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Abstract

Purpose – The purpose of this paper is to study the alignment measurement in collaborative networks, using the fit concept and predictive performance measurement as its main enablers. A performance prediction approach is used in order to control a collaborative business network based not only in present and past performance measurements of each partner, but also taking into account the future behaviour of the intra- and inter-organisational processes performance.

Design/methodology/approach – An exploratory case study was applied to a Brazilian collaborative network and mathematical approaches normally used in control theory were adopted to support alignment measurement.

Findings – The use of predictive measurements to manage the alignment between the results of inter-organisational processes and performance targets set by the collaborative network.

Research limitations/implications – This approach was applied in a specific supply chain network, based on three industrial companies. For other network typologies it will be necessary to evaluate the alignment that can be achieved.

Practical implications – This predictive approach makes it possible to manage performance pro-actively using feedforward and feedback control. Therefore, tools that consider performance estimation are used based on a data fusion approach, with a proper combination of leading and lagging measurements, which make it possible to use forecasting methods and tools to achieve good predictions.

Originality/value – The paper introduces an approach to alignment measurement leveraged by the new paradigm of performance prediction and presents an alignment metric for collaborative networks.

Keywords Brazil, Partnership, Performance management, Forecasting, Strategic alignment, Collaborative networks, Performance prediction, Alignment measurement, Alignment prediction

Paper type Research paper

1. Introduction

Nowadays, business environments are characterised by constant changes that imply shorter time-windows for business opportunities, shorter products and service life cycles, as well as volatile market demands. Consequently, in order to be competitive, companies need to decrease their product's time-to-market, increase production flexibility, deliver complex and functional products, and shift from standardisation to a customisation approach (Chituc and Azevedo, 2005). Therefore, achieving higher levels of performance in the shortest time possible is a constant challenge demanded by organizations.

In that context, research on collaborative models such as collaborative networks (CN) may constitute a solution to address these challenges (Dekkers and van Luttervelt,

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2006; Faria and Azevedo, 2006). However, in order to perform a collaboration strategy, important requirements have to be followed in order to achieve higher levels of integration in the most flexible way (Camarinha-Matos *et al.*, 2005), such as: common strategies and goals, high level of mutual trust, and the ability to manage inter-organisational processes, infrastructures and policies for business practices. Since this integration must be orchestrated in order to achieve suitable performance behaviors, it is necessary to ensure the expected alignment with respect to the strategic objectives of the CN.

However, due to the constant need to explore a business opportunity, before the competition the ability to decrease the response time of products and respective process designs (Dekkers, 2002), and to select partners and manage CNs in a more proactive way, requires specific approaches that make it possible to align the CN's participants as quickly as possible. This fact has been abruptly increasing the dynamic complexity of the CN since the time required to achieve the expected performance behaviour in the entire CN (performance ramp-up time) needs to be forcibly lower. Indeed, it is possible to say that the ability to achieve, as quickly as possible, a high level of alignment between the results of inter-organisational processes and the performance targets established by the CN is a critical objective.

Since the time factor has proved to be a key element for a reliable CN management process, several authors state that traditional performance measurement and management approaches can be considered unsuccessful. These solutions mainly use performance data that are extracted after a feedback period, and only after this period can the data be analysed in order to promote improvement actions for the next period (Lohman *et al.*, 2004; Braz *et al.*, 2011). This means that the reaction time is conditioned by feedback and improvement periods (Seifert *et al.*, 2008). In fact, this approach is no longer sufficient and it is necessary to explore a more proactive and feed-forward paradigm. Therefore, it is important to find an advanced approach that can decrease this reaction time, reducing the importance of the feedback periods and provide decision-makers with leading performance data capable of supporting them in estimating future performance behaviours.

In fact, in order to achieve the desired levels of performance in the shorter time and thus make the network more competitive than their opponents (single or inter-firm networks) a new concept is proposed to be explored: the fit concept in the scope of CN alignment. This concept aims at supporting CN managers so that they can go deeper into the network management system, and start analysing each partner as a promoter of the overall CN performance excellency (Dekkers, 2009).

In sum, the aim with this research is to explore three main research questions. First, we aim to explain not only how a predictive performance management approach is capable of restricting the importance of the CN performance feedback control, but also which should be its architecture. Finally, aiming to support the achievement of the overall objectives of the CN, it is important to understand how the alignment degree of the entire network can be analysed based on the individual performance of each partner and the inter-organisational processes outcomes.

Therefore, these research questions explore the fit concept and the predictive performance management as the main enablers for proactive alignment measurement in CN. In this work, the fit concept focuses on the partner's capacity to achieve the expected performance in a collaboration strategy. Furthermore, predictive performance management represents the ability to control a system based not only on present and past measurements, but also taking into account future performance behaviours. In other words, there is an evolution from a feedback to a feed-forward approach. We propose the integration of these qualitative and quantitative concepts, which would make it possible to support decision makers in selecting the right partners for a certain business opportunity, as well as measuring and controlling its alignment, envisioning the entire life cycle of the CN.

The remaining of the paper is organised as follows: in Section 2, the CN alignment needs are presented. In Section 3, the performance prediction concept is addressed and the performance predictive engine (PPE) tool is presented. Then, in Section 4, a method for predictive alignment assessment is explored. The Section 5 focuses on the alignment prediction and the Fit Degree metric is introduced. Finally, some conclusions are presented in Section 6.

