.

The question is: what main requirements should these methods fulfil to be efficient in practice? When specifying those requirements, Wu (1996) focuses above all on the technical aspects that must be complied with, while Singh et al. (2006) highlight the importance of such improvements for enabling and facilitating group work and consistent decision making. The properties proposed by those authors could be summarised as:

- A common, easily understood language to allow decisions to be discussed by the people involved in the process.
- Efficiency in its use. The results of the process must be justified by the time and effort required by the team.
- A graphical and standardised interface language would help to make the application process easier.
- A tool focused on quantitative analysis. The decisions to be taken must be based on scientific and objective data analysis.
- A way to emphasise the initial problem situations as well as to provide clear guidelines and innovative concepts to improve the operational performance of the system.
- Reflection of a systemic vision. The study should not lose perspective of the system to be analysed and improved. The optimisation of one point of the process should be evaluated in light of its effect throughout the system.
- Seeing redefinition and redesign as a starting point for production system strategic improvement planning.

In this context, the lean production movement developed and introduced the value stream mapping (VSM) technique as a functional method aimed at rearranging production systems from a lean point of view (Rother et al. 1998, Womack et al. 2002, Pavnaskar et al. 2003).

Prior to analyzing and describing VSM, it is worth explaining that lean production is presented as a management philosophy based on the minimisation of all the resources used in all the company's activities. It looks for the identification and elimination of every activity that does not, from the customer's point of view, add value to the design, production and supply chain management-related processes of every company (Womack et al. 1990, 1996, Rother et al. 1998, Marchwinski et al. 2003).

According to Hayes et al. (2005) and Sakakibara et al. (1997), this production philosophy does not guarantee or enable operations to create an enduring strategic advantage over time. In spite of that, lean practices have been implemented too successfully around the industry in recent years not to be considered either valuable or deserving of special character and protagonism in the history of organizational management (De Toni et al. 2002, Zhongjun et al. 2005).

1.1. Value Stream Mapping

Although various applications have recently been developed (Jones et al. 2003, Tapping et al. 2002b), originally VSM was mainly focused on the analysis and improvement of disconnected flow lines in manufacturing environments (Rother et al. 1998). This framework is defined and described by Hayes et al. (1979a,1979b) in a well-known product-process matrix.

With regard to the VSM application process, it is based on five phases put into practice by a special team created for such a purpose (Rother et al. 1998). The phases are (1) selection of a product family, (2) current state mapping, (3) future state mapping, (4) definition of a work plan and (5) achievement of the work plan.

Some lean guidelines are needed to assist users in the definition of the future state map. These guidelines are summarised below:

(1) The production rhythm must be imposed by product demand. Takt time will be the concept that reflects such rhythm.

(2) Continuous flow must be established where possible (unique product transfer batches).

(3) Pull systems must be used among different work centres when continuous flow is not possible.

(4) Only one process, called the pacemaker process, should direct the production of the different parts. This process will set the pace for the entire value stream.

(5) The pacemaker process scheduling will deal with the maximisation of mix and volume production levelling using heijunka systems.

(6) Overall process efficiency should be improved. Projects such as work method and cycle time improvements, changeover time reductions and maintenance management could be launched by the VSM team.

For more detailed information about the development of each specific theoretical aspect of the guidelines see Rother et al., (2001), Harris et al., (2003) and Smalley, (2004).

Rother (1998) affirms that the main properties of VSM fulfil the utility requirements of a manufacturing redesign technique. For his part, Pavnahskar (2003), in his categorisation of lean techniques, also highlights the great potential of VSM to improve production systems. The arguments given are:

- The analysis of the initial situation is based on the acquisition and treatment of numerical data and uses a graphical interface that makes it easier to see the relationship between material and information flows.
- The systemic vision provided for each product family reflects manufacturing system inefficiencies. This aspect is also highlighted by Jones (2003).
- A common language is provided for the team to unify lean concepts and techniques in a single body. This point is also highlighted by Baker (2003).
- There is the possibility of it being the starting point of strategic plan improvement (Voelkel et al. 2003, Gregory 2003, 2004).

1.2. Manufacturing system redesign by other methodologies, methods and tools

A literature review shows that other tools, methods and methodologies in the field do not fulfil the same framework conditions as the VSM, or the same objectives or the same level or degree of completion of manufacturing system design.

Prior to analysing each of these models, it is necessary to highlight two important theoretical points on which VSM is based: the structuring of the production system and the differentiation between tools, methods and methodologies.

Regarding the first aspect, a manufacturing system could be structured as the aggregation of three subsystems (Roboam 1993, Wu 1996): (1) a physical or operational subsystem, referring to material flow; (2) an informational or auditory subsystem, referring to information flow; and (3) a decisional or managerial subsystem, referring to the process of decision-making. VSM is mainly related to describing and improving the first two subsystems, the physical and the informational.

Regarding the distinction between methods, methodologies and tools, despite there being a certain degree of generalised confusion concerning usage, a method can be described as a means of proceeding, a regulated and systematic way of obtaining an objective (Oyarbide 2003). Robson (2002) does not differentiate between method and technique, and therefore this article uses both terms interchangeably. On the other hand, Checkland (1981) and Pandya (1995) concur in their definition of methodology as a set of principles of a method, which, applied to the particular situation, guide the user to develop a method uniquely suited to the problem. Lastly, a tool could be defined as a mechanism to generate and clarify ideas or thoughts (Wu 1996, Pandya 1995). Given the characteristics of VSM described previously, in addition to being considered as a tool, VSM could also be classified as a method or technique, as the application phases and guidelines establish a clear set of rules to be followed to improve production systems.

The list below presents groups of methodologies, methods and tools that are potentially applicable to the redesign of manufacturing systems, based on a review of the literature.

