Using Experts to Develop a Supply Chain Maturity Model in Mexico

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Abstract

Purpose
This research develops a supply chain maturity model so that Mexican firms can evaluate their current supply chain operations and develop an improvement roadmap.

Design/methodology/approach
The Delphi Method was used with eighty experts in Mexico. The Delphi Method gathers multiple perspectives on supply chain operations and delineates a path to reach a group consensus. The results lead to the specification of a Supply Chain Maturity Model $S(CM)^2$. $S(CM)^2$ is validated through experimentation and a pilot test to verify the ability of the model to help managers assess the supply chain processes of a firm by identifying their maturity level in each model viewpoint. A pilot test with a Mexican firm demonstrates the practical implementation of the model.

Findings
The research results in a meta-model, called the Supply Chain Maturity Model $S(CM)^2$, that describes supply chain maturity at five levels across multiple competency areas, and provides guidance to specify an improvement plan.

Research limitations/implications
The meta-model was developed in Mexico, it may not apply to the operations of supply chains in other countries. Additionally, the large scope of the meta-model calls for further testing and refinement.

Practical implications
The research provides a means for firms to evaluate their supply chain operations and develop improvement plans.

Originality/value
The paper contributes by integrating the ideas of reference frameworks, capability maturity models, and improvement processes and demonstrates how a holistic meta-model can be developed to evaluate supply chain operations.

Keywords: Maturity Model, Supply Chain, Delphi Method

1 Introduction

In the domain of supply chain management, much research and practice focuses on improving various narrow aspects of supply chain operations such as the information technology viewpoint (Shapiro, 2001), the business process viewpoint (Lockamy and McCormack, 2004a) or the inventory management viewpoint (Lee et al., 1997). Within all these viewpoints, many advances have been made leading to improvements in supply chain operations. However, the multitude of models and advice can leave firms overwhelmed and confused on the best means to embark on a supply chain improvement program. Moreover, some projects, while necessary, if done at the wrong time or without doing other projects may do little to improve the supply chain operations. Making decisions about supply chain improvements without adequate cross-disciplinary analyses may lead to regrettable decisions resulting in waste of time, money, and market position. For these reasons, there is a need to provide guidance based on best practices and known successes on how to go about improving supply chain operations.

There are many improvement programs such as total quality management, six sigma, continuous process improvement and others that are available for companies to improve their operations. However, none of these improvement programs specifically address supply chain operations. What is needed is a model that describes the supply chain operational areas that a company should focus on for improving their overall performance. In this paper, we develop a Supply Chain Capability Maturity Model, hereafter abbreviated $S(CM)^2$. The $S(CM)^2$ is intended to help Mexican firms evaluate their supply chain operations and to develop a roadmap to improve those capabilities.

The paper is organized as follows. Section 1.1 reviews the literature on reference models, maturity models, and their application to supply chain management. Section 2 describes the research methodology and Delphi Method. Section 3 describes the $S(CM)^2$. Section 4 describes the experiments and pilot study to test the model. Section 5 discusses the model and concludes with a summary of the research findings.

1.1 Literature Review

For individual firms, enterprise reference frameworks such as Zachman, CIMOSA, and GERAM define a means to describe the structure of the firm, its decomposition into subsystems, the relationships between the subsystems, and the guiding principles for the design of the subsystems (Giachetti, 2010). As such, these frameworks are meta-models that show how all the various aspects of a firm can be integrated. Characteristic of these approaches is a modeling methodology that divides the enterprise into multiple views and abstraction levels. Svensson (2003) makes the same argument that more holistic modeling is required for supply chains. A view is intended to be an orthogonal perspective of a limited aspect of the enterprise. While an abstraction level is a matter of detail, generally described in terms of the decision time-horizon: strategic, tactical, or operational. The emphasis of this line of research has been on obtaining a holistic, high-level model with which decisions concerning enterprise design can be based on. These frameworks do not provide roadmaps or plans on how to improve the enterprise operations. To do this is left to other improvement methodologies such as total quality management, six sigma, or continuous process improvement. Nor do these models support the modeling of supply chain operations.

The idea of a modeling framework has been adapted to the supply chain literature. The Supply Chain Operation Reference model (SCOR) is a cross-functional framework developed by an industry group called the Supply Chain Council, consisting mainly of large US corporations (Stewart, 1997; Huang et al., 2004). SCOR provides a high-level model of supply chain operations as Plan, Source, Make, Deliver, and Return. However, unlike the enterprise reference frameworks, it is intended to provide a structured process for improving the supply chain (Holmberg, 2000). The SCOR model would be used to guide companies on modeling their processes and then benchmarking performance against other supply chains. Then the company can devise improvement plans to improve their performance vis-à-vis the benchmarks (Bolstorff and Rosenbaum, 2003).

The Capability Maturity Model (CMM), developed by the Software Engineering Institute at Carnegie Mellon, was commissioned by the US Department of Defense so that they could assess the ability of companies to develop software. The CMM defines five maturity levels of an organization's development processes, where a maturity level describes how well a company manages their processes. The idea being that at higher maturity levels, companies are better managed and consequently any projects they conduct will have less risk and be more likely to deliver a quality product that meets the budget and schedule. The great success and wide adoption of CMM motivated Carnegie Mellon to expand the scope of the model to now include any system development via the Capability Maturity Model Integration (CMMI), and it has motivated the development of similar frameworks in other disciplines (Bunting et al., 2002).