2. Alignment in collaborative networks

Uncertainty and fluctuations in market demands lead companies to find mechanisms that support them in providing the right product, in the right amount and in the expected time frame. In line with this, different approaches have been explored based on a shift from a "make-or-buy" to a "co-makership" paradigm (Dekkers and van Luttervelt, 2006). Therefore, empowered by this ambition organisations started to working together in order to develop inter-firm collaboration, where groups of autonomous organisations with common interests contribute with knowledge and resources for joint actions to achieve a common purpose. Therefore, in the scope of these CN, organisations explore relations that are normally the result of negotiations based on mutual trust and based on heterarchy architectures focused on a certain goal (Reupold, 2009).

In fact, adopting a contrasting network approach, organisations focus not only on the company, but also on the value-creating system itself, within which different partners work together to co-produce value (Peppard and Rylander, 2006). However, it has been depicted that an *ad hoc* collaboration by itself is not enough. Because of this observation, it was necessary explore the concept of alignment in order to assess whether an organisation is able to participate in a network by adding value to the overall objective, envisioning the strategy defined by the network.

In line with this, a collaborative performance measurement and management approach should be explored, capable of not only assessing internally how an organisation is performing, but also extrapolating if the behaviour of a certain organisation fits the expectations and goals defined for a network node during its entire life cycle. Moreover, following a predictive performance approach where an explicit model of the system to be controlled can be used to predict the future output behaviour, taking into account the network environment and their participants, makes it possible to support network decision makers in making more accurate decisions in a more proactive way.

2.1. Fit concept

For organisations to survive and prosper they must fit their resources and capabilities to the opportunities created by the external environment (Kaplan and Norton, 1992). Therefore, the fit concept was explored in order to enhance the linkage between business environment, organisational structure and internal processes (Miller, 1992).

This relationship or alignment between the requirements of the business environment and the strategy applied by the organisation is called strategic fit (Anand and Ward, 2004).

The discussion around the "Fit" concept had its most important questions dictated by authors such as Venkatraman (1989, 1990), Vankatraman and Camillus (1984) and Venkatraman and Prescott (1990) and is framed within the strategic management subject. According to Vankatraman and Camillus (1984), the "Fit" has its roots on the contingency theory, specifically from the works related with: the link between technology and structure (Woodward, 1965), leadership style (Fiedler, 1967), organisation-environment alignment (Katz and Khan, 1966; Thompson, 1967), the formulation of business strategies (Hofer, 1975) and strategic management (Miles and Snow, 1978; Snow and Miles, 1983). Then, the concept of "Fit" seems relevant when trying to raise issues related with the organisational boundaries (competences and resources) and others which deal with the business environment (opportunities and threats).

According to Miller (1992), it is "often claimed that firms must fit their settings in order to perform well". In line with this, Figure 1 shows that Fit is a process that makes it possible to understand not only whether the business environment and organisational structure are aligned (external fit), but also if there is an alignment between the structure and processes of the organisation (internal fit). On the contrary, when focusing on strategy and privileging the alignment between organisational structure and organisational processes, it is possible to achieve an appropriate approach for assessing performance of intra- and inter-organisational processes in relation to the organisational structure needs of the CN. This is what is called internal fit (Silveira and Sousa, 2010).

However, some authors argue that in most cases compatible internal and external fit does not occur simultaneously. According to Miller (1992):

> [...] managers may have to perform their adaptive tasks sequentially striving for a harmonious alignment among their internal variables in order to achieve smooth functioning, but periodically disrupting this harmony to adjust to a changing environment.

Such concerns about the uncertainty of business environments can be addressed using a collaboration strategy since it can improve the link between collaborative organisational structure and the inter-organisational processes, in order to provide a satisfactory level of internal fit.

Internal fit is usually related with performance improvements (Silveira and Sousa, 2010) to ensure a higher level of alignment. Therefore, as shown in Figure 2, the state of the internal fit in CNs can be represented by the relationships between intra- and inter-organizational processes. Moreover, in the management context this term can be

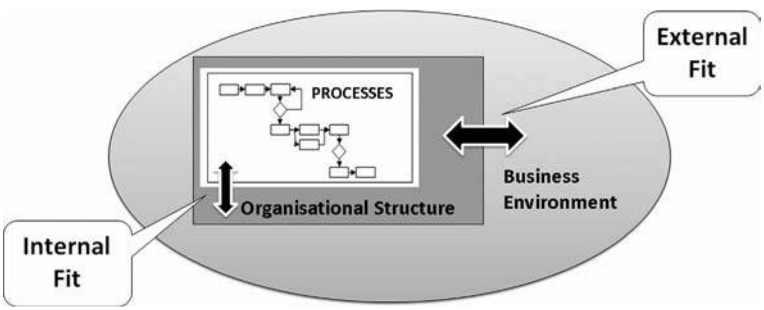

Figure 1.
Fit concept

used properly to conceptualise a situation where inter-organisational structures, stakeholders, stockholders, and whichever existing participant or process in a business environment, are strictly combined under strategic decisions to achieve specific objectives and goals.

In summary, concepts on the internal fit and its linkage to performance improvements were presented with the purpose of explore the assessment of the degree of alignment for CNs.

2.2. The degree of alignment

Although it has other connotations, the term "alignment" is usually defined as an arrangement of groups or forces in relation to one another (*Merriam-Webster Dictionary*, 2011). Therefore, in the context of CNs it is possible to understand that this term can be interpreted as an adjusted relationship between the performance achieved by participants and the strategic goals of the CN considering that each partner must contribute with self-operation efficiency in order to achieve inter-organisational alignment.

