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Agile Index: Automotive Supply Chain

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***Abstract*—**The supply chains (SCs) have to appeal to new management paradigms to improve their ability to respond rapidly and cost effectively to unpredictable changes in markets and increasing levels of environmental turbulence, both in terms of volume and variety. In this highly demanded context, the Agile paradigm provides the capabilities to SC quickly adapt to changes in the market requirements. The purpose of this paper is to suggest an Agile Index to assess the agility of the automotive companies and corresponding SCs. The proposed integrated assessment model incorporates Agile practices weighted according to their importance to the automotive SC competitiveness and obtained from the Delphi technique.

***Keywords*—**Agile; Supply chain management; Index; Delphi technique

I. Introduction

In present-day business there is the assumption that supply chains (SCs) compete instead of companies [1] while the success or failure of SCs is mainly determined in the marketplace. Supply Chain Management (SCM) is considered a strategic factor for increasing organizational effectiveness and for the better attainment of organizational goals such as enhanced competitiveness, better customer service and increased profitability [2].

The Agile paradigm is concerned with the improvement of companies' responsiveness with controllable costs [3].

Consequently, this paper main objective is to propose an Agile Index to reflect the agility of automotive supply chains. This Index is reached through a linear combination of SCM practices related to the Agile SCM paradigm. Also a Delphi method is used to develop a series of weighted Agile practices importance through academics/experts in automotive research topics.

The paper is organized as follows. Following the introduction, the main Agile practices are pointed out. After this, a model proposal on the Agile Index is described. Subsequently, the weighting construction process is presented and then the Agile Index composite indicator is obtained. Finally some considerations are drawn about the proposed Agile Index.

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II. Agile Supply Chain Management Practices

The Agile SCM is critical once it intends to create the ability to respond rapidly and cost effectively to unpredictable changes in markets and increasing levels of environmental turbulence, both in terms of volume and variety [3]. Baramichai, Zimmers and Marangos [4] consider that: "an Agile supply chain is an integration of business partners to enable new competencies in order to respond to rapidly changing, continually fragmenting markets".

Agarwal, Shankar and Tiwari [3] have shown that the Agile SC paradigm deployment depends on the following variables: market sensitiveness, customer satisfaction, quality improvement, delivery speed, data accuracy, new product introduction, centralized and collaborative planning, process integration, use of IT tools, lead-time reduction, service level improvement, cost minimization, customer satisfaction, quality improvement, minimizing uncertainty, trust development, and minimizing resistance to uncertainty.

Some of the main Agile practices in the SC context are [3; 5]: i) to increase frequencies of new product introductions ii) speed in improving customer service, iii) centralized and collaborative planning; iv) use of IT to coordinate/integrate activities in manufacturing v) to Use IT to coordinate/integrate activities in design and development; vi) ability to change delivery times of supplier's order; vii) to reduce development cycle times, viii) to increase frequencies of new product introductions

III. Model Proposal - Agile Index for Individual Company

The main objective of this section is to propose a composite indicator (Agile Index) to translate the level of agility of the automotive SC's. Since the SC is composed by a set of n companies, each one with different degrees of SCM practices implementation, the SC overall behaviour will be affected by the sum of individual companies. Therefore, the main assumption is that the level of agility of the SC is determined by the sum of the individual company's behaviour belonging to the SC.

A. Individual company behaviour

In a first step it is necessary to compute the Agile company behaviour. The hierarchical relationships evolved in the proposed model can be found in figure 1.

The indicator intends to reflect the company behaviour in terms of agility. It is a representative parameter of Agile SC management practices implemented by each company, and is obtained by combining the information from the sub-indicator Agile SC practices (P_{A1}... P_{A7}). Table 1 contains the Agile practices considered to evaluate company indicator.

