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ASSESSMENT OF SUPPLY CHAIN AGILITY IN A CLOUD COMPUTING-BASED FRAMEWORK

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Abstract. This paper presents an approach to evaluate the supply chain agility behaviour consisting in the development of an integrated index, with the data gathering, transmission and processing supported by a cloud-computing environment. The proposed approach relies on the development of two agility indices: one to assess the individual company agile behaviour, and the other one to determine the same behaviour for the entire supply chain. The supply chain is presented as a living, self-organizing open system that has the ability to incorporate new efficient agents and to remove the weakest ones. A special emphasis is given to the living subsystem responsible for the agility assessment, namely regarding the conceptual details of the components necessary to gather, process, coordinate and control the flow of information in the cloud.

Key words: Agility index, cloud computing, agile supply chain management.

1. Introduction. A supply chain (SC) can be described as a chain that links various agents, from the customer to the supplier, through manufacturing and services so that the flow of materials, money and information can be effectively managed to meet the business requirements [8]. In present-day business there is the assumption that SC's compete instead of companies. Supply Chain Management (SCM) is considered a strategic factor for enhanced competitiveness, better customer service and increased profitability.

The static connections between enterprises are typically insensitive to the changes in the business environment. Instead, flexible, agile, short and dynamic connections that facilitate seamless information flow across different value chains are needed for dynamic business partnership formation to take place [4].

The extent of business-to-business (B2B) interactions and communication could be overwhelming between the various parties and services especially in an adaptive environment where a lot of information needs to be exchanged. This requires higher capabilities of interaction and communication among enterprises. The necessity to improve these capabilities makes the SCs adoption of a more agile behaviour an urgent matter, altogether with a deeper awareness about their implementation level of the main practices associated to the agile SCM paradigm. In this context, the main objective of this paper is to propose a cloud-based framework enabling that global supply chains can assess their Agile index, that is, to get information on the level of agility of their practices.

Our own view of the SC as an open living, self-organizing system that has the ability to interact with its environment is presented. This takes place by means of information, material and money exchanges as well as by the dynamic incorporation of new efficient agents and removal of non-agile ones. It is becoming clear that the SCs must be able to adopt the right decisions regarding this latter issue in order to survive. Thus the capability to assess their agility level is a critical asset in maintaining a high fitness to a volatile environment (economic, social and business processes).

More specifically in this paper, without forgetting the metabolic processes of material and money exchanges, we focus our attention at a conceptual level on the subsystems necessary to process information for the coordination, guidance and control of the agility assessment system.

2. Background. The changing conditions of competition, the increasing levels of environmental turbulence and requirement for organizations to become more responsive and also more efficient are driving the interest in the concept of supply chain agility [17]. The agile paradigm is related to market sensitiveness and confers the ability to read and respond to real demand [6]. Since customer requirements are continuously changing, it is more difficult for SCs to deliver the right product, in the right quantity, in the right condition, to the right place, at the right time, at the right cost. To overcome these conditions, Hoek et al. [9] suggest that

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SCs should be agile to respond appropriately to market requirements and changes. Khan et al. [13] also state that agile SC practices support an appropriate response to market instability, responding in real time to the unique needs of customers and markets. That is, the SCs should have flexible and responsive capabilities in terms of their processes, networks and how they are integrated across other organisations [18]. Agile Supply Chain Management is crucial since 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 [1, 5, 10].

A new business model is introduced by Cloud Computing where consumers can have access to hardware and software, in a pay-per-use manner as we do with public utilities like water or electricity. According to Mell [16] cloud computing has five main characteristics: on-demand self-service, the user can access computing capabilities when needed without human interaction with the service provider; broad network access, capabilities are available over the network and accessed by standard mechanisms as internet protocols; resource pooling, the computing resources are pooled to serve multiple consumers; rapid elasticity, capabilities can be elastically provisioned and released according to consumer demand; measured service, resource usage can be monitored, controlled, and reported.

According to the type of provided resources three service models are considered [16, 23]: Infrastructure as a Service (IaaS), when it offers storage, computation and network capabilities; Platform as a Service (PaaS), when it offers facilities to develop software products; Software as a Service (SaaS) when the user can buy a subscription to some on-line software.