According to Francisco *et al.* (2010), there are three main instants in the CN's life cycle which can be determined to measure inter-organisational alignment, which are: partner selection, agreement and operation management. Therefore, the alignment should be measured primarily during partner selection and repeated during the entire life cycle of the CN, including the instant of agreement, and especially when the network is running (operation). Furthermore, in order to visualise this approach (Figure 3), we can imagine that there are lines that should converge, becoming closer and closer. This means that in this situation there is a higher level of internal fit causing an alignment between organisational structure and process outcomes.

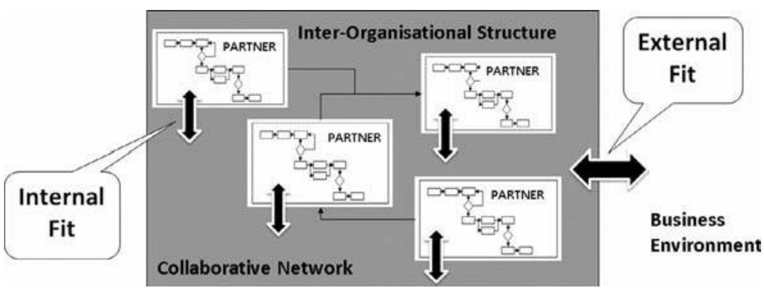

Figure 2. Internal fit concept adapted to collaborative networks

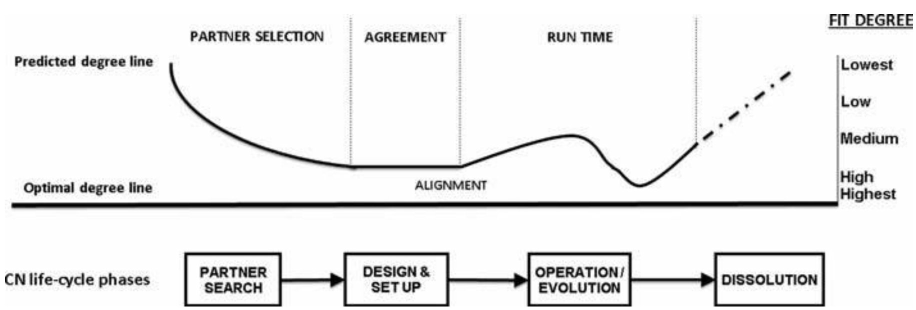

Figure 3. Alignment degree throughout the CN life cycle

In fact, in this proposal for assessing alignment in CNs, it is focused specifically on the internal fit, which is an alignment between the inter-organisational structure and the intra- and inter-organisational processes of the CN. However, there should be a trade-off in order to prevent the external fit from becoming inconsistent as a result of a misalignment between business environment and inter-organisational structure.

2.3. Performance management in collaborative networks

Basically, a performance management system (PMGS) brings together a set of management concepts and supporting technologies in order to build a conceptual framework capable of supporting decision makers in identifying bottlenecks to improve or maintain business performance. Furthermore, many systems with different perspectives have been created over the past decades, and adapted to changing performance management concepts. Meanwhile, not many PMGS models have been designed for CNs, even though the need for these models is increasing. These system models must be supported by management concepts to design a performance management framework, as a hypothetical description of a complex entity or process, which may be considered as the basis to design and implement a PMGS.

According to Azevedo and Francisco (2007), a PMGS should be designed for the CN's life cycle and should use available data, such as previous collaboration experiences or other forms of performance data. In fact, a framework that defines a set of concepts and practices to visualise a generic frame of performance management is proposed to deal with complex entities in collaboration. Figure 4 shows a hierarchical framework called collaborative network performance management system (CNPMS) that intends to establish specific layers to accommodate some modules, tools and life cycle phases.

The CNPMS framework has two main layers: the data and information layer and the functionality layer. The first layer comprises exclusively the data repository that deals with data acquisition and management. All performance and general information data are the result of new data collection actions and past experiences relating to each CN participant. The performance repository module continuously receives data on performance in real-time and also data relating to the analysis of results.

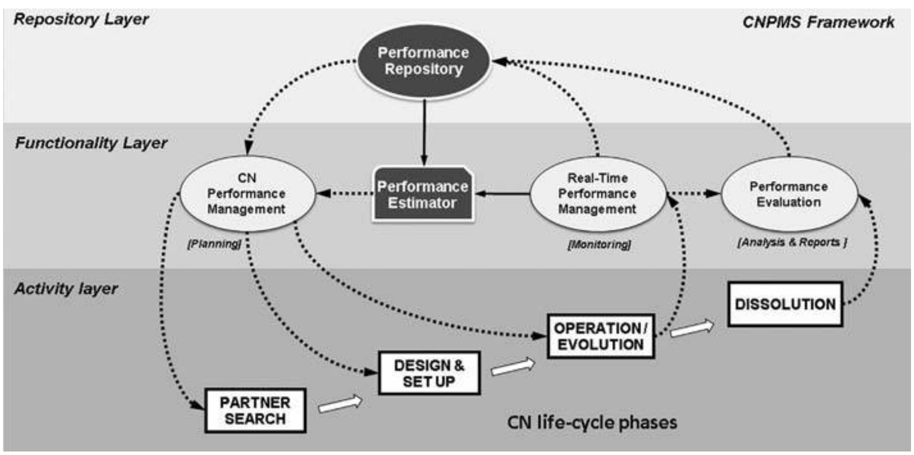

Figure 4. Collaborative network performance management (CNPMS framework)

Therefore, it can keep the data updated to new collaboration demonstrations or to enable the evolution of the overall performance.