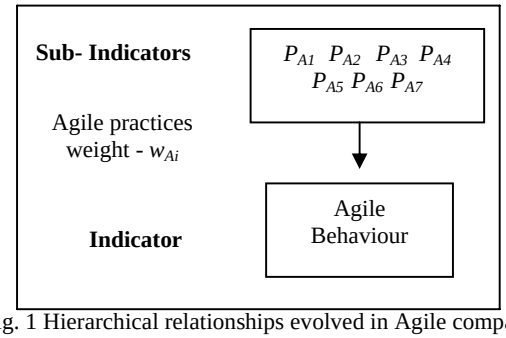

Fig. 1 Hierarchical relationships evolved in Agile company behaviour

TABLE I
MODEL INDICATOR AND SUB-INDICATORS FOR EACH COMPANY

Indicator	**Sub- indicators**
B_A = Agile behaviour	P_A= To use IT to coordinate/integrate activities in design and development
	P_{A2}= Ability to change delivery times of supplier's order
	P_{A3}= To use IT to coordinate/integrate activities in manufacturing
	P_{A4}= To reduce development cycle times
	P_{A5}= Centralized and collaborative planning
	P_{A6}= To increase frequencies of new product introductions
	P_{A7}= To speed in improving customer service

Each sub-indicator is assessed in a 5 points likert scale were 1 means "practice not implemented" and 5 "practice totally implemented".

B. Agile Indicator

For each company considering the Agile paradigm the following indicator is proposed. Agile behaviour (B_A): it reflects the company ability to respond rapidly and cost effectively to unpredictable changes.

It is supposed that this indicator can be computed by a weight sum of the individual sub-indicators. Considering that a SC is constituted by a number of n companies, for each one company j (j = 1, …, n) a generic formula in Equation 1) can be used to compute each model indicator B_A according to the Agile paradigms.

$$\left(B_A\right)_j = \sum_{i=1}^{7} w_{Ai} \times \left(P_{Ai}\right)_j \qquad (1)$$

Where:

- $(B_A)_j$ represents the company j Agile behaviour;
- $(P_{Ai})_j$ represents for company j the implementation level of Agile practice i.. A total of 7 practices (i = 1, …, 7) are considered. The implementation level for each practice is assessed in a 5 points likert scale, where 1 means "practice not implemented" and 5 "practice totally implemented.
- w_{Ai} is the Agile practice i weight. This weigh is common for all companies belonging to the same SC. The weights values reflect the importance of each Agile practice in the SC. It assumes values between 0 (not important) to 1 (extremely important). For each company the behaviour B_A goes from 1 (none practice implemented) to 5 (all the seven practices are implemented).

IV. COMPOSITE INDICATOR - AGILE INDEX TO SUPPLY CHAIN

Considering that the SC is composed by n companies, the SC Agile Index will be function of individual companies' Agile behaviours. Therefore the variables $(B_A)_j$ will be the used as sub-indicators. They can be aggregated using Equation 2.

$$Agile_{SC} = \frac{\sum_{j=1}^{n}\left(B_A\right)_j}{n} \qquad (2)$$

Where

- n is the number of companies considered in a particular SC
- $(B_A)_j$ represents the company j behaviour according to the Agile paradigm.

The SC Agile Index goes from 1 (the Agile paradigm is not put into practice in the SC companies) to 5 (all the SC companies deployed completely the Agile paradigm).

V. WEIGHTING CONSTRUCTION

A Delphi questionnaire survey was conducted to develop a series of weighted Agile practices and paradigms importance through academics/experts in automotive research topics. According to Linstone and Turoff [6] the key steps in preparing a Delphi study are: (i) the definition of experts and their selection; (ii) the number of rounds; and (iii) the questionnaire structure in each study round. Using this technique, generally, the number of rounds ranges from two to seven and the number of participants varies between 3 and 15 [7].

In this research eleven (11) academics/experts in automotive research topics were selected to be part of the study. Virtual (by email) interviews were launched with academics/experts in automotive research topics to verify the validity of the considered Agile practices according to their importance to the agility of the automotive SC.

