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Biological System Behaviours and Natural-inspired Methods and Their Applications to Supply Chain Management

Abstract

People have learnt from biological system behaviours and structures to design and develop a number of different kinds of optimisation algorithms that have been widely used in both theoretical study and practical applications in engineering and business management. An efficient supply chain is very important for companies to survive in global competitive market. An effective SCM (supply chain management) is the key for implement an efficient supply chain. Though there have been considerable amount of study of SCM, there have been very limited publications of applying the findings from the biological system study into SCM. In this paper, through systematic literature review, various SCM issues and requirements are discussed and some typical biological system behaviours and natural-inspired algorithms are evaluated for the purpose of SCM. Then the principle and possibility are presented on how to learn the biological systems' behaviours and natural-inspired algorithms for SCM and a framework is proposed as a guide line for users to apply the knowledge learnt from the biological systems for SCM. In the framework, a number of the procedures have been presented for using XML to represent both SCM requirement and bio-inspiration data. To demonstrate the proposed framework, a case study has been presented for users to find the bio-inspirations for some particular SCM problems in automotive industry.

1 Introduction

The study of bionics bridges the functions, biological structures and organizational principles found in nature with our modern technologies, and numerous mathematical and metaheuristic algorithms have been developed along with the knowledge transferring process from the life-forms to the human technologies and management[1-2]. People have learnt from biological system behaviours and structures to design and develop a number of different kinds of optimisation algorithms that have been widely used in both theoretical study and practical applications in engineering [3-6] and business management [7-8].

An efficient supply chain is very important for companies to survive in global competitive market. An effective SCM is the key for implement an efficient supply chain. Professor Martin Christophe believes that the competitiveness in 21st century will be among the supply-chains, not among the enterprises [9]. Though there have been considerable amount of study of SCM [10-16], as far as the authors are aware, there have been very limited publications of applying the findings from the biological system study into SCM. However, there is a large amount of biological study by biologists [17-22] and a number of natural-inspired algorithms have also been developed [23-30]. These research results and achievements can be analysed and amalgamated for obtaining bio- inspirations for SCM. So, it is very important to develop a mechanism to apply those results and achievements for SCM. In this paper, through systematic literature review, various SCM issues and requirements are discussed and some typical biological system behaviours and natural-inspired algorithms are evaluated for the purpose of SCM. Then the principle and possibility are presented on how to learn the biological systems' behaviours and natural-inspired algorithms for SCM and a framework is proposed as a guide line for users to apply the knowledge learnt from the biological systems for SCM. In the framework, a number of the procedures have been presented for using XML to represent both SCM requirement and bio-inspiration data. To demonstrate the proposed framework, a case study has been presented for users to find the bio-inspirations for some particular SCM problems in automotive industry.

2 Supply Chain Management

A supply chain is a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities transform natural resources, raw materials, and components into a finished product that is delivered to the end customer. A typical supply chain begins with the ecological, biological, and political regulation of natural resources, followed by the human extraction of raw material, and includes several production links (e.g., component construction, assembly, and merging) before moving on to several layers of storage facilities of ever-decreasing size and increasingly remote geographical locations, and finally reaching the consumer. A high efficient supply chain would bring a great profit to an enterprise, integrate resources, reduce logistics costs and improve logistics and overall level of service. In contrast, an inefficient supply chain will bring additional transaction costs and information costs, reduce the production capacity of the all enterprises on the entire supply chain and waste of resources. So the management of a supply chain is very important for a enterprise to survive in competitive market in the business environment of the globalisation.

In the 1980s, the term SCM was developed to express the need to integrate the key business processes, from end user through original suppliers. Original suppliers are those that provide products, services, and information that add value for customers and other stakeholders. The basic idea behind SCM is that companies and corporations involve themselves in a supply chain by exchanging information about market fluctuations and production capabilities. Keith Oliver, a consultant at Booz Allen Hamilton, is credited with the term's invention after using it in an interview for the *Financial Times* in 1982.[31-34]

The Council of Supply Chain Management Professionals defines supply chain management as follows: "Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners that can be suppliers, intermediaries, third-party service providers, and customers" [35].