The second layer is set up by three main functionalities regarding activities to manage the CN during its life cycle phases:

(1) CN performance management supports process planning and leads the activities during the Search phase, the design and set-up phase and the operation phase and, also, when capturing data from the performance repository to provide performance benchmarking for partner selection. Furthermore, it helps describe the performance targets that will be upgraded and improved using proper key performance indicators (KPIs) that will predict the performance and also contribute to the deployment of the CN project.

(2) Real-time performance management to measure the outputs, making it possible to solve emerging problems and formulate improvements more quickly during the evolution phase, and also to monitor the efficiency and effectiveness of intra- and inter-organisational processes. In the operation phase, proper KPIs that instantiate the performance are applied, which helps face these challenges and align the CN participants.

(3) The performance evaluation functionality deals with the compilation of performance data in the dissolution phase in order to understand the performance and knowledge achieved during the life cycle phases, and if the CN has achieved its objectives. Then, this performance memory is transferred to the performance repository. Therefore, this functionality provides information about the performance generated by participants at each stage of the life cycle.

Then, the activity layer comprises the life cycle phases, the three milestones to measure the alignment and the activities that must be developed and accomplished, such as: capturing the partners' abilities, defining KPIs, managing projects, defining targets, KPI forecasting, performance reports.

In addition, an important module was introduced to the CN performance management functionality – the performance estimator. Practically, an estimator tool provides predictions of potential partner performances in order to feedforward their behaviour. At the same time, the estimator defines the possible performance targets and performance forecasts in the CN operation, among other objectives that require predictive values.

3. Performance prediction as a new paradigm to improve business management

Even though performance prediction is a highly explored issue in computer engineering, mainly in software performance models, some initiatives have used these models to predict behaviour of a production system or even to extrapolate the performance measurements from one setting to another.

From the methods available, the model predictive control (MPC), also referred to as receding horizon control and moving horizon optimal control, has been widely used in industrial process (Bemporad and Morari, 1999; Balaji *et al.*, 2008). The name MPC stems from idea of employing an explicit model of the system to be controlled, which can be used to predict the future output behaviour taking into account the present characteristics of the system.

In the CN context, the prospective performance measurement (Westphal *et al.*, 2007) can be considered as one of the pioneers in the predictive performance management for CN. This approach introduces the vision of partners' selection based of their future behaviour.

3.1. Performance forecasting methods and approaches

It is important to mention that according to the new approaches used in performance, there has been a change in paradigm from performance measurement to performance management, from feedback to feedfoward analysis and from an individual measurement to a corporative or collaborative performance measurement (Busi and Bititci, 2006).

Indeed, this research has its pillars on the concept that it is possible to make a feed-forward control using leading measurements (Harbour, 2009) when it is necessary to plan systems and their targets, contrarily to the traditional feedback control that uses lagging measurements. In fact, this means taking "improvement actions" instead of "corrective actions" (Busi and Bititci, 2006). However, since this predictive approach intends to explore a pro-active performance management using the combination of feedforward and feedback control (Figure 5), it is necessary provide a proper combination of leading and lagging measurements capable to increase as much as possible the estimation reliability of the system performance.

Seifert (2009) argues that it is necessary to reduce the feedback time referring to the time spent in collecting data to analyse performance. After that, new solutions should be designed and implemented to improve processes. To face this challenge, the author suggests the use of performance value predictions as is following depicted.

3.2. A performance value estimator tool using a data fusion approach

Usually process data in organisations are vast and disperse. As a result, it becomes increasingly difficult to combine, manage and integrate a large amount and variety of available data. Therefore, it is crucial to develop and integrate tools for data fusion approaches in the company's working methods. According to Hall and Llinas (1997), data fusion is:

> A process dealing with the association, correlation and combination of data and information from single and multiple sources to achieve refined position and identity estimates, and complete and timely assessments of situations and threats, and their significance.

It can be seen as a group of techniques that combine data from multiple sensors (performance databases) and related information from associated databases, so as to achieve improved accuracies and more specific inferences that those achieved with

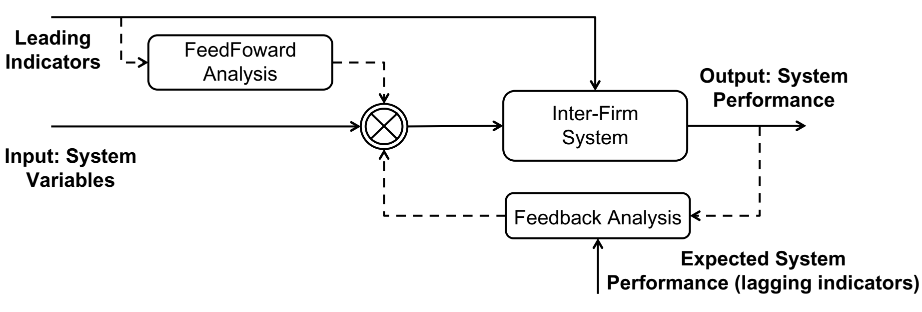

Figure 5.
Feedfoward and feedback control system

a single sensor. In fact, data fusion processes encourage the use of modern techniques, such as the Kalman Filter, clustering algorithms, neural networks (NN) or decision-based methods, including the Bayesian method, in order to identify targets or patterns.