Many of the aforementioned ideas of maturity have been adapted to supply chains. Stevens (1989) presents a model that consists of four stages named: baseline, functional integration, internal integration, and external integration. The model recommends that an enterprise first integrates the internal operations and then the external operations. While useful this advice is very abstract and provides little actionable advice. Cooper et al. (1997) seek to differentiate supply chain management from a purely logistics perspective and define a model that highlights six key processes within an enterprise: Purchasing; Logistics; Marketing and Sales; Production, Research and Development; and Finance. Their model does not consider how an enterprise would go about determining their capabilities in any of these processes nor how to improve them. These two models are theoretical constructs with little empirical support. An exception is the work by McCormack and Lockamy (2004b) who adopt a business process orientation in their empirical study of the correlation between process maturity and supply chain performance. Using a survey instrument based on the SCOR model, their results indicated some correlation on a few measures, but overall they conclude that their measures of business process maturity might be too high-level to reveal correlations with business performance.

Knowledge and research literature are well developed for supply chain modeling, improvement methods, and supply chain operations. What is under-developed is an actionable set of guidelines to apply this knowledge in the assessment and improvement of a company's supply chain operations. Due to the existence of the knowledge and information, this suggests a research methodology that can capture this knowledge, integrate it, and develop a supply chain improvement meta-model. To accomplish this we use the Delphi Method discussed in the next section.

There are several precedents for our utilizing the Delphi Method to research supply chain maturity. For example, the evaluation of information technology in logistics firms (Kengpol and Touminen, 2006), the identification of supply chain solution in a building sector (Hong-Minh et al., 2001), and the impact of ERP on supply chain management (Akkermans et al., 2003) were all studied via the Delphi Method. In our context, the advantage of a Delphi Method is it allows us to obtain a multi-disciplinary assessment of necessary supply chain perspectives, maturity, and improvement methods.

What distinguishes the present work from the literature is the definition of maturity levels is based on the Delphi Method to aggregate and organize expert opinion. We also discuss a pilot study where the resulting maturity model was used to evaluate a company's supply chain operations and develop improvement plans. Finally, the model is based on the business operations in Mexico, and therefore might provide some insights as to how supply chain operations differ between developing counties and developed countries.

2 Research Methodology

The Delphi Method was developed by the Rand Corporation in the 1950's with the objective to provide a technique to achieve the most reliable consensus of a group of experts. The Delphi Method structures group communication so that individuals and the group as a whole can deal with a complex problem (Linstone and Turoff, 1975; Okoli and Pawlowski, 2004). The Delphi Method involves the iteration of three activities:

1. gather the opinion of a group of experts, generally using a survey
2. synthesize and statistically summarize these opinions
3. provide feedback to the participants seeking a revision in their judgments, if any.

Figure 1 depicts the research methodology divided into three phases. Prior to starting the Delphi Method, we did an extensive literature review to provide an initial maturity model that the experts could build upon. The purpose of the initial maturity model was to reduce the number of iterations of the Delphi Method required to reach consensus. To create the initial maturity model, we drew heavily on the modeling approach advocated by CIMOSA and GERAM of having multiple viewpoints and abstraction levels. From the CMMI, we adapted their five-stage maturity model. Merged together these models provide three dimensions that provide boundaries within which to conduct the Delphi Method.

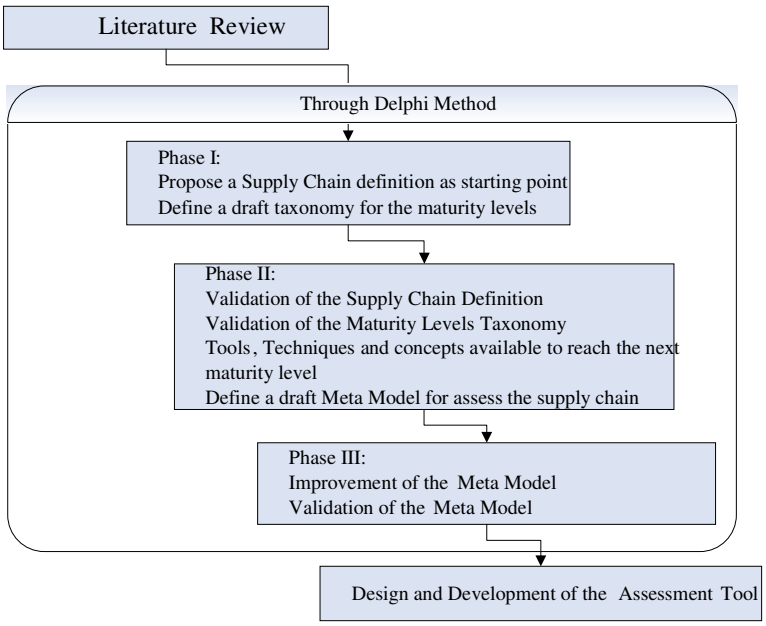

Figure 1: Research Methodology

The research progressed according to the Delphi Method as follows. In Phase I, the experts were asked to classify supply chain knowledge into the framework so that we obtained a consensus definition of supply chain operations, views, and abstraction levels as well as a draft taxonomy of the maturity levels. The Phase I results were collected, analyzed, and synthesized into an updated maturity model. To synthesize the results of Phase I, we classified opinions as either essentially the same but expressed differently or different in content. When the content was the same but differed in expression, we combined the responses, editing it to obtain a summary response reflecting the content. Where significant variations in opinion were collected, then we combined the responses but highlighted where differences occurred so that in Phase II the experts would be able to respond directly to where consensus was not achieved.