The elements of supply-chain management have always existed in business. What changed was the willingness of businesses to recognise the inter-relationship of the various sub areas, and to pursue the benefits generated through coordination and integration, both from a strategy / planning perspective and operationally. The sub areas comprising a supply chain include (1) Forecasting / Planning, (2) Purchasing / Procurement, (3) Logistics, (4) Operations, (5) Inventory Management, (6) Transport - Warehousing, (7) Distribution and (8) Customer Service

The study of supply chain management has attracted enormous interests [10-14, 36-38]. The researches on the supply chain management have been related to the sub-areas of the supply chain management. The number of research topics is very big. There are no practical meanings to list all the research areas in one paper. The previous and existing research has been mainly focused on applying the available theories, techniques, methods, tools and best practice applications to investigate various issues to enhance the supply chain business activities. As far as the author are aware, there is not systematic researches on applying the natural-inspired methods to the various issues of the supply chain management though some work has been done. In this paper, the focus is on the application of the natural-inspired methods for the supply chain management, so the following is to summarise the main supply chain management areas that can be studied using a natural-inspired method.

1) The relationships between supply chain partners. The study in this area is normally to investigate the relationship between supply chain linkages and supply chain performance (cost-containment and reliability of supply chain partners). The research method is to build relationship models in order to identify the characteristics of determinants of linkages in the supply chain stakeholders (suppliers, internal stakeholders and customers). To have a good relationship between the partners is vital important for achieving the successful SCM. It is the good relationship that would secure the common understanding of partners' business requirements and targets, agree on win-win business strategy and plans, to collaborate on the joint planning, joint purchasing and information sharing etc. This is especially important in today's business environment with the advent of B2B e-commerce and increasingly complex and dynamic competitive markets [15,39-40].

2) Supply chain information integration. The power of information technology can be harnessed to help supply chain members establish partnerships for better supply chain system performance. Supply chain partnerships can mitigate deficiencies associated with decentralized control and reduce the “bullwhip effect”. The study in this area is mainly focused on the information sharing and information security issues through information system integration. It is very important for the partners to agree on what kind of information to be shared, in which data formats and how to secure the data. The research is normally to build various data models, sharing methods and ways for the secure information flow [16,41-42].

3) Supply chain performance evaluation. A high efficient supply chain would bring a great profit to an enterprise, integrate resources, reduce logistics costs and improve logistics and overall level of service. To determine if the efficiency of a supply chain is high or not, it is required to analyse and evaluate of the performance of a supply chain. The goal of supply chain performance evaluation is to achieve the compromise between service level and cost through mutual cooperation between enterprises. An effective and rational performance evaluation of a supply chain is particularly important. A rational method can be used to evaluate and improve the original supply chains, the new fabricated supply chain and those chains with the rearrangement of the work flow and hence for eventually obtaining the optimum supply chain models [43]. The research method is normally to propose and develop a performance indicator system and objective functions and various analysis, evaluation, simulation and optimisation models. The relationships between a set of performance indicators and objective functions are normally either implicit or highly non-linear. So it is very difficult if not impossible to applying the traditional mathematical analysis methods to carry out the supply chain performance study. Hence, considerable research work has been carried out to propose and develop various methods for the supply chain performance evaluation [12, 37, 43-48].

4) Logistics management. CSCMP (*Council of Supply Chain Management Professionals*) has defined the logistics management is that part of SCM that plans, implements and controls the efficient, effective forward and reverses flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements. Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfilment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. The research work has been on all those areas. Especially, some meaningful work has been done on the transportation routine design and optimisation. Various algorithms have been developed for the finding the optimum solution of transportation routine.[24,49-52]

3 Natural-Inspired Methods

People have learnt from biological systems and structures to design and develop a number of different kinds of optimisation algorithms that have been widely used in both theoretical study and practical applications [23]. Besides, a considerable amount of research work has been carried out by biologists with the meaningful outputs that can be used for engineering bionic application study [17-21, 53]. In this section various natural-inspired methods and the research findings will be discussed and analysed for investigating how these methods and findings can be applied for SCM, especially for the four areas discussed in Section 2.