A PPE tool to predict performance was developed by Azevedo and Almeida (2011) and Francisco *et al.* (2010). This tool introduced a hybrid architecture capable of performing a stochastic and deterministic factor analysis. Therefore, the PPE tool uses the NN concept to model and extract information from the historical performance data according to defined factors which have an impact on the process results. With this approach, it is possible to achieve accurate values since this estimator tool is capable of learning the system's behaviour and, using the generalisation capability, it is possible to retrieve the expected results imposed by the environment. Moreover, the NNs are non-linear, which is a crucial advantage because in the real world almost all systems are non-linear. However, usually there are noises in process modelling and measurement which influence the reliability of the estimation values. In order to reduce the impact of these errors, it is possible to apply the Kalman Filter to improve the accuracy of the values by filtering the noise (Haykin, 2001). The Kalman Filter is a tool that is used to optimise the estimation of state models (Ribeiro, 2009). This stochastic controller is known for being capable of supporting estimations for past, present and future states, even when the accuracy of the system modelling is not known. In a mathematical layer of abstraction, it can be seen as a tool used for estimating the instantaneous "state" of a linear dynamic system disturbed by white noise.

The PPE (Figure 3) is a component that operates in parallel with the system to be emulated (Figure 6). This receives the measurements (leading measurements) in real-time and the predictable information about the factors that positively or negatively influence the system, following a proactive performance management approach. Then, with this information, the PPE is capable of producing target estimations for the performance indicators chosen. Estimates of these indicators can also be monitored in real-time, thus making it possible to estimate and predict the system's reaction to improvement processes over time.

4. Alignment prediction: method for predictive alignment assessment

The main objective of this research is to explore a metric that makes it possible to instantiate the alignment between participants in a CN, mainly in terms of compliance with the agreed performance targets. Furthermore, it is expected to adapt this

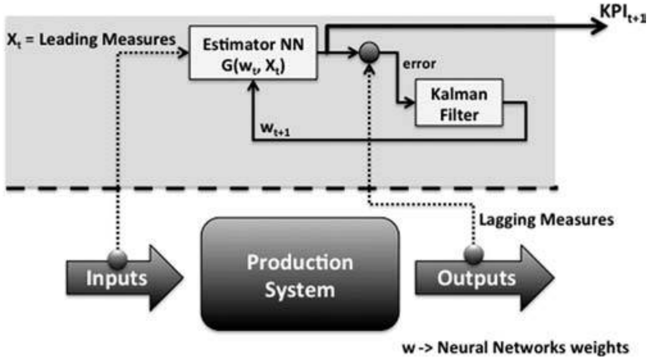

Figure 6.
Performance estimator engine concept

measurement in order to assess the future alignment, thus providing an interesting contribution to the evaluation of CN performance.

After defining the theory, a qualitative and quantitative approach was explored aiming to validate this in a real industry scenario. Therefore, selecting a CN that was able to provide the necessary information, it was possible to perform a qualitative exercise based on structured interviews. The aim was to provide a clear understanding of the main interactions between the different partners of the CN, as well as their intentions and limitations. Then, after all the data are compiled, the Fit Degree process was deployed in order to evaluate the alignment degree of the different organisations involved in the network, not only based on past performance data, but also comparing the target and estimated performance behaviours.

4.1. Fit Degree process

As previously mentioned, more and more companies need to work in a collaborative way, which forces them to share objectives and strategies in order to be more competitive in today's market. Following this trend, a new management layer should also be developed which should be responsible not for the individual efficiency of the elements of the network, but for the contribution of each partner to the global performance of the network. In line with this, a CN performance management framework is proposed for evaluation purposes that support the alignment prediction approach using a tool kit that consists of a performance estimate engine (such as the PPE) and a mechanism for qualitative classification (such as the Fuzzy Expert System).

In a broad way, the "Fit Degree" is an alignment metric that is obtained comparing the estimated values of key alignment indicators (KAI), that are selected by the decision makers in the CN from the existing set of KPI, with the target process values (compliance degree (CD)). Following, the comparison results are instantiated using a decision table developed by the experts that reveal if these targets have been achieved or why the participants in the CN were not able to achieve these performance goals. The classification of the CN alignment is then performed using the fuzzy logic to determine the qualitative rate for the future degree of alignment for the CN.

The Fit Degree process proposed for the overall CN alignment estimation should comprise a series of tasks as depicted in the following business process model (Figure 7):