The Delphi method used in this research comprised two rounds. In the first round the respondents were asked to give them perception about the importance of each suggested practice to the agility of the automotive SC. In the second round respondents were provided with the consolidated results from Round 1 and were invited to reconsider their options to see if they would like to adjust their original choice.

C. Selection of expert panel

The success of the Delphi method depends principally on the careful selection of the panel members). A group of experts was selected to determine the weights associated to the Agile practices.

As the information solicited requires in-depth knowledge and sound experience about, for one hand the automotive industry, and for the other the Agile SCM paradigm, a purposive approach was adopted to select this group of

experts [6; 8; 9].

The following two criteria were formulated in order to identify eligible participants for this part of the study: (i) having current/recent involvement in automotive industry research topics; (ii) having a sound knowledge and understanding of Agile SCM paradigm.

In order to obtain the most valuable opinions, only academics/experts who met the two selection criteria were considered. A total of 21 academics/experts were invited to participate in this study, but only 11 agreed on collaborate with us.

D. Two Rounds of Delphi Questionnaires

In order to decide about the weights that will be associated to the Agile practices a two rounds Delphi questionnaires methodology was used. The panel members constituted by academics/experts were informed that would be two rounds of questionnaire

The first round of Delphi questionnaire (see Appendix A) was sent to the group of panel members by e-mail in end-February 2011. In this first round the 21 academics/experts were asked to give their perception about the importance of the Agile practices to the competitiveness of the automotive industry. From these 21 academics/experts, 11 responses were collected. Similar to round 1 the second round questionnaire (see Appendix B) was forwarded to the group of panel members (11 academics/experts) by e-mail in the first week of March. In this round the results of Round 1 were consolidated and presented and the experts were requested to reconsider whether they would like to change any of their original choices in the light of the consolidated results from round 1. All the eleven questionnaires were completed at the mid-March 2011.

Table II shows the rank of Agile practices importance to a SC to be considered Agile.

After the Round 2 Delphi questionnaire, as regards the Agile practices, the ones ranked as the most important are the ability to change delivery times of supplier's order, to reduce development cycle times, and to use IT to coordinate/integrate activities in design and development. The one considered as the less important to the agility of the automotive SC is to increase frequencies of new product introductions.

E. Analysis of consistency after the two rounds

In order to obtain a measure of consistency of the 11 experts/academics responses, a statistical test was applied. The Kendall's Coefficient of concordance is used to study the degree of association among rankings of several objects by several judges [10]. This coefficient varies between “0” indicating no agreement between judges and “+1” indicating complete agreement among the judges on the ranking of various attributes. Using MegaStat application for Excel, the Kendall's Coefficient of concordance was computed for each set of experts/academics responses related to Agile practices importance.

Table II show that Kendall's Coefficient of concordance for Agile practices rankings were improved after the two rounds. Therefore, it can be concluded that after the second round of Delphi questionnaire there is a significant amount of agreement among respondents with the group of experts/academics.

F. Weighting determination

A series of weighted Agile practices was developed based on the ratings advocated by the 11 academics/experts. Each Agile practice rating was measured using a score between 1 and 5, with 1 representing “nothing important" and 5 representing "extremely important".

The weighting for each set of variables, this is the Agile practices importance, was computed by using Equation 3 [11]:

$$w_z = \frac{M_z}{\sum_{g=1}^{n} M_g} \quad (3)$$

Where:

- w_z represents the weighting of a particular variable z (practice importance)
- M_z represents the mean rating of variable z
- $\sum_{g=1}^{n} M_g$ represents the summation of mean rating of each set of variables

Using Equation 3 it was computed the weighting for each of the Agile practices (Table II).