Intending to clarify the differences between cloud and conventional computing Armbrust et al. [3] highlight three new aspects in the cloud computing model from an hardware provisioning and pricing point of view: i) "The appearance of infinite computing resources on demand"; through virtualisation technology, cloud computing provides access to a wide range of machines as virtual instances whose number varies depending on the amount of required resources. ii) "The elimination of an up-front commitment by cloud users". iii) "The ability to pay for use of computing resources on a short-term basis as needed". Users can start using a small amount of resources and increasing it as their needs grow. Moreover, they just pay for what they used.

According to several authors [12, 21, 24] in a time where business environment changes very fast, cloud computing appears to be a way to enable companies facing the constant change of customer demands and market conditions, building more dynamic supply chains. While traditional software systems automate processes within a single enterprise, supply chain management may require the collaboration between companies across the entire world. Deploying a supply chain platform in the cloud provides the opportunity for all supply-chain partners for sharing data on the Internet as a pay-as-you-go service.

Since the main objective of this paper is to suggest an agility index assessment model supported on a cloud computing environment, a review of the main agile SCM practices found in the literature was made. Table 2.1 presents a summary of the agile SC practices identified in the literature. The reviewed practices are deployed at three levels of analysis according to the observable dyadic relations in the supply chain: (i) agile practices developed upstream; these are associated directly with interactions between a firm and their suppliers; (ii) agile practices deployed by firms in their daily, internal operations; these depend only on the firms' decisions to enforce an agile behaviour, and (iii) agile practices deployed downstream; these are those incorporating agility concerns in all kinds of flows (materials and information) between the firms and their downstream partners involved in delivery activity.

3. Agility assessment. The numerical assessment of the SC agility level relies on the determination of the initial set of agile practices subject to analysis. Any member (an individual company) of the SC should be able to produce a report on the implementation level of each practice of such set. At the same time a set of relative weights of each practice reflecting the overall evaluation policy of the SC must be available.

After the identification of the target practices, the attribution of relative weights to each practice can be seen as the second critical task for the agile index elicitation. From the entire range of possibilities to establish the weights of the Agile practices the Delphi approach is appealing due to its commitment to a consensual result when resourcing to a panel or committee of experts.

According to Linstone and Turoff [15] 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. Generally, the number of rounds ranges from two to seven and the number of participants varies between three and fifteen [20].

Table 2.1: Agile practices in the supply chain context

Agile practices	**References**				
First tier supplier ⟶ *Focal firm*	[19]	[7]	[14]	[1]	[22]
To use IT to coordinate/integrate activities in design and development.				√	√
To use IT to coordinate/integrate activities in procurement.					√
Ability to change delivery times of supplier's order.					√
To reduce the development cycle time.					√
Focal firm	[19]	[7]	[14]	[1]	[22]
To use IT to coordinate/integrate activities in manufacturing.			√	√	√
To integrate supply chain/value stream/virtual corporation.	√				
To use centralized and collaborative planning.				√	
To reconfigure the production process rapidly.	√				
To produce in large or small batches.		√			
To accommodate changes in production mix.					√
To reduce manufacturing throughput times to satisfy customer delivery.					√
To reduce development cycle times.					√
To minimize set-up times and product changeovers.		√			
To organize along functional lines.			√		
To facilitate rapid decision making.			√		
Focal firm ⟶ *Customer*	[19]	[7]	[14]	[1]	[22]
To use IT to coordinate/integrate activities in logistics and distribution.					√
To increase frequency of new product introductions.			√	√	√
To speed up adjustments in delivery capability.					√
To speed up improvements in customer service.				√	√
To speed up response to changing market needs.					√
To capture demand information immediately.			√		
To retain and grow customer relationships.			√		
To develop products with added value for customers.			√		

Whenever the linear additive model assumption is verified, the Agility index assessment of the SC is simply reduced to the (weighted) average of the individual companies' indices. From the focal company perspective it may happen that the different roles of the individual components of the SC present diverse relative importance concerning the determination of the Agility index of the SC.

3.1. Agility index for an individual company. To compute the company agility behaviour it must be possible to grade the levels of implementation of the focused agile practices. These indicators form a representative quantification of the n agile practices implemented by each company $(P_{A_1}, P_{A_2}, \ldots, P_{A_{n-1}}, P_{A_n})$. Each indicator is associated with a relative weight reflecting the practice's importance according to the global SC policy and can be measured in a 5 points Likert scale (1 means "practice not implemented" and 5 "practice totally implemented").