In Phase II, the experts provided feedback to validate the results of Phase I, and to resolve the differences highlighted in Phase I. Additionally, the experts generated a list of tools, techniques, and methodologies to associate with each maturity level. Again, as in Phase I, the results were analyzed and synthesized to obtain a consensus model that was sent for review once more in Phase III.

In Phase III, no additional information was sought from the experts, but rather we sought to clarify the model and reach consensus. Following consensus, the final maturity model, called $S(CM)^2$ was obtained. To validate the model, experiments and a case study were conducted. The model validation is described in a later section.

A key element of the above described Delphi Method is the identification and selection of experts. An expert is a professionally or scientifically qualified individual who is recognized in the field of study. In this research, an expert was defined as anyone with five or more years of experience in supply chain operations or closely related fields such as logistics, procurement, or sales. A pool of potential experts was identified by using the extensive relationships the university has with Mexican industry. Expertise was determined by a questionnaire on qualifications and experience. Each expert received an invitation letter requesting their participation in the research, describing the objective of the research, and a brief explanation of the research approach. To account for the possibility of industry-specific viewpoints, the experts were drawn from a variety of industries shown in Table 1. The average experience of the experts consulted was twelve years.

In addition to identifying experts, a second relevant task is to define the sample size for each phase. In the literature, the number of experts reported covers a wide range depending on the purpose of the research. For example, Holsapple and Joshi (2000) use 31, Akkermans et al. (2003) use 23, Okoli and Pawlowski (2004) use 18, and Haynes (2007) uses 20. According to Turoff (1970), the most recommended values are between 10 and 50. In the research project, we decided to keep the number of experts for Phase I at the low end of this range because the purpose of Phase I was to obtain a variety of opinions on the definition of the main dimensions of the maturity model. In Phase I, we obtained responses from 18 experts. In Phase II, the research method uses experts to first respond to the results of Phase I, and then the experts also build upon the maturity model by identifying the tools, techniques, and methods to associate with each maturity level. Consequently, for Phase II, we wanted more experts to see if there is wide agreement with the results of Phase I, and because the identification of tools, techniques, and methods covers a much larger spectrum such that a wider range of opinions would be helpful. In Phase II, we obtained responses from 80 experts in total, including all of the experts used in Phase I.

Table 1. Industries Represented by Experts and Their Number

Glass industry (3)
Air condition equipment (5)
Consultancy and business services (8)
Imports and sales (3)
Logistics services (5)
Automotive parts and supplies (4)
Pharmaceuticals (2)
Cement and building materials (3)
Footwear (1)
Electric industry (5)
Publishing newspapers, journals, and magazines (1)
Chemical industry (3)
Food and agricultural products (7)
Computer parts and software (4)
Furniture (4)
Steel and metals industry (6)
Medical devices (2)
Beauty supplies (1)
Construction equipment (3)
Beverages (9)
Home improvement industry (1)
Plastic Industry (3)

Once the model was built, the next step was to verify its conceptualization through a comparison with the models previously reviewed such as SCOR and GERAM. After the verification, the model was validated as a diagnostic tool through the application of a case study. The case study describes a couple of enterprises and the participants in the study were asked to identify the maturity level of the enterprises. A second validation process was run in parallel to increase the confidence in the model. The second validation involved interviews with experts in the supply chain field. Their comments and responses were analyzed to define strengths, weaknesses, and future research related to the model. Once the meta-model was validated, the final step was to design an assessment tool, which allowed passing from one maturity level to the next one.

3 The Supply Chain Capability Maturity Model

The Delphi Method's iterative phases of soliciting expert opinions, organizing the opinions, and soliciting revised opinions led to the Supply Chain Capability Maturity Model S(CM)^2. Figure 2 depicts the S(CM)^2 as consisting of three dimensions: the supply chain views, the abstraction levels, and the life-cycle maturity levels. Each box in the model denotes the interaction of the three dimensions and contains descriptions and assessment questions associated with that maturity level in that view and abstraction level. For example, the intersection of the inventory view, manageable level, and tactical abstraction level would include a description of what inventory capabilities at the tactical time-frame are required to be at the manageable level. The model is designed such that being at maturity level 3 in supply chain view Production Systems indicates the enterprise also possesses all the capabilities of levels 1 and 2 in that view.

For each maturity level, the model defines key improvement factors and appropriate tools that a firm can use to move up to the next higher maturity level. This is an important aspect of the model because once an enterprise determines its maturity level, then the next question is how to improve supply chain capabilities? This is done by defining an improvement roadmap using the key improvement factors and tools associated with each maturity level.