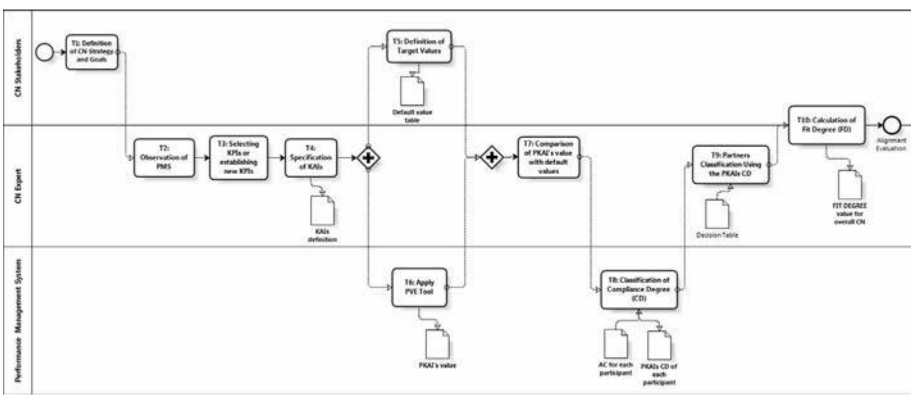

Figure 7.
Fit Degree process

(1) *T1: defining the CN strategy and goals*. First, the CN stakeholders must define the main goals to be achieved by the entire network in order to identify the strategy to be followed by each participant in the system.
(2) *T2, T3 and T4: collecting key alignment indicators*. The main KPIs capable of providing the appropriate alignment information should be selected from the list of KPIs already calculated in each of the CN partners. Performance should be translated in terms of the strategic purposes and expected outcomes for the inter-organisational processes of the CN.
(3) *T5: defining target values*. After the KAIs are selected, it is necessary to turn the CN objectives into KAI target values.
(4) *T6: predicting performance* (*PPE tool application*). After the KAIs are selected, the PVE tool should be applied in order to obtain the predictive values (PKAI).
(5) *T7: predicting performance* (*will-be vs to-be comparison*). After the estimated values of the KAI are obtained, the CN manager must compare these values with the expected (targets) in order to evaluate the individual performance of each partner in the network.
(6) *T8: classifying the compliance degree*. During this stage, the matrix that supports the classification of the CD should be defined according to the network strategy.
(7) *T9: classifying partners using PKAIs CD*. During this stage, the values of the CD should be put in a decision table which will be used to classify each participant in the network, and thus calculate the individual internal fit. Depending on the number of KAIs chosen, the decision table must be designed following a multi-variable approach.
(8) *T10: predicting alignment (Fit Degree calculation)*. Finally, using the values of the individual alignment classification (AC), it is necessary to calculate the value for the Degree Fit that represents the overall predictive degree of alignment.

In order to apply the process described before, a series of approaches, methods and tools should be used in order to guide the tasks and achieve the right outcomes. Therefore, in the following topic the steps that should be followed and the tools that should be used are presented in detail.

4.2. Research practical applications

A supply chain consisting of three industrial companies was used in order to properly describe each of the steps outlined for the proposal presented here. In this use case, one of the main goal is to be able to anticipate malfunctions, managing the future alignment of the network, and thus maintain product and service quality, improve process productivity and allocate resources more effectively.

Applying the Fit Degree methodology in a complex environment, such as a supply chain network, can present important difficulties due to the complexity of the interactions between the different individuals in the CN. Indeed, the values obtained by a participant certainly interfere with the values obtained by the subsequent element of the network. Therefore, a series of factors and its propagation by the network must be taken into account, including the occurrence of: preventive maintenance, overbooked orders, personnel and environmental attendance, production performance, supply and transportation reliability, equipment reliability, raw material quality, storage and handling reliability and process factors.

4.2.1. From KPIs to KAIs. In a CN, it is necessary to guarantee that the best partners are selected, that is, those that meet the requirements and demands of the network strategy. Therefore, in order to evaluate the degree of compliance of the participants, two KPIs were strategically defined and calculated in order to express the network performance according to the global goals that motivated the creation of the CN.

In order to select the suitable KPIs, initially the PMGS was observed aiming to select the indicators that best translate the inter-operational processes and which show whether the overall performance of the CN is being fulfilled. It is important to remember that, at this stage we must focus on the inter-firm relationships and not in the internal behaviour of each partner. The chosen KPIs will then be used as the KAIs that can effectively translate the performance objectives and goals of the CN.

In line with this, for the case in analysis, two KPIs were determined for time and quality aspects, respectively, suppressing, in this case, any cost indicator (Hronec, 1993). These indicators are:

(1) DDT – delay of delivery time (of orders).

(2) NON – orders (delivered) with non-conformities.

4.2.2. Turning the KAIs into predictive KAIs (PKAIs). Following, using the PPE tool, each of the defined KAIs must be forecasted in order to estimate the system's behaviour for the following period or periods. In order to accomplish this, the system under analysis should be modelled according to the historical data, using a learning machine such as NN (Farahat, 2004).

These historical data, which include system input and output information, must be carefully selected since this decision will strongly influence the estimation reliability, as following described. The input information, also defined as the leading factors or performance drivers, expresses the factors that can influence/disturb the overall system performance, as presented in Table I. These factors can be divided into system factors (U) and process factors (Q). In other words, from the leading factors selected, there are variables that are known beforehand (system factors), as is the case of the number of requested orders, as well as the overbooking possibility and the scheduled actions for preventive maintenance. However, although restrained within a known or proposed range, variables such as the production performance and the supply and transportation reliabilities affect the system in an unpredictable way. Therefore, this last group of data is defined as process factors. Finally, the output data (lagging factors or outcome measures) express the KAI's values in the conditions imposed by the input data.

In order to increase the system modelling reliability, it is important to model each of the CN partner instead of the CN as a global system. However, even if this approach is followed, it is necessary to be aware of the errors that can occur, not only from the generalisation process of the NN, but also from the noise brought about by the information sources and sensors. In line with this, the PPE tool applies, in a transparent way, a Kalman Filter that will decrease modelling and measurement errors.

After this preliminary task of data and network structure design is performed, the predictive performance engine is already capable of retrieving the predictive values

Factor	Type	Description
Preventive maintenance	U	It affects the available time to schedule production since it reduces the number of production days hampering the recovery from delays, which accumulate daily
Production performance	Q	This factor takes into account speed loss and affects the overall equipment effectiveness (OEE)
Overbooking	U	Factor that express if there are more orders than planned production capacity. Overbooking can be seen as a result of inefficient planning or seasonality
Supply reliability	Q	Factor responsible for expressing how reliable are the deliveries on time by suppliers. This factor can strongly affect delivery times
Equipment	Q	Factor responsible for expressing the capability and usefulness of the equipment to meet the product's quality requirements
Storage and handling	Q	Factor responsible for expressing the capability to store and handle the product package with adequate protection rules and appropriate equipment and facilities
Row material quality	Q	Factor responsible for expressing the raw data reliability. This factor can significantly affect the appearance of non-conformities
Environment	U	Factor responsible for expressing the protection level of the system against climate factors
Transportation	Q	Factor responsible for expressing the quality of transportation of material between supplier and client. This factor can strongly affect delivery times
Personnel skills	U	Factor responsible for expressing the production personnel's ability to operate processes efficiently
Absenteeism	Q	Absence of employees that directly affect the equipment operation

Table I.
Description of the PPE leading factors

for each KAI, for the following period. During this stage, it is essential to collaborate with the CN manager, who has a clear picture of the system and can supply the framework with more reliable data and with less effort. In Tables II and III, it is possible to visualise the input and output data retrieved from the PPE tool only for one partner of the CN under study. Therefore, the same procedure had to be performed for the entire network, following the existing dependencies and synergies between the CN elements.