For each company the *Agility Behaviour* (AG) index is proposed representing the set of agility-related practices implemented. It is supposed that for each company this index can be computed aggregating the correspondent individual indicators (agile practices) according to their importance. For each company a generic weighted average can be used to compute the AG:

$$AG = \frac{\sum_{i=1}^{n} w_{A_i}.P_{A_i}}{\sum_{i=1}^{n} w_{A_i}}, \tag{3.1}$$

where P_{A_i} represents the implementation level of agile practice and w_{A_i} is the relative weight of the same practice. A total of n practices are considered. The positive weights reflect the relative importance of each practice in the SC. Equation 3.1 shows that the company agility behaviour is a function of each agile practice implementation level (P_{A_i}) and corresponding weight (w_{A_i}). Notice that when the Delphi methodology is followed the denominator of Eq. 3.1 equals to the unity, however different weights attribution schemas can be envisioned.

3.2. Agility index for the supply chain. To synthesize the SC's Agility index, the individual companies' agility behaviours will be considered as sub-indicators which are aggregated in a weighted average to obtain the SC Agility index ($Agility_{SC}$):

$$Agility_{SC} = \frac{\sum_{j=1}^{m} w_{C_j}.AG_j}{\sum_{j=1}^{m} w_{C_j}}, \tag{3.2}$$

where m is the number of companies considered in a particular SC, AG_j stands for the j-th company's agility behaviour given by Eq. 3.1 and w_{C_j} represents the relative contribution of the j-th company to the overall Agility index.

It is assumed that the practices weights are common for all companies belonging to the same SC. Notice that $\sum_{j=1}^{m} w_{C_j} = 1$, hence provided that all the individual agility indices are defined in the range [1, 5] the SC agility index is also described in the same range, where 1 means that the agile indicators are not put into practice by the SC companies and 5 represents an absolute adhesion, from all of the SC companies, to the agile practices.

4. Assessment Example. In this section the construction of the Agility index is illustrated. Seven companies from an automotive SC were chosen to illustrate the Agility index application. The research companies comprise one automaker and four first-tier suppliers, one second-tier supplier and also one first-tier customer. Each company was considered equally important regarding the SC agility assessment, i.e. $w_{C_j} = 1/7$, $j = 1, \ldots, 7$, in Eq. 3.2.

The literature review was used as a guidance to identify the most suited practices for the studied SC, a subset of 15 practices adapted from Table 2.1 was selected. In a first stage the data related to the individual assessments is collected, each company produces the implementation levels, P_{A_i}, $i = 1, \ldots, 15$, of the selected agile practices. This makes it possible to register the agility behaviour of each company, AG_j, $j = 1, \ldots, 7$, and also to compute the Agility index, $Agility_{SC}$, to the entire SC. Table 4.1 presents the collected data and the results of the computation of the agility indices.

Table 4.1: Agility behaviour for individual companies and supply chain.

Practices	**Weight(w_{A_i})**	**Implementation level per company**						
		C1	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*
P_{A_1}	0.063	2	3	2	3	1	4	1
P_{A_2}	0.066	3	5	4	3	5	4	2
P_{A_3}	0.067	3	3	3	3	5	3	2
P_{A_4}	0.067	3	4	3	4	1	3	1
P_{A_5}	0.070	5	4	5	3	1	3	1
P_{A_6}	0.070	5	4	5	4	1	2	1
P_{A_7}	0.069	4	5	2	3	1	3	1
P_{A_8}	0.069	2	5	2	4	5	3	1
P_{A_9}	0.063	3	5	4	5	5	3	5
$P_{A_{10}}$	0.083	3	5	4	5	5	3	5
$P_{A_{11}}$	0.076	5	5	5	5	5	4	2
$P_{A_{12}}$	0.072	5	5	5	5	5	5	5
$P_{A_{13}}$	0.065	3	4	1	4	1	5	3
$P_{A_{14}}$	0.052	3	4	3	3	5	3	3
$P_{A_{15}}$	0.048	3	4	3	3	1	4	1
Company Agility, see Eq. 3.1		3.513	4.368	3.457	3.859	3.192	3.457	2.315
SC Agility Index, see Eq. 3.2					**3.452**			

According to the agility values of the companies $C1$ to $C7$, it is possible to identify the case study company with the better and worst agility behaviour. The better agility performer is the company $C2$ and the worst is the company $C7$. This result comes from the implementation degree of the agile practices in each company. Company $C2$ has totally implemented almost all the analysed agile practices, which makes it an agile performer. Contrary, the company $C7$ only has totally implemented three of the fifteen selected practices.