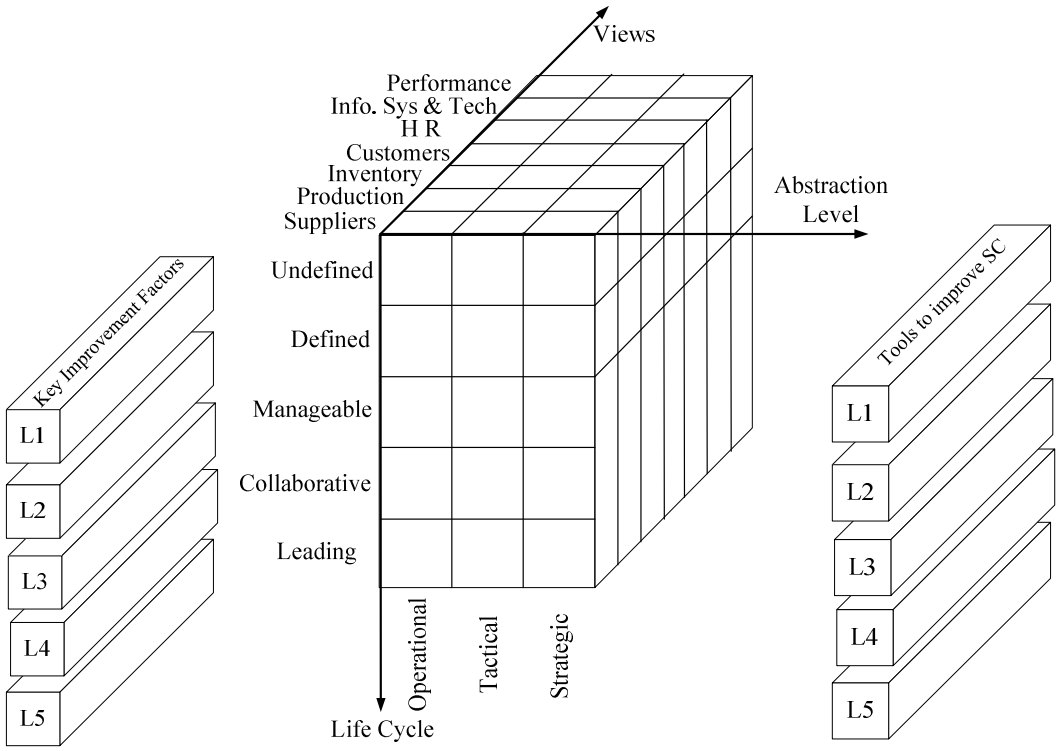

Figure 2: Graphical depiction of the S(CM)^2

3.1 Maturity Levels

Table 2 defines the maturity levels from lowest to highest. All enterprises are assumed to start at the Undefined Level. Note that in the model an enterprise can be at different maturity levels in different model views. The assessment of maturity level is done by the assessment tool described in a later section.

Table 2. Maturity Levels

Level	Level Name	Description
1	**Undefined**	Describes a competency area for which the enterprise has no documentation or standardization. The processes are ad hoc, dependent on the person doing the activity, and reactive to the environment.
2	**Defined**	Describes a competency area for which the enterprise has defined the process and procedures. The competency areas are isolated and there is little formal efforts to integrate the many processes.
3	**Manageable**	Describes a competency area for which the enterprise has defined established procedures that they measure and manage to those measurements. Moreover, the enterprise has taken action to integrate and coordinate the internal processes and systems of the enterprise.
4	**Collaborative**	Describes a competency area for which the enterprise has established procedures to collaborate with suppliers and customers.
5	**Leading**	Describes a competency area for which the enterprise has established procedures to collaborate with suppliers and customers, it measures these practices, and regularly obtains feedback to improve these practices.

3.2 Supply Chain Views

The supply chain views describe competencies that a firm needs to master in order to achieve one or more enterprise goals. In Phase I, the experts were asked to identify, classify, and prioritize competencies needed for supply chain operations. These were categorized into seven views. In Phase II, the experts were asked to concur with the categorization performed or to suggest changes to the categorization. The final consensus defined seven views that collect all the needed supply chain competencies. The views are to some sense orthogonal in that there is minimum overlap of concepts between views. The definitions of the views are:

Supply Chain Management & Logistics: This view contains functions, processes, activities, and tasks related to the integration, collaboration, and development of the suppliers. The processes include defining policies to select and develop suppliers; defining collaboration strategies with the suppliers; implementing quality assurance in the transportation and delivery of raw materials; and making commercial agreements such as incoterms.

Production Systems: This view includes the functions, processes, activities, and tasks regarding the transformation of the product or service. In other words, the reference actions, which add value to the product or service, such as reduction of defects, scrap, and reworks; documentation and standardization of functions and processes; internal logistics issues; deployment of projects to reduce the lead time; implementation of production planning strategies etc.

Inventory Management: This view encloses all the reference actions related to the inventory management and control. Therefore, reference actions related the management and control of all kinds of inventories such as raw materials, finished goods, work in process, scrap, spare parts, etc. are included in this view.