- Flow diagram charts
- Structured systems

- Architectural systems
- Modelling and simulation software

1.2.1.- Flow diagram charts

The various modalities of flow diagram charts are a well-known set of tools to model any of the three subsystems mentioned. Among the diverse range of modalities one can find process activity mapping, which provides, among other tools, a series of mapping tools geared to supply chain management analysis (Hines et al. 1997, Hines et al. 1999, Jones et al. 1997). The business process reengineering (BPR) movement supported these kinds of tools for two reasons: first, they are based on the measurement and analysis of key point indicators (Hammer 1990, Davenport 1993); and second, various possible standardised languages make them practical and useful (Baudin 2002, Aguilar-Savén 2004). Although these tools can be used via specialised software on a quantitative or even dynamic level, their practical usage is focused on the qualitative and statistical analysis of processes (Oyarbide, 2003).

1.2.2.- Structured Systems

There is a set of methodologies that could be grouped under structured systems and that use adapted flow diagram charts as one of their tools (Wu 1996), (Pandya 1995). The three best known are:

- IDEF0 (Icam DEFinition Zero) (Roboam 1983)
- SADT (Structured Analysis and Design Technique) (Marca et al. 1988)
- SSADM (Structure System Analysis and Design Method) (Ashworth 1988, Downs et al. 1988).

These three methodologies perform a functional structural analysis to describe in a hierarchical way the activities of a system. Knowledge of the relationships among the different elements of a system improves the three subsystems. Nevertheless, they are mainly qualitative methods with superficial mathematical analyses that overlook the quantitative data of the production system (Baines et al. 1998, Wu 1996).

Among the most obvious differences between the three, it could be said that IDEF0 resembles a collection of tools more than a structured methodology (Wu 1996, Aguilar-Savén 2004), SADT has a simpler language that is related to BPR (Baines et al. 1996) and SSADM is the most detailed method adapted to manufacturing systems (Downs et al. 1998).

For his part, Baines (1998) shows that both IDEF0 and SADT are models that require relatively little time to construct, although the precision obtained in a real system will also be quite low.

1.2.3.- Architectural systems

An enterprise architecture is a model or a framework used to represent a company. This framework can be used, through planning and analysis of the company, to assist in selecting hardware and software products for use at different phases of the enterprise, to design organisational "reporting structures", and to study the flow of materials and information throughout the company. Without an enterprise architectural model, executives, managers, and technologists in a company are, by default, making decisions based on their personal models of the company. Typically, these are limited to small parts of the company, and only to one or two life phases. Furthermore, even these limited models are not effectively shared with the rest of the organisation (Bernus et al. 1996).

Three of the existing methodologies are considered as GERAMs (Generalized Enterprise Reference Models) developed by the IFAC/IFIP Task Force on Architectures for Enterprise Integration. As such, they extend more limited, specific enterprise models to a generalised model which can be applied to all industries and life phases. Without such an overall model of the company, interfaces among software tools, databases, work processes, etc, used in different parts and phases of the company are difficult or impossible to integrate (Bernus et al. 1996). These three models are known as:

- GRAI (Graphes à Resultats et Activités Interreliés) (Dougmeints et al. 1983)
- CIMOSA (Open System Architecture for CIM) (Kosanke et al. 1999)
- PERA (Purdue Enterprise Reference Architecture) (Williams 1998)

1.2.4.- Modelling and Simulation software

Material and information flow modelling and simulation software programmes are also interesting tools for redesigning manufacturing systems (Wu 1996). Different software packages in this area can be divided into two groups: discrete event simulation and dynamic systems software. Although the first of the two can be used to provide more precise models, dynamic systems software requires less effort (Baines et al. 1998). In spite of their dynamic character, level of accuracy and quantitative nature, as well their having a focus similar to the VSM framework, acquiring the required software, providing training and investing the amount of time necessary could be important reasons why the software is not so useful in many companies (Baines et al. 1998, Oyarbide 2003, Aguilar-Savén 2004).

Table 1 summarises the characteristics and field of application for each model described in this section. The characterisation has been conducted based on those properties considered best suited to each system. In this sense, it is worth making clear that each property has been identified using a generic and a global approach.

[Insert Table 1]

The differences most worth mentioning between each model and VSM are presented below.

First, the various flow diagram chart modes are too generic and, compared to VSM, not very well adapted to manufacturing system modelling.

As for structured systems and architectural models, it can be said that aside from their primarily qualitative character, they are mainly aimed at creating and implementing an integrated Information system on a company level, with a defined and/or rationalised structure or architecture based on BPR criteria (Aguilar-Savén 2004, Stanescu et al. 2002). In fact, profiles of the most important authors and teachers of such models reflect their information technology and information systems training and experience. VSM, however, is a technique that is much more focussed on flow adjustment analysis and development on a production process level than on a global company level. Although architectural systems can provide process analysis with a similar level of detail, based on a top-down deployment, their focus is not as geared towards production engineering.

With respect to modelling and simulation software, these tools are closest to the VSM field of application. Also, in order to highlight their level of affinity, during the past few years dynamic simulation software has been developed based on VSM language (for example, e-VSM and lean-modeller), as have real applications in which VSM maps have been complemented with computer simulations (Yang Hua et al. 2005, Gregory 2003). However, VSM usage is more focussed on generic analysis and improvement rather than the level of precision that can potentially be provided by simulators.

It can be concluded, therefore, that despite the possibility of using the different models cited to redesign production systems to a greater or lesser degree, their focus is distinct from the aims and methods of VSM.

2. RESEARCH AIMS

On a theoretical and academic level, VSM has been presented as an original and practical method to design and create efficient and flexible production environments. However, with respect to the real world practical application of the technique, different practices have been developed and reported since its creation, and every report has pointed out the strengths of the tool in contexts dealing with very specific and unique cases (Huang et al. 2005, Singh et al. 2006, Seth et al. 2005, Gregory 2004, Voelkel et al. 2003, Jacobs 2003, Sullivan et al 2002, Arbulu et al. 2003, Mackle 2003, James 2006). Nevertheless, there are no crossed or scientific analyses that explore in depth the true applicability and potentiality of the VSM in different discrete part manufacturing systems. In this sense, Pavnaskar et al. (2003) called for practical VSM applications to be developed to help establish the technique in the scientific sector.