Summing up and analysing Table 4.1 we can say that the overall agility behaviour of the companies is positive, as reflected in the aggregated SC Agility level, however there is a link in the SC that presents a negative (less than 3 in the Likert scale) agile value implying that this weak behaviour is perhaps the first that should be corrected in order to enhance the Agility of all the SC. This indicator gives insight on the average behaviour of all the companies that contributes for the production of the final product, which means that if one partner in the SC has not the required flexibility this could compromise the agility behaviour of all the SC and its public image.

5. Cloud Computing Supporting the Living Agility Assessment. Cloud computing has transformed how global business networks interact, delivering a flexible, collaborative model. According to Aljabre [2] Cloud computing provides the ability for multiple users to collaborate on projects or documents in the cloud. This point has been reiterated and reinforced recently as a major selling point to businesses. This makes the cloud computing a great option for the assessment of the proposed Agility index since all the SC partners around the world can provide their level of implementation of the deployed agile practices in the cloud and all the filled information can be treated in order to provide a clear overview of both the individual companies and the whole SC's Agility behaviour.

According to several authors and practitioners, cloud computing is an unavoidable path for SCM. Kefer [12] proposes three ways in which cloud computing can improve SC operations: a cloud solution can give real-time visibility to where a product is at any given time; moving to the cloud implies standardize the data from all the partners and define security rules; a cloud platform builds a collaborative community. Schramm et al. [21] signal several changes that adoption of cloud computing will drive into supply chains: new competitors; speed to market for new products and services; large-scale transformation. Wrigth [24] and Schramm et al. [21] pointed out some SC processes best suited to cloud computing: planning and forecasting; logistics; sourcing and procurement; service and spare parts management.

Notwithstanding these well-known advantages of performing the SCM in a cloud environment, to which one could add up its inherent environmental gains, the cloud can also be the enabling mean of a thorough SC agility assessment process. This can be viewed as a suite of integrated applications (processes) and tools that support a specific, major business capability or need – in a close agreement with the definition of a virtual business environment (VBE) presented in Iyer and Henderson [11] . Such VBE involves different processes that together can be seen as a living system as depicted in Fig. 5.1.

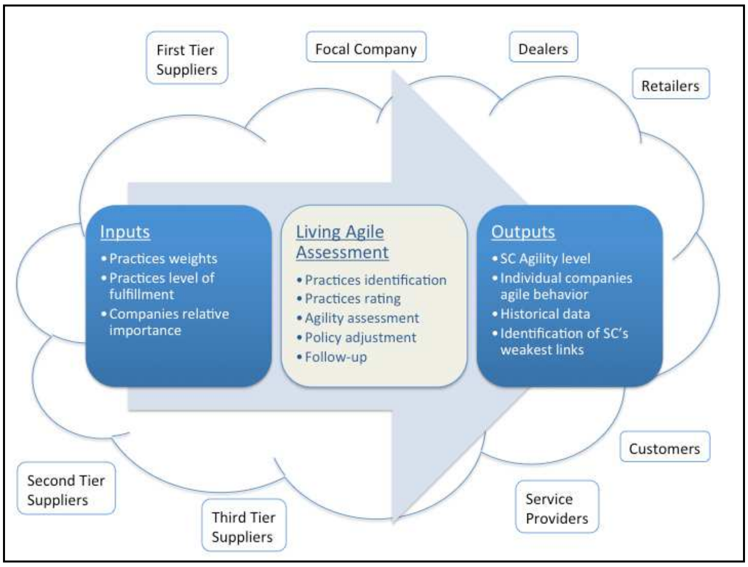

Fig. 5.1: Agility index assessment process for the SC

Despite that much of the organizational knowledge and expertise is scattered across the SC (even a single undifferentiated employee may contribute with the elicitation of an unforeseen key practice) one should expect that at the top of the institutional management hierarchy there are enough experts with a brighter wide enough vision able to capture all the relevant aspects of the agile practices. However the dimension of the supply chain, the various sources of uncertainty and the specificities of the member enterprises as well as their complex interrelationships make the identification of practices a difficult task. Moreover a proper communication of the evaluation policies as well as the participation in their definition may promote the enthusiastic enrolment in their enforcement.