Customer Relationship Management: The customers view includes all the reference actions in regards to meeting the customer's expectations. Consequently, some of the actions enclosed in this view are identifying the customer needs; attending the customers' complains; developing customers' loyalty to the company products and services; following up the sale after delivery; implementing projects to increase the perception of value in the products and services provided by the enterprise etc.

Human Resource Management: The Human Resources view contains the reference actions related to the enterprise's employees, their integration in the company and the work environment. Therefore, in this view are reference actions such as training; development of a work culture; implementing actions to reduce the employees' turnover; implementing projects to improve the enterprise's work conditions; development of rewarding strategies etc.

Information Systems & Technology Management: This view encloses the reference actions directly linked to the development and implementation of information systems, and the technology management processes. Some of the actions included in the view are evaluating and implementing technological solutions such as ERP systems, RFID solutions, Warehousing Management Systems; automated equipments and so on; documenting and standardization of the data collection process; implementing projects to reduce the down times in the information systems and equipments of the enterprise etc.

Performance Measurement Systems: This view comprises the reference actions oriented to measure the enterprise's performance regarding processes, functions, and employees. Thus, some of the reference actions enclosed in this view are defining the enterprise KPI's; defining the periodicity of the information analysis concerning the performance of a process, function or employee; communicating to the employees the meaning of each performance indicator, and how to calculate it; standardize the use and presentation of the performance indicators and so on.

3.3 Abstraction Levels

The $S(CM)^2$ adopts the common conceptualization of three abstraction levels of strategic, tactical, and operational (Ballou, 2004). The strategic level considers those activities that should be done in a long time period, generally during more than one year. The tactical perspective considers an intermediate time horizon; generally less than one year. Finally, the operational perspective considers short-range activities on the order of hours or days.

3.4 Life-cycle Maturity Assessment

Figure 3 shows the assessment process, which starts with completing a questionnaire. The questionnaire helps managers to determine the company's maturity level classification for each view in the $S(CM)^2$. The questions were developed based on the reference actions of the model. The questionnaire has seven sets of questions; each set is defined by view, and this arrangement is similar to what is done with the assessment tool used by the CMMI. Table 3 shows a subset of the questions used to assess the enterprise's supply chain processes according to the suppliers view. Similar questions were developed for the other views as well.

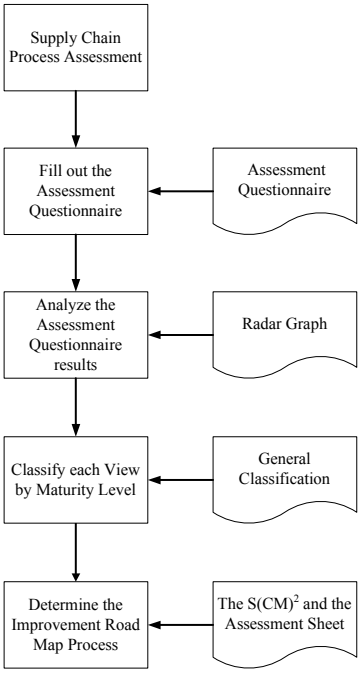

Figure 3: The S(CM)^2 Assessment Methodology

Within a view, each question assesses attainment of a single maturity level in that view. The possible answers for each question are "yes" or "no". When the answer is "yes", then the enterprise should document the evidence that supports the affirmative answer. A negative answer in one of the level questions implies an improvement opportunity because the expected level characteristics are not meet. Thus, the enterprise receives a maturity classification of the last level completed. The questions that are answered no are used to define an improvement roadmap based in the reference actions and the tools recommended in the model.

Table 3: Partial Assessment Questionnaire for the view Suppliers

Level	Questions	Answer	Evidence
Undefined	1. The main problems related to the supply of raw materials and consumables are identified and documented. 2. There are improvement projects oriented to solve the problems identified in the last question.		
Defined	3. There are processes documented and implemented to assess the quality of the raw materials and consumables. 4. There are policies documented and implemented to add a new supplier to the enterprise's suppliers catalog. 5. There are meetings periodically with the suppliers to evaluate and to provide feedback related to their service level.		

Manageable	6. There are processes documented and implemented to assess the suppliers' service level. 7. There are processes which collect data and provide statistical information related to the delivery time and order completion of every supplier. 8. There are projects jointly with the supplier to develop and to integrate them in the enterprise's supply chain processes. 9. There are policies documented and implemented to select and to hire outsource services (3rd Party Logistics, 4th Party Logistics).		
Collaborative	10. There are procedures documented and implemented to determine the level of collaboration and integration among the suppliers and the enterprise's processes. 11. There are procedures documented and implemented to determine if it is worth to invest in developing a supplier. 12. There are procedures documented and implemented to develop the suppliers' service level and the collaboration. 13. There are procedures documented and implemented to certify new suppliers and to renew the certification to current suppliers.		
Leading	14. There are procedures documented and implemented to deploy projects jointly with the suppliers to develop new products. 15. There are procedures documented and implemented to aware the suppliers in advance about any change in the raw materials and consumables for the new or current products. 16. There are documented and implemented best practices related to collaboration and selection of suppliers. 17. There had been Benchmarks studies about the collaboration and supplier selection processes developed by the enterprise.		