Therefore, the main purpose of the present research consists in exploring and determining the VSM technique's real applicability for disconnected flow line environments.

Applicability through application has been used to validate the characteristics highlighted by the theory (Schippers 2000) and to research attempts to provide solutions to the following problems through an analysis of real world applications.

First, regarding model efficiency, does the VSM application process help production systems comply with project objectives?

Second, which resources are required to VSM application process? the following aspects shall be measured: times and terms required by team members in charge of implementation.

Finally, do real world applications reflect the theoretical potential of VSM? The aim is to evaluate both the real world usage of lean concepts provided by VSM and the possibility of integrating concepts and tools not necessarily developed within the lean movement.

From the research, we draw conclusions and make recommendations for practitioners to facilitate VSM's practical use and we identify the main theoretical points that must be refined and reinforced to convert it into a technique of reference for manufacturing system redesign.

3. RESEARCH METHODOLOGY

In order to find the solutions, a research methodology based on the multiple case study strategy was adopted (Eisenhardt 1989, Yin 1993, 1994).

We consider this methodology because it is the best way to have high validity with practitioners – the ultimate user of research – and also fits well with the refinement theory objective. Voss (2002) emphasises the importance of conducting and publishing case research because, not only is it good at investigating how and why questions, it is particularly suitable for developing new theories and ideas and can also be used for theory testing and refinement (McCutcheon et al. 1993, Meredith 1998, Snow et al. 1994). Many of the breakthrough concepts and theories in operations management, from lean production to manufacturing strategy, have been developed through field case research. Finally, case research enriches not only theory, but also the researchers themselves (Voss et al. 2002).

Another argument supporting the adoption of case study methodologies is put forth by authors such as Kitchenham et al. (1995) and Schippers (2000), who support them in research whose main aim is the evaluation of the applicability of methods and tools geared to the improvement of company performance, an area under which this research could be classified. Likewise, it is worth pointing out that a large amount of VSM analysis research using specific examples has employed case studies (Sullivan et al. 2002, Seth et al. 2005, Singh et al. 2006).

As is common in case research methodology, the entire process would be monitored and controlled by researchers who combined different ways to collect the data of the process. This multi-method approach helps to obtain the triangulation necessary to guarantee the credibility of the research (Denzin 1998, Robson 2002, Voss et al. 2002, Yin 1994). In this sense, observations and interviews are considered ideal methods for different phases of the research.

Observation is understood to mean the recording of an event exactly as it occurs; it is a direct data collection method that provides very specific understanding and perspectives which are not attainable using other methods (Snow et al. 1994). Interviews, on the other hand, enable the main actors in the process to participate in information generation, as research requires attitude, perception, motivation, knowledge and/or behavioural data, for which responses from personnel are therefore ideal (Snow et al. 1994, Voss et al. 2002).

Among the different types, this research has opted for semi-structured interviews, using flexible questionnaires to better record different interviewee viewpoints and to open the field of study to new perspectives. However, this does not mean that the format and method used in the questionnaire are not properly structured or organised to ensure consistency and avoid deviations (Yin 1994, Collins et al. 1997, Bourne et al. 2002).

Regarding the method adopted for data analysis, Eisenhardt (1989) and Voss et al. (2002) advise that this should be conducted in two stages: first, an internal case analysis (seeking triangulation between the different data collection methods adopted) and, second, a crossed analysis of all cases, as it is necessary to know each case before generalising and comparing cases.

The research programme established involves three main stages: (1) selection of ideal cases; (2) VSM application; and (3) process evaluation. Table 2 illustrates the sub-stages and how adopted data acquisition methods fit in.

[Insert Table 2]

As for temporal planning, the research took place over 12 months, between February 2004 and February 2005. The initial key company selection stage lasted for the first three months; the application of the four initial VSM stages ran through May, June and July; and finally, the suggested project impact was evaluated, and VSM was implemented during the months of January and February 2005. What follows is a more detailed description of the process followed for each stage.

4. RESEARCH DEVELOPMENT

The research team's first step was associated with finding the number of companies interested in applying VSM (see Table 2). These companies had to meet three main requirements.

First of all, the company should be suffering from a production and operations management-related problem in order to make a manufacturing system redesign process attractive. Second, the company should correspond with a disconnected flowline-based manufacturing system (repetitive, mixed, job shop), (Hayes et al. 1979, White et al. 2001). Finally, the chosen companies should have enough diversity among their manufacturing activities to allow generalisation of the main conclusions to the selected systems' framework (Miles et al. 1984).

The validation of these features among the twelve companies which were interested and fulfilled the initial requirements, along with determining the appropriate number of cases to allow in the research project (Eisendardt 1989), concluded with the selection of the six definitive cases by March 2004. This validation was undertaken through personal interviews with each company's project applicant and by visits to the facilities to learn more about the main logistical problems.

Once the companies were chosen, a special team was created in each of them with specified individuals to manage the VSM process (Rother 1998, Tapping et al. 2002a):

- The Value Stream Manager would be responsible for the product family where the VSM process is carried out. This person should report the evolution of the process to the general management of the company.
- The Facilitator would be the person who knew the production process best. The person in this role would be responsible for providing the required data and information.
- The Coordinator would collect the required data, manage the documentary files and act as a secretary in meetings.
- Finally, the Lean Specialist would be the role of the principal researcher. The main function would be to guide the team in technical lean manufacturing aspects and to provide tool training. Nonetheless, this person should not interfere in the team's decisions, as suggested by the literature on case studies (Yin 1994).

Team selection was carried out through a special evaluation to assure that every member had the required capabilities to start the VSM process. After each team was created, additional special educational training about lean manufacturing concepts and VSM was provided for its members in various special workshops.