G. Composite indicator aggregation

The Agile Index is composed by the weights determined through the two rounds of the Delphi questionnaire. The Agile Index is derived based on the assumption that this is a linear and additive model. In order to test this assumption, correlation matrix for the variables was determined. The correlation coefficient values range from “-1” to “+1”. The value “-1” indicates a perfect negative relationship, a value “+1” indicates a perfect positive relationship and “0” indicates no relationship at all [10]. Table III contains the correlation matrix for the weighted Agile practices.

Table III reveals that the variables are not highly correlated at 5% significance level.

TABLE II
RESULTS OF ROUND 1 AND ROUND 2 OF DELPHI QUESTIONNAIRE FOR THE AGILE PRACTICES IMPORTANCE

	Statistics / Variables	Round 1 Mean rating	Round 1 Rank	Round 1 W	Round 2 Mean rating	Round 2 Rank	Round 2 W
Agile Practices	To use IT to coordinate/integrate activities in design and development	4.09	4	0.15	4.0	3	0.15
	Ability to change delivery times of supplier's order	4.55	1	0.16	4.8	1	0.18
	To use IT to coordinate/integrate activities in manufacturing	4.09	4	0.15	3.8	5	0.14
	To reduce development cycle times	4.27	2	0.15	4.4	2	0.16
	Centralized and collaborative planning	4.18	3	0.15	3.9	4	0.14
	To increase frequencies of new product introductions	2.90	6	0.11	2.9	7	0.11
	To speed in improving customer service	3.55	5	0.13	3.3	\6	0.12
	Number (n)		11			11	
	Kendall's Coefficient of concordance		0.268			0.505	
	Level of significance		0.007			0.000	

Notes: For "Mean rating"= 1 nothing important and 5 = extremely important

TABLE III
CORRELATION MATRIX AMONG THE WEIGHTED AGILE PRACTICES

Correlation matrix		P_{A1}	P_{A2}	P_{A3}	P_{A4}	P_{A5}	P_{A6}	P_{A7}
Agile practices	P_{A1}	1.000						
	P_{A2}	-.553	1.000					
	P_{A3}	.298	-.120	1.000				
	P_{A4}	.332	.267	.539	1.000			
	P_{A5}	-.319	-.064	.346	-.346	1.000		
	P_{A6}	-.237	.214	.115	.214	-.316	1.000	
	P_{A7}	.000	-.143	.262	-.017	-.132	.710 *	1.000

Notes:** Correlation is significant at the 0.01 level (2-tailed)
* Correlation significant at the 0.05 level (2-tailed)

More, the majority of them are even insignificantly correlated with each other. Therefore, it is logical and valid to consider a linear and additive model in deriving the Agile Index.

VI. AGILE INDEX APLICATION – A CASE STUDY

H. Methodology

The main objective of this research is to propose an Agile Index for the SC. A case study approach was chosen for testing the suggested Agile Index. This approach is adequate when the boundaries of a phenomenon are not only still unclear, but there is also no control over behavioural events [12]. Since SC behaviour may differ from country to country [13] it is more effective to focus on one SC in one country before moving on to cross- SC's and cross-country studies. A single SC research design concerned with the Portuguese automotive SC was chosen. Furthermore, at this early stage of research, it is better to cover the different tiers within a SC to test the Agile Index.

The Portuguese auto components industry sold 80% of the production to foreign markets, having a strategic role in the economy representing 2.2% of the country's Gross Domestic Product [14]. The case study selection was also made on "planned opportunism" [15]. The researched automaker is a partner in an international research project that aims to study and manage the influence of lean, Agile, resilient and green SC management paradigms on SC performance.

To limit expert bias in the study results, data concerned to personal judgment of the participants were obtained through structured interviews. The interview was made to each company member. The Researched companies' managers were interviewed according to the interview protocol in Appendix C.However, despite the company anonymity was assured, the respondents may make effort to protect the image and reputation of their companies. Also, other sources of evidence such as industry databases, newspaper clippings and company web sites were used to corroborate and augment evidence.