3.1 Natural-inspired algorithms for finding complex system solutions

In the last few decades, more and more researches suggest that nature is a great source for inspirations to both develop intelligent systems and provide solutions to complicated problems. Taking animals for example, evolutionary pressure forces them to develop highly optimized organs and skills to take advantages of fighting for food, territories and mates. Some of the organs and skills can be well refined as optimization algorithms, and the evolution is a process to fine-tune the parameter settings in the algorithms. In this section, five nature-inspired algorithms are reviewed, including Ant Colony Optimization (ACO), Bees Algorithm (BA), Genetic Algorithm (GA), Firefly Algorithm (FA) and Artificial Neural Network (ANN) for the purposes of SCM.

1) Ant colony optimisation.

The ACO is a metaheuristic approach to solve problems that has been inspired by the ants' social behaviours in finding shortest paths. Real ants walk randomly until they find food and return to their nest while depositing pheromone on the ground in order to mark their preferred path to attract other ants to follow [54]. If other ants travel along the path and find food, they will deposit more pheromone as to reinforce the path for more ants to follow [55]. In the past decades substantial amount of research has been done to both develop the ACO algorithm itself and practical applications to solve the relevant problems in the real world. The initial ACO algorithm, Ant System (AS), was proposed by Marco Dorigo in 1992 in his PhD thesis [56]. Dorigo and Gambardella introduced Ant Colony System (ACS) as a variant of AS in 1997 [57]. In parallel, Stützle and Hoos invented the MAX-MIN Ant System in 1996[43]. In the early twenties, Iredi et al. published the first multi-objective algorithm which is a very popular extension to the original ACO algorithm [58].

The ACO was initially introduced as a cooperative learning approach to the Travelling Salesman Problem (TSP), and it now has been applied to a wide range of combinatorial optimization problems, frequently faced in logistic and production planning management such as scheduling (e.g. Job-shop scheduling problem[25], Single machine total tardiness problem[59]), vehicle routing (e.g. Capacitated vehicle routing problem[60], Stochastic vehicle routing problem[61]) and assignment problems (e.g. Frequency assignment problem[62]). The collaboration behaviour of ant colony can also be used to study the relationships between supply chain partners and supply chain information sharing and integration.

2) Bees Algorithm (BA)

The BA has been inspired from the food foraging behaviour of honey bees whose colony can typically extend itself over 10 km to 14 km and in multiple directions simultaneously to exploit a large number of food sources[63]. The colony tends to attain the optimal use of its members. Theoretically, the richer (more nectar or pollen) and closer a food source is, the more bees that would be sent to it. The food foraging process begins with scout bees' searching activities. They fly randomly to explore all the food sources in all directions. When they return to the hive, they report the searching results to the others by performing waggle dance [64] which communicates these important pieces of information about the food source, including its direction, distance and quality rating. The waggle dance is essential in the food source evaluation and it helps the colony to deploy flower bees to the food sources precisely. The BA is a population based optimisation algorithm first developed in 2005.

BA have also been applied to many combinatorial optimization problems, ranging from manufacturing[65] to computer image analysis[26], and it is proved to have a very robust performance and a high success rate compared with other intelligent optimisation methods. BA can be used to study the collaboration issues between partners of a supply chain and especially on the study rules a SME should play in a supply chain. Similarly, the collaboration behaviour of bee colony can also be used to study the relationships between supply chain partners and supply chain information integration.

3) Genetic Algorithm (GA)

GA generates solutions to search, optimization and machine learning problems via applying techniques inspired by biological evolution. Genetic algorithms were initially developed in computer simulations in the early 1950s [66-68]. To perform a GA, the first step is to initialize the population that normally is composed of randomly generated individuals covering the entire range of possible solutions, and size of the population is determined by the nature of the problem itself. The next step is to evaluate the fitness of each member of the population. A fitness function is employed in this stage to provide fitness values for each individual, and the results are then normalized in order to sort the entire population by descending fitness values. Once the selection process has finished, it comes to the reproduction stage where this generation performs repeatedly until one of the termination criteria is met.