Table 3 shows the diversity of the different companies involved in the final selection as well as the project applicant's and the selected teams' positions. As the reader probably already realizes, the activities, project descriptions, number of workers, product lines, main manufacturing processes, product-process and lay-out configurations, ways to respond to the market and initial lean level are quite different among them. The researchers determined this initial lean level based on the conclusions derived from the first semi-structured interview and a visit to each facility. In short, each company had to recognise and describe their previous experience in projects of this kind: changeover time reduction experiences; pull system implementation; JIT supplying; product-focused layout reconfiguration; production leverage; work methods and efficiency improvements.

[Insert Table 3]

Likewise, as can be seen in Table 3, the member profile of each team reflects, above all, individuals experienced with production and process engineering. Thus, the position of value stream manager may seem more like management and administration, and the coordinator's profile resembles a profile for a process technician, while the facilitator is a figure in a more ambiguous position: in each individual case he/she may respond, to a greater or lesser degree, from either a management or process perspective.

Once the companies and the team had been selected and trained, the aforementioned five major steps were carried out. Each team member was assigned a number of hours to develop the first four stages. These hours were defined on the basis of the suggestion, contained in the modest amount of literature written on this topic, that it takes a few days to complete the first four steps of the process (Keyte 2002, Womack 2001). Each of the members was assigned 24 hours for the value stream manager, the facilitator and the lean specialist, and 68 hours for the coordinator.

Anticipating that the toughest step would be collecting the production data, the coordinator would have more hours to develop tasks. In addition, three months of lead-time was established to work on the first four stages of the whole process. The assigned time would be integrated into the three month period as each team considered it appropriate to do so. Last of all, once the working plan was defined, its evolution would be evaluated by the research team in six months.

5. SUMMARY OF RESULTS

This section summarises the results obtained from the research. Following the analysis, both internal for each case and crossed for all cases, results were extracted, structured and presented according to the main issues identified at the start of the research (see Section 2 Research Aims).

5.1. Technique efficiency

First, an attempt shall be made to respond to the question of attaining objectives defined in the future state map. Table 4 synthesizes the indicators attained 6 months after the implementation of the plan.

[Insert Table 4]

As can be seen, 4 of the 6 companies complied with the proposed objective, company B nearly achieved 100% of it and company F did not meet its obligations at all. Therefore, it can be concluded that the VSM process has served as a guide and has met the established objectives quite satisfactorily, a view also supported by the final satisfaction evaluation interviews held with teams. Different companies, when asked to classify 4 points of VSM on a scale of 1 to 5, produced a range of scores between 3 and 5, demonstrating that VSM can be considered a satisfactory technique for redesigning production systems. Among the strengths of VSM highlighted by teams, the following two stand out: its validity as a consensual basis for future improvements and the corpus that acquire lean techniques.

Another point worth highlighting from both Table 4 and process evaluation is the lack of correlation between success and failure of the experience and the characteristics of production systems and the issue under analysis.

Regarding the relationship between companies' initial lean levels and the results achieved, companies that were initially better prepared were also those that, via VSM analysis, were able to detect interesting points for improvement among lean concepts and tools not sufficiently well known, such as the introduction of heijunka replenishment systems. In fact, in their appraisals, those companies have identified that as a strength.

5.2. Required resources

As explained previously, the few references about the duration of the first four stages of the process (from the selection of the product family to the definition of the working plan) indicate that the process could be completed in a few days. Nonetheless, the study has shown that the time dedicated by each member of the teams to various meetings and development tasks has been significantly higher, as has the lead time of the whole process.

[Insert Table 5]

Table 5 presents a brief report on the metrics associated with the effort required by the team. Although the range is too wide to conclude a valid mean value in each indicator, it is possible to draw conclusions about some qualitative aspects: (1) the coordinator was the bottleneck resource of the team and the time dedicated was related mainly to data collection and treatment processes; (2) the number of meetings was too high to share the information collected and to develop the future planned actions; and (3) the lead-time was shorter than the three months initially anticipated, but longer than one month.

The last evaluation interview also demonstrated that the hardest step in four of the six companies was data collection and treatment in relation with current state mapping. The other two companies showed the greatest effort in the future state mapping stage, related to the time required to discuss and approve the future situation.

There were several aspects that facilitated the application process of the four VSM phases. First, companies which had IT technologies such as ERP-s, with centralised production data, had an easier time collecting data for the initial map as they were able to make reliable comparisons with data from the plant. On the other hand, the use of electronic spreadsheets also facilitated the task of processing the large amounts of production data collected. These processing tasks mainly involved adding individual reference route data for each product family.

In addition, it was felt that there were two aspects that could have proven problematic, but in fact, were not an issue in terms of workload.

The first is choice of product family. Despite theoretical expectations that an identification method or algorithm would have to be employed (Duggan 2002, Hyer et al. 2002), practice proved that the choice was clearly made by the team, either because the product family was already sufficiently defined or due to logical criteria related to typologies or the functionality of each product in the catalogue.

The second issue concerns prioritisations of projects in the future map. In practical cases there were not any long debates about selection. Three out of six companies prioritised improvements involving greater application simplicity and less associated cost. Two companies selected projects involving a change of layout because of a need to tackle this kind of wastage during the first stage. The sixth company chose a project based on urgency.

5.3. Gap between theory and practice

This point attempts to synthesize the results obtained for the gap that exists between theory and practice regarding the real world usage, both of concepts and tools arising from VSM and other production approaches. Table 6 contains results for studies related to the use of lean concepts based on the application of VSM criteria.

[Insert Table 6]

As can be observed, not all concepts or activity guides provided by VSM theory are required and their employment is not expected in each practical case; in fact, on average, only 50% of the concepts provided are used. Therefore, 5 of the 6 cases also consider the use of aspects more closely related to the theory of constraints (TOC) (Goldratt et al. 1986, Shams-ur 1998, Watson et al. 2006), specifically the DBR (Drum, Buffer, Rope) scheduling system.