A case-study approach is developed in this section, looking at four companies from the Portuguese automotive SC. The objective is to test the Agile Index proposed in the previous section

TABLE V
INDIVIDUAL COMPANY'S AGILE BEHAVIOUR

Agile Practices	Weights (1)	*Company 1* P_{A1} (2)	*Company 1* B_{A1} = (1)x(2)	*Company 2* P_{A2} (3)	*Company 2* B_{A2} = (1)x(3)	*Company 3* P_{A3} (4)	*Company 3* B_{A3} = (1)x(4)	*Company 4* P_{A4} (5)	*Company 4* B_{A4} (1)x(5)
P_{A1}	0.15	4	0.60	3	0.45	3	0.45	3	0.45
P_{A2}	0.18	3	0.54	3	0.54	3	0.54	2	0.36
P_{A3}	0.14	4	0.56	4	0.56	4	0.56	4	0.56
P_{A4}	0.16	5	0.80	4	0.64	5	0.80	5	0.80
P_{A5}	0.14	3	0.42	2	0.28	2	0.28	2	0.28
P_{A6}	0.11	4	0.44	2	0.22	2	0.22	2	0.22
P_{A7}	0.12	3	0.36	4	0.48	4	0.48	5	0.60
Total			3.72		3.17		3.33		3.27

Notes: P_{A1}= To use IT to coordinate/integrate activities in design and development; P_{A2}= Ability to change delivery times of supplier's order; P_{A3}= To use IT to coordinate/integrate activities in manufacturing; P_{A4}= To reduce development cycle times; P_{A5}= Centralized and collaborative planning; P_{A6}= To increase frequencies of new product introductions; P_{A7}= To speed in improving customer service.

I. Summary of the case study profile

A sample consisted of four companies within the Portuguese automotive SC was selected. The case study comprises one automaker, and three 1st tiers suppliers. The selected companies have some common characteristics. In the automotive SC context, the balance of power among SC members is uneven.

The automaker has huge power, controlling the entire production cycle from the product design to product manufacturing and parts sourcing, and in some cases the suppliers' processes. Typically, in this SC there are a limited number of suppliers for components and parts, and the control of the automaker can extend to second-tier suppliers (the first-tier suppliers can only purchase components and materials from some approved suppliers).

J. Agile Index determination

Based on the summarized data the company's behaviour according to the Agile paradigm is computed (Table V).

According to the Table V, the researched company with more ability to respond rapidly and cost affectively to unpredictable changes, that is, the one with a higher level of implementation of the suggested Agile SCM practices is the company 1, which is the automaker. This company has implemented totally the practice "to reduce development cycle times" and almost totally implemented the following ones: (i) to use IT to coordinate/integrate activities in design and development; (ii) to use IT to coordinate/integrate activities in manufacturing; and (iii) to increase frequencies of new product introductions. This makes possible to state that most of the responsiveness of this company is based on the technology.

By the other side, the company with low levels of implementation of Agile practices is the company 2, which is an plastic parts manufacturer and a first-tier supplier.

Using the equation 2, the Agile Index to the focused automotive SC is computed.

Agile SC = $(B_{A1} + B_{A2} + B_{A3} + B_{A4})/4$ = (3.72 + 3.17 + 3.33 + 3.27)/4 = 3.37

As the Agile Index (Agile SC) could goes from 1 to 5, in this particular case study' SC its value is 3.37 revealing that the researched automotive SC has a moderate Agile Index.

VII. DISCUSSION

This paper follows an innovative approach suggesting an integrated composite index, entitled Agile index, to translate the automotive SC behaviour in terms of agility. The proposed integrated assessment model supports the development of two Agile indexes: one to assess the individual company behaviour in terms of the Agile paradigm, and the other one to determine the same behaviour, but for the entire SC.

This research approach was developed in touch with the automotive SC reality. The Agile Index was constructed with the collaboration of experts/academics on and also on the automotive reality.