GA has been widely adopted to solve complex problems, especially in the areas of scheduling, global optimization and control engineering. The implementation of genetic algorithms is one of the easiest compared to alternative intelligent optimization algorithms, but the building block hypothesis has been criticized that it lacks of theoretical justification [27,69] . Moreover, in some cases, the termination criterion is not clear. If the fitness function only has 0/1 as results, GA normally cannot solve the problem. GA can be used in the various optimisation problems in the supply chain management. Especially, the principle of GA in that those are best fit to the environment survive can be integrated in to the business strategy design for a company in a supply chain.

4) Firefly Algorithm (FA)

Fireflies produce luminescent flashes as a signal system to communicate with other fireflies, especially to prey attractions [28] . FA is inspired by the firefly's bio-chemical and social aspects and based upon the following three assumptions: (a) Each firefly attracts all the other fireflies with weaker flashes; (b) Attractiveness is proportional to their brightness which is reverse proportional to their distances; (c) No fireflies can attract the brightest firefly, and it moves randomly [29]. The brightness of firefly is associated with the objective function f(x),$x \in M_d$, assume that there exists n fireflies x*i*, i = 1,2,…,n initially positioned randomly in the space. Given the distance between firefly i and firefly j as $r_{ij} = d(x_i, x_j)$, the attractiveness between them should follow monotonically decreasing function, e.g. $= ke^{-r_{ij}}$, where k is the max attractiveness value. The flash intensity I is associated with the objective function f(x), i.e. $I = af(x)$ only firefly with higher flash intensity attracts the other one i.e. $I_i < I_j, j = 1, 2, \cdots, n. j \neq i$. FA can be possibly applied in the optimisation of transportation system design of a logistic system.

5) Artificial Neural Network (NN)

ANNs are information processing paradigms inspired by the way biological neural systems process data. In most cases an ANN is an adaptive system that changes its structure based on external or internal information that flows through the network. In more practical terms neural networks are non-linear statistical data modelling or decision making tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. However, the paradigm of neural networks - i.e., *implicit*, not *explicit* , learning is stressed - seems more to correspond to some kind of *natural intelligence* than to the traditional symbol-based *Artificial Intelligence*, which would stress, instead, rule-based learning. Learning in neural networks is particularly useful in applications where the complexity of the data or task makes the design of such functions by hand impractical. There have been a significant number of publications about ANN and its applications [30, 70-72].

Application areas of ANNs include system identification and control (vehicle control, process control), game-playing and decision making (backgammon, chess, racing), pattern recognition (radar systems, face identification, object recognition), sequence recognition (gesture, speech, handwritten text recognition), medical diagnosis, financial applications, data mining (or knowledge discovery in databases, "KDD"), visualization and e-mail spam filtering. But as far as the authors are aware, there are very limited efforts in apply ANN in supply chain management. However, the authors believed that ANN can be applied in customer service, business intelligence and information sharing of the supply chain management.

3.2 Fish schooling

In biology, any group of fish that stay together for social reasons are shoaling and if the group is swimming in the same direction in a coordinated manner, they are schooling [73].

Fish derive many benefits from shoaling behaviour including defence against predators [74] (through better predator detection and by diluting the chance of individual capture), enhanced foraging success, and higher success in finding a mate. It is also likely that fish benefit from shoal membership through increased hydrodynamic efficiency. The fish use many traits to choose shoal mates. Generally they prefer larger shoals, shoal mates of their own species, shoal mates similar in size and appearance to themselves, healthy fish, and kin (when recognized). There have been many publications on fish schooling study. Amintoosi M et al proposed a fish school clustering algorithm to study student sectioning problem [75]. Julia K. Parrish et al surveyed similarities and differences in behavioural algorithms and aggregation statistics among the various schooling models and then developed a modelling framework that synthesizes the other people's work and to identify relationships between behavioural parameters and group-level statistics [76]. Lopez et al discussed the studies on collective motion by means of individual-based modelling that have allowed a qualitative understanding of the self-organization processes leading to collective properties at school level, and provided an insight into the behavioural mechanisms that result in coordinated motion [77]. Conradt thought that two important factors that influence collective decision-making are information uncertainty and conflicting preferences. He found that relatively simple cognitive mechanisms can lead to effective information pooling. Groups often face a trade-off between decision accuracy and speed, but appropriate fine-tuning of behavioural parameters could achieve high accuracy while maintaining reasonable speed. The right balance of interdependence and independence between animals is crucial for maintaining group cohesion and achieving high decision accuracy [78]. Cai developed artificial fish school swarm algorithm applied in a combinatorial optimization problem to minimize the turnaround time of vessels at container terminals so as to improve operation efficiency customer satisfaction [79]. He found the algorithm has better convergence performance than genetic algorithm (GA) and ant colony optimization (ACO).