4.2.3. Definition of specification pattern. After the predicted performance values are obtained, they may or may not be in compliance with the values previously defined as targets by the CN's decision makers. Therefore, it is important to compare these values with the predefined values (targets).

When assessing the PKAI values, it is necessary to define specification pattern values or intervals in order to classify the degree of compliance with these pattern values for each node of the network (Table IV). Normally, goals must be established when assessing performance. For example, in a manufacturing operation the number of losses for finished products is a common concern (how many of the total products were produced with irreparable non-conformities?). This methodology proposes five degrees to assess compliance with defined targets: very good, good, medium, bad, very bad. Following this specification pattern value table makes it possible to compare and classify the PKAIs to determine the degree of compliance with targets.

4.2.4. Compliance degree classification process. After the pattern table is created, the PKAIs from each participant in the CN are compared with the pattern values. The PKAI of each participant is then classified according to the specification pattern value table. This classification will be used to determine the classification of the degree

Factor	Values for the next period
Number of orders	15
Preventive maintenance	True
Production performance	0.2
Overbooking	False
Supply reliability	0.05
Equipment	0.2
Storage and handling	0.2
Row material quality	0.03
Environment	0.9
Transportation	0.1
Personnel skills	0.35
Absenteeism	0.015

Table II. Input data – leading and lagging factors

KPI	Estimation value (%)
DDT	2.35
NON	1.22

Table III. Output data – estimation KPI values

Classification of compliance degree	DDT specification pattern	NON specification pattern
Very good	$DDT^i < 2\%$	$NON^i < 1\%$
Good	$2\% \leq DDT^i < 5\%$	$1\% \leq NON^i < 2\%$
Medium	$\% \leq DDT^i < 10\%$	$2\% \leq NON^i < 5\%$
Bad	$5\% \leq NON^i < 10\%$	$5\% \leq NON^i < 10\%$
Very bad	$NON^i \geq 10\%$	$NON^i \geq 10\%$

Table IV. Comparison between predicted and predefined values

of alignment using a decision table which was created to describe the main concerns when assessing if the set of PKAIs of a CN participant, or potential partner, coincide with the strategic goals of the CN.

However, more than two PKAIs can be used, which makes it necessary to follow a multi-variable approach to determine the AC of each participant. Therefore, the AC table (Figure 8(a)) instantiates the degree of alignment of one participant and clarifies whether its performance meets the expectations of the CN. Furthermore, these predicted individual alignment values may or may not comply with the values previously expected by the CN's decision makers. It is therefore imperative that these values are used to determine the future level of the overall alignment. It can also be noted that the decision table may consider some PKAIs as more important than others and not linearly as in Figure 8(b), or even that the PKAI may surpass the other when it is more important.

This matrix calculates the AC for each participant using both PKAIs, making it possible to visualise the participants that will perform better or worse in the future. Following this step, the Fit Degree can be calculated to determine the overall degree of alignment.

4.2.5. Fit Degree calculation process. The objective of this last step is using fuzzy logic to calculate the Fit Degree of the CN's overall performance. Indeed, one of the main advantages of this decision support tool is its ability to determine a qualitative value for the future alignment of the CN, or even just to analyse the potential performance of each possible partner.

Using the Matlab® fuzzy logic tool, it was possible to configure the fuzzy mechanism, taking into account the requirements and specifications of each element with responsibilities in the network. The triangular and trapezoidal membership functions are used in the fuzzification process. The inputs and outputs are the KAI from the estimator tool and the partner evaluation, respectively. During this process, the membership functions were specified taking into account the different requirements of the CN under study.

In fact, the fuzzy logic, which is normally used when there is not enough knowledge and certainty about the system to be controlled, presents interesting characteristics that make it possible to model non-linear systems more easily. With this non-linear system modeller, it is possible to achieve a better definition, decrease the modulation error and control more complex systems.

In the context of the proposal presented here, one of the main advantages of this decision support tool is its ability to analyse the future alignment of the CN. In this context, a fuzzy module was developed not only to analyse each possible partner, but also to evaluate the final network configuration.

At the end of this process, it was possible to achieve a 3D graph (Figure 8) that represents the non-linearity desired for each of the nodes of the CN. As it is possible to see in the following image, as the KAI values increase, as expected, there is a decrease in the reliability of the partner, selected to fulfill a certain node requirement of the CN. Here, the navy blue color means that a certain partner "fits very well" and the color yellow means that it "fits very badly". From the analysis of the selected partner, it was possible to conclude that the Fit Degree obtained was "High".