Responses from a final, definitive interview with each team were intended to provide deeper insight into the reasons why they opted for the final state map. In summary, despite not having used all of the lean concepts available, companies generally considered that the future state map represented a medium-high qualitative jump from their initial position.

When asked for the main reason for a lack of greater ambition in the future state map, responses were varied, but it was understood that the majority of companies considered the implementation of lean production flows to be too demanding in relation to effort and internal company resources. In addition, it was felt that many lean concepts were not adopted due to the lack of a real perceived benefit to pay back the aforementioned implementation effort.

So, the majority of companies chose to integrate concepts that provided solutions which were easier to apply, could be done in less time and required less effort, such as TOC, which corroborates the results obtained from observations.

To complete the results, there are two aspects worth highlighting that are not sufficiently reflected in Table 6. First, there seems to be a degree of confusion regarding pacemaker positioning. In fact, all companies that have adopted this point have made it coincide with the bottleneck. In reality, it is possible for the pacemaker and bottleneck to coincide - there are even references in the literature about cases where this occurs (Tinham 2003, Tomlinson 2002) - but they do not have to (Rother 2004).

Second, the establishment of continuous flows and FIFO lanes, involving the assignment of resources to specific references, has meant difficult decisions have had to be taken, in which, in addition to load capacity, diverse factors have had to be taken into account.

6. CONCLUSIONS

The results obtained from the research indicate that VSM is a useful, efficient and applicable tool for tackling the redesign of production systems based on disconnected flow lines. This is apparent from redesign results and in the satisfaction expressed by implementation teams.

The best way of summing up the conclusions is to organise them into two groups. First, we will present the main aspects that practitioners must know, and the literature does not comment on well enough, before starting to put into practice VSM. Second, some VSM theory refinement advice is provided to complete, enrich and convert the technique into one of the most important references for manufacturing system redesign.

6.1. Advice for practitioners

Despite the wide range of times dedicated by the various teams, the obtained mean values in the project (see results in Table 5) could be used as an initial reference to plan the duration of the project.

In summary, the greatest load falls on the figure of the coordinator who has a maximum commitment of 142 hours in the worst-case scenario. One should expect between 4 and 12 meetings and count on a lead-time of around 4 to 10 weeks maximum duration.

The practitioners should also dedicate more time to the current state map development phase, which can be speeded up using IT during the data contrasting process in the ERP and whose processing can be shortened using electronic spreadsheets.

On the other hand, it is interesting to note that the first phase – product family selection, the fourth improvement project deployment – did not involve a lot of time dedicated to decision-making, being conscious of the fact that in certain cases these points may be conflictive.

From experience we concluded that, apart from the correct management of the application process, achieving the initially defined time deadline required work on two key issues: (1) the work performance grade of the team; and (2) attention to the team's training process on lean and production system design concepts. Both of them are obviously related.

6.2. Theory refinement needs

The most important conclusion that can be drawn is that there is a large gap between the theory as proposed in the VSM literature and the level of usage in real world applications. Research has demonstrated that an important key to understanding this phenomenon is the perceived implementation complexity and difficulties in appreciating benefits.

In this sense, numerous companies have adopted intermediate solutions that are less ambitious. Therefore, an important area for improvement with regard to enrichment of the theory and of the guidelines provided, would be the inclusion of possible intermediate channels, such as the integration of TOC-DBR guidelines, which has been widely called for in different cases.

Another point that is related to the previous point but that requires theoretical reinforcement is the need to promote certain concepts that are underemployed. For example, heijunka systems are related to internalisation of the production rhythm based on internal supply, and while not particularly well known, study of them and training for them have proven to be of interest, particularly for companies with a greater involvement in lean production.

On the other hand, there is a particularly confusing aspect of theory application that must be clarified, i.e. the relationship between the bottleneck and the pacemaker process. In most cases the bottleneck responds to a fixed resource, but it would be interesting to develop a tool that could facilitate ideal pacemaker placement and incorporate bottleneck status and the typology of the production system.

Finally, another important future development to enhance VSM would be a tool which, based on a load-capacity analysis and demand forecasts, is able to evaluate the suitability of assigning references to specific posts in order to obtain continuous flows and connections via FIFO lines.

Therefore, the contribution of this article is an analysis of the three aspects related to the results: technique efficiency, resources required for application and the gap between theory and practice. Results have guided the definition both of key points, so that practitioners can perform the application process with greater efficiency, and of theoretical aspects to reinforce the conversion of VSM into a reference in production system redesign.

ACKNOWLEDGMENTS

The research team would like to thank the following participating companies for their collaboration: Astigarraga Kit Line, Hobest, Maier, GSB Forja, UEB and Geyser-Gastech.

REFERENCES

Aguilar-Savén, R.S. (2004) "Business process modelling: Review and framework". International Journal of Production Economics, Vol. 90, No 2, pp, 129-149.

Arbulu, R.J., Tommelein, I.D., Walsh, K.D., Hershauer, J.C., (2003), Building Research and Information. Vol. 31, No. 2, pp. 161-171.

Ashworth, C.M. (1988) "Structured Systems Analysis and Design Method (SSADM)". Information and Software Technology, Vol. 30, No. 3.

Baines T.S., Harrison D.K: , Kay J.M. and Hamblin, D.J. (1998) "A consideration of modelling techniques that can be used to evaluate manufacturing strategies", The International Journal of Advanced Manufacturing Technology", Vol. 14. pp. 369-375.

Baker, P., (2003) "We're all in this together", Works Management, No. 30, pp. 30-33.

Baudin, M. (2002), "Lean Assembly. The Nuts and Bolts of making assembly operations flow", Productivity Press, New York, USA.

Bernus, P., Nemes, L. and Williams, T.J., (1996), "Architectures for Enterprise Integration", Chapman and Hall, London U.K.

Bourne, M., Neely, A., Platts, K., Mills, J. (2002) "The success and failure of performance measurement initiatives: Perceptions of participating managers", International Journal of Operations and Production Management. Vol. 22, No. 11, pp. 1288-1310.