The findings from the previous studies can be comparatively analysed to obtain the natural inspirations for the researches of how to learn the fish schooling's behavioural properties to develop new business models for partners to achieve the collective decision-making, to study information sharing models and to help partners to develop collaborative business environments for the supply chain management. Besides, this is a very interesting natural-inspired way for SMEs in a supply chain to learn how to collaborate to gain group strength for work with the giant dictating companies.

3.3 Bird flocking

Flocks of birds can initiate a turn up to three times faster than they can biologically respond to their neighbour. This means that the birds respond faster than the mechanism they have for sensing and responding, which cannot be true. The real mechanism relies on anticipation and a learned response. This could be a source of building business capability that performs better than the sum of the individual components would indicate. Observation in flocks shows a slow start time then acceleration as the wave moves along all axis of the flock [80]. This could also be significant for a business in terms of response times and variability in the response, which are the important for the supply chain management. Birds of prey tend to target individuals that are away from the main flock. It could be the basis of a business model for competitions.

3.4 Animal cohesive motions

Nature is rich with many different examples of the cohesive motion of animals. This is also a source for obtaining natural inspirations for SCM, especially how partners to collaboratively responding the changes of business environments. Nikolai et al proposed a model that predicts that higher updating frequency, which they related to perceived threat, leads to more synchronized group movement, with speed and nearest-neighbour distributions becoming more uniform. Their experimental results suggested that the behaviour of fish (at different states of agitation) can be explained by a single parameter in their model: the updating frequency [22].

Gueron et al investigated the dynamic behaviour of small herds by means of simulations of two-dimensional discrete stochastic models. They explored the variety and characteristics of spatial patterns that develop during migration. They observed that animals move away from individuals that intrude too closely into their environment, but are attracted to individuals at a distance. Between these extremes, there appears to be a neutral zone, within which other individuals engender no response. In particular, the neutral zone, if not too large, permits the individual to remain in contact with the herd, while reducing the frequency with which acceleration or deceleration must be undertaken. This offers obvious energetic benefits [81].

Ballerini et al reconstructed the three-dimensional positions of individual birds in airborne flocks of a few thousand members and found that the interaction does not depend on the metric distance, as most current models and theories assume, but rather on the topological distance. So a topological interaction grants significantly higher cohesion of the aggregation compared with a standard metric one [53].

3.5 Symbiosis

Symbiosis is normally used to describe the range of relationships that exists between organisms. It is used in the biological sense in that it covers all relationships and not in the lay sense which means a win-win relationship. At one end of the spectrum, commensalism is where two organisms directly benefit from their relationship and at the other is parasitism where one organism suffers or dies because of the relationship. Antibiosis goes one-step further and creates an environment where no other organism can survive or prosper. Parasites in general cover a wide range of relationships. In all cases, the host suffers although the impact is everything from death to minor. What is important is the way in which the parasite takes advantage of the host. Parasites adopt a number of strategies to invade hosts then evade host defence mechanisms. The key rule for all parasites is that they must leave the host and have moved onto another host before the host either dies or creates an effective barrier to the parasite. This is similar behaviour to that exhibited by the FMCG (fast moving consumer goods) industries they need to continually create new products for the supermarket channel so that the margin is not gradually eroded. Further parallels can be seen when comparing the sale of goods to multiple retailers and the cross species activity of certain viruses [7].