4 Model Validation

The S(CM)^2 has two objectives of providing a model to measure the supply chain performance of current operations, and to provide a method for the company to develop an improvement roadmap. Our model validation examines whether the S(CM)^2 is suited for these two uses: first, that the model can be used to assess an enterprise's supply chain operations, and second, that the model can be used to develop an improvement roadmap. Two approaches to validation were performed. The first is an experiment of the assessment capability of the model, and the second is a pilot test of the model in an actual enterprise to demonstrate whether it can develop an improvement roadmap.

4.1 Experiments

The experiments' objective is to determine whether practitioners would be able to use the model and correctly assess the enterprise's maturity levels. A correct assessment means that after reading the enterprise description, the participants could review the model questions and they assign a maturity level matching what is shown in Table 4.

To do the experiments, we created descriptions of two fictitious enterprises named *X* and *Y*. The enterprise descriptions were developed to describe different levels of maturity for each enterprise and view as shown in Table 4. The maturity levels are assigned ordinal numbers shown in parenthesis to use in statistical analysis. The enterprise descriptions described the company, its mission, and operations.

Table 4: Intended Maturity Levels for each Enterprise

View	Enterprise *X*	Enterprise *Y*
Suppliers	Defined (2)	Collaborative (4)
Production	Manageable (3)	Defined (2)
Inventories	Undefined (1)	Manageable (3)
Customers	Manageable (3)	Defined (2)
Human Resources	Undefined (1)	Collaborative (4)
Information Systems and Technology	Defined (2)	Collaborative (4)
Performance Measurement Systems	Defined (2)	Manageable (3)

Fourteen participants were asked to review the enterprise descriptions, and for each model viewpoint, to specify the maturity level. Participants were selected so that they represent industry practitioners who would use the model for assessment. We were able to recruit fourteen participants for the experiments.

The null and alternative hypotheses are defined as follows

H_o: The mean of the participant answers is different than the intended value

H_a: The mean of the participant answers is equal to the intended value

The two-sided student t-test was used to test the null hypothesis at the 5% confidence level. Table 5 shows the responses obtained from the fourteen participants and the results of the student t-test in which the null hypothesis was rejected for each viewpoint. Consequently, there is evidence to accept the alternative hypothesis that the mean participant response equals the intended value. This indicates

that the S(CM)^2 can serve its purpose to enable industry practitioners to accurately and reliably assess an enterprise's maturity level.

Table 5: Results of the Case Study

	Enterprise X							Enterprise Y						
Participant	S	P	I	C	HR	IS&T	MS	S	P	I	C	HR	IS&T	MS
1	2	3	1	3	1	2	1	5	2	4	1	5	5	3
2	2	3	1	2	1	3	2	5	1	4	1	5	3	4
3	4	4	2	2	2	2	2	4	3	3	3	5	4	3
4	2	3	1	4	1	1	2	5	1	5	1	4	5	2
5	2	3	1	2	1	2	2	3	2	3	2	4	3	2
6	2	3	1	2	1	2	1	4	1	2	1	5	4	2
7	2	3	1	2	1	2	2	4	2	4	2	4	4	2
8	2	4	1	3	1	3	2	4	2	3	2	5	5	2
9	2	2	1	3	1	2	1	4	2	3	1	3	4	3
10	2	3	1	2	1	2	2	3	2	3	1	4	3	2
11	2	4	1	2	1	2	2	5	2	3	2	4	4	3
12	2	3	1	3	1	3	2	3	2	3	2	4	4	2
13	3	4	1	2	1	3	2	4	1	4	2	4	5	4
14	2	4	1	4	1	2	2	5	2	3	2	4	5	4
Avg	2.21	3.29	1.07	2.57	1.07	2.21	1.79	4.14	1.79	3.36	1.64	4.29	4.14	2.71
std dev	0.58	0.61	0.27	0.76	0.27	0.58	0.43	0.77	0.58	0.74	0.63	0.61	0.77	0.83
μ_0	2	3	1	3	1	2	2	4	2	3	2	4	4	3
t =	1.38	1.75	1.00	-2.12	1.00	1.38	-1.88	0.69	-1.38	1.79	-2.11	1.75	0.69	-1.30
$t_{0.025,13}$ =	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16	2.16
Result	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK

In addition to the mean response from the participants, we analyzed the distribution of responses from the participants.

Table 6 shows the percentage of each response with the expected response shaded. For Enterprise X, the greatest difference occurred when assessing the customer view 'C'. The intended maturity level was 3, but 57% of participants assessed it to maturity level 2.

For the customer view 'C' in Enterprise X, the highest response was level 2, when the expected level was 3. However, in an actual setting mistakenly assessing a lower level than the actual level is not very problematic because the enterprise will not skip the improvement actions dictated for that level. So for example, if this was an actual case and the enterprise was assessed at level 2 instead of level 3, then the enterprise would have as part of its improvement roadmap doing the improvement actions for level 3, which it already possesses. More problematic is when the enterprise is assessed at a level higher than its actual level. This could result in a waste of time and resources because the enterprise focuses on improvements for which the prerequisite capabilities are not yet attained.