Checkland, P. (1981), "Systems thinking, systems practice" Wiley, New Jersey, USA.

Collins, R.S. and Cordon, C., (1997), "Survey methodologies issues in manufacturing strategy and practice research", International Journal of Operations and Production Management. Vol. 22, pp. 230-240.

Cooney, R. (2002), "Is Lean a universal production system? Batch production in the automotive industry", International Journal of Operations and Production Management, Vol. 22, No. 10, pp. 1130-1147.

Davenport, T.H., (1993). "Process Innovation: Reengineering work through Information Technology". Harvard Business School Press, Boston, Massachusetts, USA.

De Toni, A. and Tonchia, S. (2002), "New production models: a strategic view", International Journal of Production Research, Vol. 40, No. 18, pp. 4721-4741.

Denzin, N.K. (1998). "The research act: a theoretical introduction to sociological methods", Prentice Hall, New Jersey, USA.

Dougmeints, G., Breuil, D. and Pun, L. (1983), "La gestion de la production assistée par ordinateur", Hermes, Bordeaux, France.

Downs, E., Clare, P. and Cole, I. (1988). "Structured Systems Analysis and Design Method: Application and Context". Prentice Hall, London, UK.

Duggan, K.J. (2002). "Creating mixed model value streams. Practical Lean techniques for building to demand". Productivity Press, New York, USA.

Eisenhardt, K.M. (1989), “Building theories from case study research”, Academy of management review, Vol. 14, pp. 532-550.

European Commission, (2004), “Manufuture, a vision for 2020. Assuring the future of manufacturing in Europe”, Luxemburg.

Goldratt, E.M. and Fox, R.E. (1986), “The race”, North River Press, Massachusetts, USA.

Gregory, A. (2003), “Look before you leap”, Manufacturing computer solutions, February, pp. 30-31.

Gregory, A. (2004), “Running like clockwork”, Works Management, Vol. 57, No. 2, pp. 14-16.

Hammer, M. (1990), “Reengineering work: Don’t automate, obliterate”, Harvard Business Review, Vol. 68, No. 4, pp. 18-25.

Hayes, R.H. and Wheelwright, S.C. (1979a), “Link manufacturing process and product life cycle”, Harvard Business Review, Vol. 57, pp. 133-140.

Hayes, R.H. and Wheelwright, S.C. (1979b), “The dynamics of product-process life cycles”, Harvard Business Review, Vol. 57, pp. 127-136.

Hayes, R.H., Pisano, G., Upton, D. and Wheelwright, S. (2005), “Pursuing the competitive edge”, Wiley, New Jersey, USA.

Harris, R., Harris, C. and Wilson, E. (2003). “Making materials flow”. The Lean Enterprise Institute. Massachusetts, USA.

Hyer, N. and Wemmerlöv, U. (2002), “Reorganizing the factory”. Productivity Press, Portland, USA.

Hines, P., Holweg, M. and Rich, N. (2004), “Learning to evolve. A review of contemporary Lean thinking”, International Journal of Production Management, Vol. 24, No 17, pp. 994-1011.

Hines, P. and Rich, N. (1997), “The seven value stream mapping tools”, International Journal of Operations and Production Management, Vol. 17, pp. 146-64.

Hines, P. and Esain, A. (1999), “Value stream mapping: a distribution industry application”, Benchmarking: an International Journal, Vol. 6, No. 1, pp.60-77.

Hopp, W.J. and Spearman, M.L. (2000), “Factory physics: foundations of manufacturing management”, Mc Graw Hill, New York, USA.

Huang, C.C. and Liu, S.H. (2005), “A novel approach to Lean control for Taiwan-funded enterprises in mainland China”, International Journal of Production Research, Vol. 43. No 12, pp. 2553-2575.

Hunt, I., O’Sullivan, D., Rolstadas, A., Horan, M. and Precup, L. (2004), “Survey of manufacturing curricula from around the world”, Production Planning and Control, Vol. 15, No. 1 , pp. 71-79.

Jones D.T., Hines P. and Rich, N. (1997), “Lean logistics”. International Journal of Physical Distribution and Logistics Management, Vol. 27, No. ¾, pp. 153-173.

Jones, D. and Womack, J. (2003), “Seeing the whole”. The Lean Enterprise Institute, Massachusetts, USA.

Jacobs, J., (2003), “Towbar maker is pulled by demand”, Works Management, No. 10, pp. 10-13.

James, T., (2006), "Powering the transformation", Manufacturing Engineer, Vol. 85, No 1, pp. 26-31.

Jones, M. (2003), "Softly, softly", Works Management, No. 14, pp.14-15

Keyte, B. (2002), "Value Stream Mapping and Management". APICS Greater Jacksonville Seminar (web document), www.Lean.org.

Kosanke, K., Vernadat, F. and Zelm, M. (1999), "CIMOSA: enterprise engineering and integration",Computer in Industry, Vol 40, pp 83-97.

Mackle, K. (2003), "Take a walk downstream". Metalworking production, January, pp. 14-15.

Marca D.A. and Mc Gowan, C.L. (1988), "SADT: Structured Analysis and Design Technique", Prentice Hall, London, UK.

Marchwinski, C. and Shook, J. (2003), "Lean lexicon: a graphical glossary for Lean thinkers", Lean Enterprise Institute, Massachusetts, EEUU.

Marchwinski, C. (2004), "State of Lean report 2004" (web document), www.Lean.org.

Mc Cutcheon, D. and Meredith, J. (1993), "Conducting case study research in operations management", Journal of Operations Management, Vol. 11, No.3, pp. 239-56.

Meredith, J. (1998), "Building operations management theory through case and field research", Journal of Operations Management. Vol. 16, pp. 441-454.

Miles, M.B. and Huberman, A.M. (1984), "Qualitative data analysis: a sourcebook of new methods", Sage Publications. London, UK.