To build and enable this new collaborative infrastructure the managers can choose to deploy a cloud service promoting the discussion around a set of practices based on the ones presented in the previous section, allowing the introduction of new practices and the removal of inadequate ones. This common environment will likely allow the emergence of unsuspected collaborations between knowledge workers in different enterprises of the SC – in some cases sharing a common view on a particular set of practices, in others disagreeing or even fighting for opposite ones. The resulting group authorship, regardless of the intensity of the discussion (being moderated or not), has the advantage of being readable by anyone in the organization making the entire process of knowledge elicitation persistently visible. After a stabilization period it is expected that a homeostatic state is achieved through the assimilation and acceptance as legitimate of the ground rules for the assessment of the whole SC.

Regarding the practices' rating task several methods for defining the set of weights for the SC agile practices can be devised. The VBE can be enriched with some sort of polling user interface through which selected contributors can cast their perception of the importance of each practice. This can be simply an extension of a numeric Delphi study to a wider group of participants (some possibilities include experts and academics inside and outside organization with a mix of selected workers in key points of the SC).

The Agility index assessment can be an effective tool to be used not only by strategic decision makers, who need comprehensive models to support their decisions aimed to the enrichment of the SC, but also by the individual SC partners aiming at improving their added value in the SC. In this regard it is important that the entire evaluation be made simple, preferably in a familiar sound environment. The VBE should offer a controlled interface simplifying the innovation of applications and services as well as the control of their introduction. Frequent assessment loops (or even a continuous one) and location independence access to the differentiated evaluation assets should help to improve the overall SC performance by enabling a clear perception on what agile practices should be reinforced by each individual company.

Moreover, the Agility assessment process presents a dynamical open-system time-variant nature. The assessment panel composition can change (or simply their believes and knowledge about the assessment process), a new set of practices can be devised (by the inclusion of new practices, removal of obsolete ones or adaptation of their relative weights), the perceived relative importance of each individual company to the agility of the SC can change, or even the SC structure can suffer a rearrangement due to the inclusion/exclusion of some companies and to the establishment of new partnerships.

All these factors contribute to the need for frequent policy adjustments mediating successive agility assessment cycles. The flexibility and reusability offered by the VBE, allowing not only abandoning an environment and moving to the next but also the retrieval of a previously used environment at a future date, are key features for this task.

The follow-up task is also critical since the practical adhesion of the SC's enterprises and employees to the agile practices should be higher if they feel themselves as an integral part of the collective intelligence system that is being formed. To this aim it is essential that the individual components be aware of the current status of the evaluation process and can maintain track of the previous evaluations conditions and results. Moreover the usefulness of the VBE can be highly improved if complemented with a simulator of the evaluation process giving a greater feedback on the effective role of the SC partners, and his real impact on the agility index of the organization.

From a top management perspective the ubiquitous location independent access altogether with the addressability and traceability are major features of the deployed VBE. To have direct access to historical data of individual companies, to have an immediate glimpse of the evolution of the assessment process, or to possess in real time a benchmark of the different companies (actual and putative) are some of the examples of valuable assets for the decision-making activity.

6. Conclusion. The SC can be viewed as an open living, self-organizing system that has the ability to interact with its environment. Arguably the major effect of this interaction consists on the dynamic incorporation of new efficient agents and removal of non-agile ones. In this regard the capability to assess the agility level is a critical asset in maintaining a high fitness to a volatile environment. Conceptually the subsystems necessary to process information for the coordination, guidance and control of the agility assessment system can themselves be seen as part of a living system that finds just the right environment in the cloud.

Cloud computing introduces a new business model where consumers can have access to hardware and software, through the Internet, in a pay-per-use manner as we do with public utilities. From a SC perspective cloud computing has transformed how global business networks interact, delivering a flexible, collaborative model. The establishment of a dedicated virtual business environment in such a common infrastructure offers a controlled interface simplifying not only the introduction of the proposed agility assessment model to the entire SC but also its validation and subsequent analysis of historical data.

The proposed approach supports the development of two agility indices: one to assess the individual company agile behaviour, and the other one to determine the same behaviour, but for the entire SC. Managers can use the proposed assessment model as a mean to adjust the organizations' behaviour according to the reached agility index score in order to improve the company efficiency. Moreover, it makes it possible to implement functional benchmarking approaches in the SC and to do a ranking among the companies, according to the agility index value. 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.

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