In all the views the participant's assessment was never more than a single level from the actual with the single exception of the information view for Enterprise Y. These results help to suggest that the model can help users consistently assess maturity levels.

Table 6: Distribution of the Case Study Answers

	Enterprise X							Enterprise Y						
Level	S	P	I	C	HR	IS&T	MS	S	P	I	C	HR	IS&T	MS
1			93%		93%	7%	21%		29%		43%			
2	86%	7%	7%	57%	7%	64%	79%		64%	7%	50%			50%
3	7%	57%		29%		29%		21%	7%	57%	7%	7%	21%	29%
4	7%	36%		14%				43%		29%		57%	43%	21%
5								36%		7%		36%	36%	
Ref	2	3	1	3	1	2	2	4	2	3	2	4	4	3

4.2 The Pilot Test

The experiments allowed us to determine the ability of $S(CM)^2$ to assess maturity levels. However, the assessment was done based on a written description of the companies practices, capabilities, and operations. The ability of the model to support assessment in the experimental scenario might not carry over into actual industrial settings. To evaluate the model in an actual industry setting, we conducted a pilot study with a Mexican sheet metal company that agreed to participate in the study. Over a period of two weeks the research team worked with the operations managers of the company using the $S(CM)^2$ assessment tool.

The assessment process requires completing a questionnaire of seven sections, one for each view. This questionnaire helps managers to obtain the maturity level classification for each view in the $S(CM)^2$. The possible answers for each question are “yes” or “no”. In case the answer will be yes the enterprise should document the evidence which support the affirmative answer. A negative answer in one of the level questions implies an improvement opportunity such that the expected level characteristics are not meet. Thus, the enterprise receives a maturity classification of the last level completed. This classification allows us to define an improvement roadmap based in the reference actions and the tools recommended in the model. Once the level is complete the enterprise may continue improving its processes from this maturity level to the next level up to reach the leading maturity level.

Within the questionnaire sections, each question is numbered according to the maturity level for each view. For example, in the supplier chain management & logistics view the numbers used are S# such that the managers can identify the improvement opportunities. This numeration maps each level and view to actions to met the maturity level requirements. Additionally, in order to prioritize needed improvements, the roadmap improvement utilizes a color convention implying the improvement urgency. Maturity levels 1 and 2 are denoted by red, levels 3 and 4 by yellow, and level 5 by green.

Figure 4 shows the results displayed in a radar graph. Each axis represents the result of the assessment using the following abbreviations: S = Supplier, P = Production , I = Inventories, C = Customer, H = Human Resources, T= Info. Systems & Technology, and M = Performance Measurement Systems. The further from the center, then the higher the maturity level in that viewpoint. For example, this particular company was assessed at level 2 for Supplier’s viewpoint, level 3 for Production, and so forth as shown in the figure. The numbers along each axis identify the assessment questions where the company fell short. It is in these areas that the company must work on to improve their capabilities in those viewpoints. For example, in viewpoint T for Information Systems and Technology, the company is at level 1. To improve along this view, they need to address

the capabilities raised by questions #7 and #8. Satisfactorily addressing these issues brings them to level 2 for Information Systems and Technology. Then they must address issues raised by questions #12, #13, and #14 to attain level 3 and then continuing addressing the issues related to the question numbers indicated along that axis in the graph.

Working with the company and the results of the maturity assessment, an improvement roadmap was developed that prioritizes their inventory management as a starting point. Some of the strategies discussed included the adoption of a system such as MRP to help manage inventory better and the establishment of collaborative agreements with companies they outsource with. Additionally, issues were identified in the competency areas of human resources, information systems and technology, and customers where improvements were needed. These results validate the capability of the S(CM)^2 to assess the supply chain processes in an enterprise, identify possible actions to improve the processes, and define a holistic improvement roadmap. Overall, post-assessment interviews with the company's management indicated satisfaction with the results and the recommended improvement roadmap.