Modarress, B., Ansari, A. and Lockwood, D.L.. (2005), “Kaizen costing for Lean manufacturing: a case study”. International Journal of Production Research, Vol. 43, No. 9, pp. 1751-1760.

Oyarbide, A. (2003), “Manufacturing systems simulation using the principles of system dynamics”. Dissertation, Cranfield University, UK.

Pandya, K. (1995), “Review of modelling techniques and tools for decision making in manufacturing management”. IEEE Proceedings. Science, Measurement and Technology. Vol. 142, No 5, pp. 371-377.

Pavnaskar, S.J., Gershenson, J.K. and Jambekar, A.B., (2003), “Classification scheme for Lean manufacturing tools”, International Journal of Production Research, Vol. 41, No. 13, pp. 3075-3090.

Roboam, M. (1993), “La méthode GRAI. Principes, outils, démarche et pratique”, Teknea, Toulouse, France.

Robson, C. (2002), “Real word research: a resource for social scientists and practitioner-researchers”, Blackwell, Massachusetts, USA.

Rother, M. and Shook, J. (1998), “Learning to see: value stream mapping to add value and eliminate muda”, The Lean Enterprise Institute, Massachusetts, USA.

Rother, M., Harris, R., (2001). Creating continuous flow”. The Lean Enterprise Institute, Massachusetts, USA.

Rother, M. (2004), “Value Stream Mapping in a make–to-order environment” (web document), www.Lean.org.

Sakakibara, S., Flynn, B.B., Schroeder, R.G. and Morris, W.T. (1997). "The impact of Just In Time Manufacturing and its infrastructure on Manufacturing Performance". Management Science. Vol. 43, No. 9, pp. 1246-1257.

Schippers, W.A.J. (2000) "Structure and applicability of quality tools". Dissertation. Eindhoven University of Technology, Netherlands.

Seth, D., Gupta V., (2005) "Application of Value Stream Mapping for Lean operations and cycle time reduction: an Indian case study". Production planning and control", Vol. 16, No. 1, pp. 44-59.

Shams-ur, R. (1998). "Theory of constraints. A review of the philosophy and its applications". International Journal of Operations and Production Management. Vol. 18, pp. 4336-355.

Singh, R.K., Kumar S., Choudhury, A.K. and Tiwari, M.K., (2006) "Lean tool selection in a die casting unit: a fuzzy-based decision support heuristic". International Journal of Production Research, Vol. 44, No. 7, pp. 1399-1429.

Smalley, A., (2004), "Creating level pull". The Lean Enterprise Institute, Massachusetts, USA.

Snow, C.C., and Thomas, J.B. (1994). "Field research methods in strategic management: contributions to theory building and testing". Journal of Management Studies. Vol. 31, No. 4. pp. 457-480.

Stanescu, A.M., Dumitrache I., Curaj, A., Caramichai, S.I. and Chircor, M. (2002) "Supervisory control and data acquisition for virtual enterprise". International Journal of Production Research, Vol. 4, No. 5, pp. 3545-3559.

Sullivan, G.W., McDonald, T.N. and Van Aken, E.M. (2002). “Equipment replacement decisions and Lean manufacturing”. Robotics and Computer Integrated Manufacturing, Vol. 18, pp. 255-265.

Tapping, D., Luyster, T. and Shuker, T. (2002a). “Value Stream Management. Eight steps to planning, mapping and sustaining Lean improvements”, Productivity Press, New York, USA.

Tapping, D. and Shuker, T. (2002b). “Value Stream Management for the Lean Office. Eight steps to planning, mapping and sustaining Lean improvements in administrative areas”, Productivity Press, New York, USA.

Tinham, B. (2003). “How to ensure your IT adds value”. Manufacturing Computer Solutions, February, pp. 26-29.

Tomlinson B. (2002). “Applications of Lean Techniques in a discrete manufacturing environment”. Control. November, pp. 23-26.

Voelkel, J.G. and Chapman, C. (2003). “Value Stream Mapping: This tool puts you and your customer on the same page”, Quality Progress, May, pp. 65-69.

Voss, C., Tsikriktsis, N. and Frohlich, M. (2002). “Case research in operations management”, International Journal of Operations and Production Management, Vol. 22, pp. 195-219.

Watson, K. J., Blackstone, J.H. and Gardiner, S.C. (2006). “The evolution of a management philosophy: The theory of constraints”. Journal of Operations Management. In Press.

White, R.E. and Prybutok, V. (2001), “The relationship between JIT practices and type of production system”. The International Journal of Management Science, Vol. 29, pp. 113-124.

Williams T.J. (2005), "The Purdue Enterprise Reference Architecture and Methodology (PERA)", In Molina, A., Sanchez, J.M. and Kusiak, A., ed., "Handbook of Life Cycle Engineering: Concepts, Tools and Techniques", Chapman and Hall, London, UK.

Womack, J.P., Jones, D.T. and Roos, D. (1990). "The machine that changed the world: The Story of Lean Production". Rawson Associates, New York, USA.

Womack, J.P. and Jones, D.T. (1996). "Lean Thinking. Banish waste and create wealth in your corporation", Touchstone Books, London, UK.

Womack, J.P. (2001). "Jim Womack's email messages: 10 Lean steps for surviving the recession" (web document), www.Lean.org.

Womack, J.P., Womack, J. and Jones, D.T. (2002). "Seeing the whole. Mapping the extended value stream", Lean Enterprise Institute, Massachusetts, USA.

Wu, B. (1996). "Manufacturing systems design and analysis. Context and techniques", Chapman and Hall, London, UK.

Yang-Hua L. and Van Landeghem, H. (2005). "Simulation based Value Stream Mapping: the formal modelling procedure", 12th European Concurrent Engineering Conference, pp.79-85. Toulouse, France.

Yin, R.K. (1993). "Applications of case study research", Sage Publications, California, USA.

Yin, R.K., (1994), "Case study research, design and methods", 2nd ed., Sage Publications, California, USA.