The content of this paper is particularly important to managers do a check list of a set of Agile practices implementation level considered as most important to individual companies and SC competitiveness. By this way, they can adjust the organizational behaviour according to the reached Agile Index score in order to maximize customer value and to respond rapidly and cost effectively to unpredictable changes. Also, it makes possible to implement functional benchmarking approaches in the automotive SC and to do a ranking among the companies, according to the Agile Index reached. This serves as a motivation to companies try to reach better position among their partners and to be more rigorous in establishing priorities, targets and goals, in terms of agility.

Despite the important contributions of this paper, limitations of the study should be noted. First, the proposed index is focused on the automotive industry. So, the practices suggested in the integrated assessment model translate particularly the reality of this sector making it not adjusted to a different sector.

Building on from this study, future research should therefore be directed at exploring the application of the suggested Agile Index in an extended automotive SC and also different kind of mathematical models could be suggested.

APPENDIX A

Structured Interview Protocol - First Round

This framework is intended to support a research regarding the assessment of an Agile Index proposal to the Automotive Industry. To do this, it is important to get information about experts' perception on the importance of a set of practices to the agility of the automotive Supply Chain. Try to answer to the questions, please.

Academic/experts identification

Faculty Department:

Area(s) of expertise:

Do you have any research on the automotive industry?

If Yes, in what kind of field(s)?

Strategy __Operations Management __Logistics
Supply chain Management __Equipment/maintenance__
Ergonomics __ Others:_____

1 - For the following Agile practices, please describe your perception about their importance to the agility of the automotive supply chain

(1 – not important, …, 5 – totally important)

	1	2	3	4	5
To Use IT to coordinate/integrate activities in design and development					
Ability to change delivery times of supplier's order					
To Use IT to coordinate/integrate activities in manufacturing					
To reduce development cycle times					
Centralized and collaborative planning					
To increase frequencies of new product introductions					
To Speed in improving customer service					

Thanks for the collaboration.

APPENDIX B

Structured Interview Protocol - Second Round

This framework is intended to support a research regarding the assessment of an Agile Index proposal to the Automotive Industry. This is a second round questionnaire which incorporates the average answers obtained from the first round. Knowing this information, please try to answer to the questions,

Academic/experts identification

Faculty Department:

Area(s) of expertise:

Do you have any research on the automotive industry?

If Yes in what kind of field(s)?

Strategy __Operations Management __Logistics
Supply chain Management __Equipment/maintenance__
Ergonomics __ Others:_____

1 - For the following Agile practices, please describe your perception about their importance to the agility of the automotive supply chain

(1 – not important, …, 5 – totally important)

	1	*2*	*3*	*4*	*5*	*1st round Average*
To Use IT to coordinate/integrate activities in design and development						4,09
Ability to change delivery times of supplier's order						4,55
To Use IT to coordinate/integrate activities in manufacturing						4,09
To reduce development cycle times						4,27
Centralized and collaborative planning						4,18
To increase frequencies of new product introductions						2,90
To Speed in improving customer service						3,55

Thanks for the collaboration.

APPENDIX C

Structured Interview Protocol

This framework is intended to support a research regarding the determination of a Agile Index to the automotive SC.

A - *Firm characterization*

Please indicate the following data that characterize your company:

Sector:____ Number of employees:____

Primary product(s):___Primary customer activity(ies) :___

Your job title:____ Your job responsibilities :____

Your firm's position in the supply chain:____

B - *Agile practices:*

For the following practices, please give information on their implementation level in your company (1 – not implemented, …, 5 – totally implemented)

- To use IT to coordinate/integrate activities in design and development
- Ability to change delivery times of supplier's order
- To use IT to coordinate/integrate activities in manufacturing
- To reduce development cycle times
- Centralized and collaborative planning
- To increase frequencies of new product introductions
- To speed in improving customer service

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