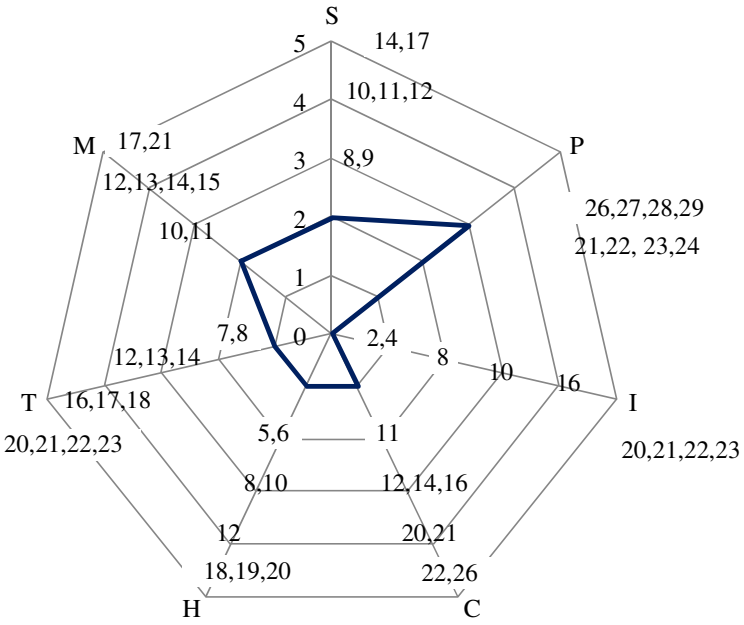

Figure 4: Maturity Levels for each view

5 Conclusion and Future Research

Enterprises seek to have tools, models, or methodologies to help them improve their supply chain processes. There are many tools, models and methodologies which might be implemented to obtain the desired improvements. However, how can an enterprise select from all of them? Can the expected results be obtained using a particular tool, or a combination of tools? Does an enterprise have the require maturity and knowledge for implementing some tool or methodology? This paper described the development and application of a supply chain maturity model called $S(CM)^2$. This is a meta-model that aggregates and organizes the best practices and knowledge of supply chain management as identified and prioritized from a panel of experts in Mexico. The $S(CM)^2$ model is designed to let a firm evaluate their supply chain practices and assess them by maturity level. Then the $S(CM)^2$ can be utilized to develop a set of plans for conducting projects to improve the firm's supply chain management practices.

The $S(CM)^2$ was developed using the Delphi Method with a panel of 80 Mexican experts representing a cross-section of industry. The Delphi Method was conducted in three iterations to identify the best practices, categorize the best practices, and to prioritize the best practices according to maturity level. To test the model's usefulness we conducted a set of experiments and a pilot study. The experiments determined that model could help managers use the model to consistently assess the maturity level of supply chain operations. The pilot study illustrated how the model could be used to assess an actual company and the description of the radar plot developed shows how it feeds into the development of an improvement roadmap. Thus, this research contributes to the current state of the art related to merging the use and implementation of several best practices making them work together in an improvement process.

There has been previous work in developing maturity models for supply chain management. Some of these models are theoretical constructs that were not tested with actual supply chains. Others such as SCOR reflect the practices of more developed countries and is based strongly on the idea of benchmarking performance with other companies. Lockamy and McCormack (2004b) did do some empirical research using a survey instrument with 58 respondents mostly from the US and Europe and found a weak relationship with the SCOR model and performance. This work expands on this by using the Delphi Method, which is more interactive data collection approach and focusing on Mexican industry. The $S(CM)^2$ provides a supply chain model including a cross-disciplinary and dynamic point of view through the model life-cycle and the abstraction levels, which implicitly consider the time variable. Besides, the meta-model provides a supply chain representation, which is different from previous models because of the languages used to build the model and the fact that it was developed specifically to assess and improve the enterprise's supply chain processes. Additionally, the language is easily recognized and common in the supply chain field.

The use of Mexican experts is of interest to understand the perspective from industries operating in a developing nation. It is also of interest because Mexico is part of the North American Free Trade Agreement (NAFTA) and many Mexican firms are second or lower-tier suppliers to U.S. firms (Haytko et al., 2007). This offers an alternate perspective than that of companies operating in the developed world because in general companies in developing countries such as Mexico have more difficult access to capital, skilled labor, and other resources. Also, developing countries do not have as long a industrial history as developed countries on which to build their capabilities. Finally, working with Mexican experts provides a perspective from industries operating in a developing nation that may differ from more developed countries due to the cultural behavior, type of main industry or economical resources. However, whether the experience and findings in Mexico apply to other countries or in supply chains that cross borders should be investigated further since the actual model does not consider international policies and importation constraints.

In any model such as presented herein, validation and model enhancement comes about only through application of the model. The validation strategy used was to first do experiments with fourteen experts assessing written descriptions of an enterprise's capabilities and operations. The experimental results indicate participants could consistently and accurately assess enterprises, but assessing a written description might not be a good proxy for assessing an actual enterprise. So, the

second part of the validation was to conduct a pilot study with a local firm. The pilot study indicated the model can work in actual industry settings. Ideally, much more validation in actual firms would be conducted, but this is hindered by the amount of time to do the assessment (about two weeks) and the availability of firms willing to let researchers study and examine their operations. Our experience indicates that to do an assessment would take about two weeks and requires that a firm have sufficient documentation of their operations to demonstrate compliance with the maturity levels.

The model and work has a few limitations. First, the model was developed in Mexico with Mexican experts and validated with Mexican firms. Whether the model generalizes to firms outside of Mexican is not known. Second, the validation only included a single pilot study due to the expense of conducting it. More validation would help create confidence in the model. Lastly, the link between adopting the model's improvement advice and actual improvements requires a research study examining a company over a long period of time and not at a single point in time as was done in this research. This last limitation is an interesting area for future research; to study a company and determine the causal strength between adopting the improvement advice and actual long-term improvements in supply chain capabilities.

The meta-model builds upon previous work in reference models for enterprises, supply chains, and maturity models. The main contribution is the integrative aspects of the previous work with an emphasis on providing an integrated methodology to assess the supply chain processes such that managers can define an improvement roadmap. As such, the model can be used as a diagnostic tool to determine the current maturity level and identify improvement to reach higher levels.

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