Zhongjun, T., Rongqiu, C. and Xuejong J., (2005). “An innovation process model for identifying manufacturing paradigms”, International Journal of Production Research, Vol. 43, No 13, pp. 2725-2742.

TABLES AND FIGURES

	Methodology - Method - Tool	Quantitative/ Qualitative	Original focus	Purpose	Framework	Dynamic/Static
VSM	Method	Quantitative	Lean Production.	Efficiency and improvement	Manufacturing system	Static
Flow diagram charts	Tool	Qualitative	BPR	Process description and improvement	Manufacturing System Company	Static
Structured systems	Methodology	Qualitative	Information Systems-BPR	Business Structure	Company	Static
Architectural systems	Methodology	Qualitative	Information Systems-BPR	Business Architecture	Company	Static
Modelling and simulation software	Tool	Quantitative	Operations Research	Manufacturing System performance and improvement	Manufacturing system	Dynamic

Table 1. Characterization of models.

Research programme
<u>Stage 1. Case selection.</u> 1.- Gathering of expressions of interests by companies in resolving issues related to Production and Operations management. 2.- Selection of key companies. Criteria: -Serial manufacturing of discrete parts. -Productive issues in the dock-to-dock framework. *Telephone interview for case validation.* 3.- Suggested VSM application for each company. 4.- Creation of application teams. 5.- VSM training. *Team definition interview.*
<u>Stage 2. Application of VSM phases.</u> 1.- Choice of product family. 2.- Mapping of initial situation. 3.- Mapping of future situation (application of guidelines). 4.- Definition of a work plan. 5.- Implementation of the work plan (during 6 months). *Observation of the VSM process.*
<u>Stage 3. Process evaluation.</u> Based on the information obtained during *VSM process observation* and a *Final Evaluation Interview.*

Table 2. Research programme.

Company	A	B	C	D	E	F
Activity	Kit furniture	Water heaters	Forging	Thermoplastic parts	Detonators systems	Mechanized and stamped parts
Applicants positions	Industry Manager	Production Manager	Logistic Manager	Manufacturing Systems Manager	Poduction Manager	Process Engineering Manager
VSM team -Value Stream Manager: -Facilitator: -Coordinator:	 Industry manager Production manager Process technician	 Production manager Process Technician Process technician	 Industry manager Mfg manager Process technician	 Mfg Syst Mgr Mfg Syst Mgr Process technician	 Production manager Process Technician Process technician	 Prcss Eng Mgr. Process Tech. Process Tech.
Project description	Production system rationalization	Layout optimization	Order fulfilment process improvement in matrix section	Lean production system redesign	Manufacturing system redesign in electric detonators job shop	Manufacturing system's diagnostic and improvement in distribution blocks mechanization
Product family	Wood shelves	5 litre heaters	Matrix UP5 family	Telephony. TSM1 and TSM7 families	Electric detonators	Water and oil distribution blocks
Number of product line workers (approx)	70	40	40	80	100	100
Main manufacturing processes	Mechanization, painting, varnishing, retractility.	Heating body processing, valve assembly.	Mechanization, electro erosion	Injection, painting, chromium-plating, assembly	Extrusion, charge, assembly.	Injection, mechanization, assembly
Product-Process classification **IVAT [1]**	V	AT	A	V	AT	T
Parts number in the family	500	92	10	20	1600	150
Layout type	Functional	Product focused	Functional	Functional	Functional	Product focused
Production Strategy (Hopp et al., 2002)	MTS	MTS	MTO	MTS	MTO	MTO

Lean level [2]	1	4	2	3	3	3

Table 3. Cases under consideration in the research Project

[1]. The product-process configuration classification is based on the IVAT structure described by Hines (Hines et al., 1997).

[2]. The Lean level indicator is measured by a semi-structured interview done to the VSM team after the training.

COMPANY	Main goal	Initial state	Foreseen state	Foreseen 6 months later	Real state 6 months later
A	Lead Time reduction	23 days	18 days	20 days	20 days
B	Area reduction Workforce reduction	495 m^2 22.5 workers	340 m^2 17 workers	340 m^2 17 workers	340 m^2 18 workers
C	Lead time variability reduction	1–3 weeks	1 week	1 week	1 week
D	Lead Time reduction	26 days	20 days	22 days	22 days
E	Response time variability reduction.	5 –10 days	5 days	5 days	5 days
F	Response time variability reduction.	4–6 days	3 days	3 days	4-6 days

Table 4. Foreseen and achieved results

Evolution indicators	Mean	Range
Number of team meetings	6.8	4-12
Number of hours in meetings	16	8-24
Value stream manager's dedication (hours)	11.3	6-14
Facilitator's dedication (hours)	13.3	9-22
Coordinator's dedication (hours)	65.5	21-142
Lean specialist's dedication (hours)	16.8	9-26
Lead time (weeks)	7.16	4-10

Table 5. Required effort summarizing results

	A	B	C	D	E	F	Nº of applicants	% of applicants
Takt time	No	Yes	Yes	Yes	Yes	Yes	5/6	83.3%
Continuous flow	Yes	Yes	No	Yes	No	No	3/6	50%
Supermarket pull systems	No	No	No	Yes	No	No	1/6	16.6%
FIFO systems	Yes	No	No	Yes	Yes	Yes	4/6	66.6%
Pacemaker process election	Yes	No	Yes	Yes	Yes	Yes	5/6	83.3%
Mix levelling	Yes	Yes	Yes	Yes	Yes	Yes	6/6	100%
Volume levelling	No	No	No	No	No	No	0/6	0%
Heijunka systems	No	No	No	No	No	No	0/6	0%
Other concepts (no Lean)	DBR.	No	DBR.	DBR.	DBR.	DBR.	5/6	83.3%
Applied Lean concepts	4/8	3/8	3/8	6/8	4/8	4/8		
Applied Lean concepts %	50%	37.5%	37.5%	75%	50%	50%		

Table 6. Lean concepts employment.