Finally, after an individual analysis of the partner performance, according the CN requirements, it is necessary to study the global alignment of this complex and heterogeneous system. From the selected CN, it was possible to get the AC presented in the following image (Figure 9). In fact, element C represents the bottleneck of the production system, and because of that, partner C is the one that contributes the most to the non-alignment of the CN. In line with this information, the CN manager can determine, making a KPI analysis, how the identified partner can improve its performance to benefit the network or simply replace the partner in order to improve the overall behaviour of the system. In fact, if this methodology was automatically applied in a CN, retrieving performance data in real-time, this could be an important asset to the system management because it makes it possible to forecast and anticipate malfunctions and

NON \ DDT	very good	good	medium	bad	very bad
very good	fvw	fvw	fw	fm	bf
good	fvw	fw	fm	bf	bf
medium	fw	fm	fm	bf	vbf
bad	fm	bf	bf	vbf	vbf
very bad	bf	bf	vbf	vbf	vbf

NON \ DDT	very good	good	medium	bad	very bad
very good	fvw	fvw	fw	fm	bf
good	fw	fw	fm	bf	vbf
medium	fm	bf	bf	vbf	vbf
bad	bf	bf	vbf	vbf	vbf
very bad	vbf	vbf	vbf	vbf	vbf

fvw fits very well
fw fits relatively well
fm fits moderately fit
bf bad fit
vbf very bad fit

Notes: (a) With linearity; (b) without linearity

Figure 8.
Alignment classification table

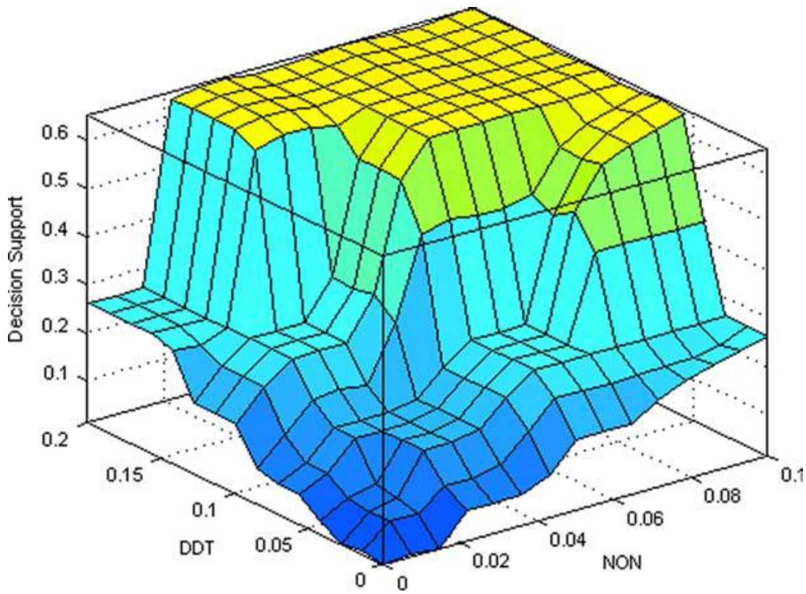

Figure 9.
Matlab® fuzzy tool and the 3D graph results

under-performances in the network. In this case, it is possible to avoid high levels of non-conformities and delays in deliveries, with low resource and time spending (Figure 10).

5. Conclusions

This paper explores the development of a predictive performance management approach capable of supporting CN managers in controlling their production chain in a proactive way, exploring feedback and feed-forward control loops. A qualitative research was also outlined in this document regarding the collaboration strategy and the fit concept. Therefore, this work introduces the alignment prediction concept in order to improve the decision-maker's knowledge about the performance behaviours in CN environments, leveraged by the emerging paradigm of performance prediction, replacing the traditional approach of collecting performance data to set goals and then monitor performance. In line with this, the intention is to evaluate, in a proactive way, if a certain CN partner is supporting and will continue to support the overall network so that it can achieve the defined targets.

In order to achieve these challenges, a predictive performance management framework for CN was developed inspired in tools normally used in the control theory. It was proposed the integration of Kalman Filters with NN as the main pillar of the PPE, aiming to extract knowledge from each partner's behaviour, and to estimate future performance using current leading performance data. Furthermore, a fuzzy logic approach was explored in order to assess, in an automated way, the performance

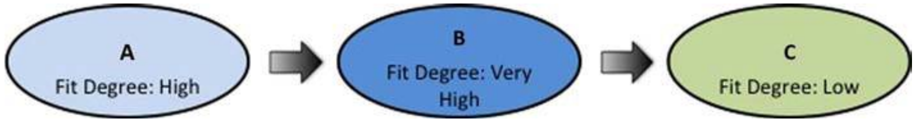

Figure 10.
Fit Degree results

behaviour of each partner, as a single entity, and the overall network alignment. Furthermore, the KAI was introduced as critical indicator for the overall network alignment which translates the main performance measurements from each partner that should be used to assess the network alignment.

Designed and implemented the framework prototype, a CN was selected in order to create a case study that presented the suitable characteristics for the implementation of these tools. For this CN, which is composed of three independent organisations, two KAIs were selected: number of orders with non-conformities and delay in delivery time. For each of them, a series of leading factors were defined and described in order to supply the performance estimator engine with the suitable data capable to support the performance estimation with more reliability as possible. After the predictive KAI were calculated, these values were then compared with the target values and introduced into the fuzzy logic engine in order to evaluate the alignment degree of the entire network. From the case selected, the partner which can be considered the bottleneck of the network was identified. It is considered the bottleneck, as its behaviour did not support the global CN in achieving excellency.

This on-going research intends to explore a series of functionalities capable to be implemented in real industrial scenarios using a performance management toolkit. Furthermore, as future research work, it is intend to enhance this toolkit by the development of methods and algorithms based on linear programming capable of analysing and evaluating the efficiency and productivity of each CN partner. Thus, CN managers are able to ranking companies according each network node requirements. For that, the strategy of the CN should be taken into account in order to support partner selection, always envisioning future alignment.

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