4 A Framework for Applying Natural-inspired Methods to SCM

The great efforts have been made in learning from nature for technology innovation in engineering. Some methods have been proposed and developed for guiding how to learn from nature for engineering applications [1-5, 82]. But the most of previous work has been focused on the engineering though there have been a few reports on how to learn from nature for business management [8, 19]. As far as authors are aware, there are no reports on frameworks or models for learning from nature for SCM. Based on the discussions in Section 2 and 3, the authors believe that it is possible and practically important to propose a framework as a guide for applying natural-inspired methods for SCM.

The underlying principle of the new proposed framework is to combine the natural-inspired methods such as those discussed in Section 3.1 and the observed biological systems' behaviours such as those discussed in Sections 3.2-3.5 to develop a method for solving a supply chain business problem as discussed in Section 2. Fig. 1 shows the proposed framework for apply natural-inspired methods for SCM. There three main tasks in the framework: (1) to build a SCM business requirement database in XML (extensible mark-up language), (2) to build a database for storing the biological system behaviour knowledge and the natural-inspired algorithms in XML, (3) to develop an algorithm to match the SCM requirements and the knowledge to generate a method for a particular SCM problem.

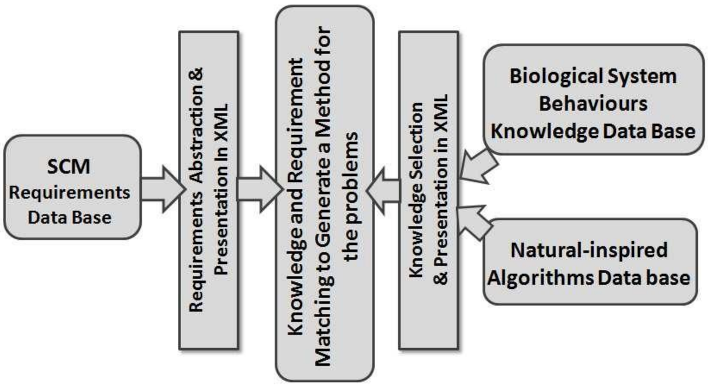

Fig. 1 The proposed framework for apply natural-inspired methods for SCM

4.1 Build a SCM business requirement database

There are two steps in building the database: (1) data collection and (2) data presentation in XML.

4.1.1 Data collection

The data collection can be achieved by systematic literature review in the area of SCM. Fig.2 shows the procedure of the data collection of SCM requirements. There are five main tasks:

(1) The first task is to classify the supply chain management into a number of sub-areas and determine the business requirements for each sub-area.

(2) The second task is to analyse these requirements to generate the lists of all possible functional specifications for selecting the natural-inspired methods.

(3) The third task is to record these requirements in the requirement log book

(4) The fourth task it to choose the criteria for examining the functional specifications for each requirement.

(5) The fifth task is to examine each requirement in the log book against the criteria and to generate priority list of the requirements or to determine which requirements should be retained and which ones should be removed from the list, then update the log book. This can be an iterative process until all requirements have been examined with satisfactory results.

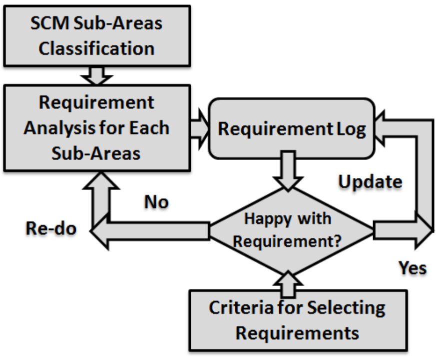

Fig. 2 The data collection process

4.1.2 Data presentation in XML

All requirements and their associated functional specifications should be presented in XML. The reason that XML is used is because the XML is a neutral data format and it is easy to be shared between partners in a supply chain, which is vital important for seamless data sharing and integration in SCM. Besides, the requirement and its functional specifications are unstructured data that are not suitable to be stored in a traditional rational database.

4.2 Build a database for storing the biological system behaviour knowledge and the natural-inspired algorithms

Similarly, there also two steps in building this database: (1) data collection and (2) data presentation in XML.

4.2.1 Data collection

The data collection can be achieved by systematic literature review, survey and interviews in the area of bionics engineering, biological studies and applied computing etc. Fig.3 shows the procedure of the data collection of the knowledge. There are four main tasks:

(1) The first task is to classify the biological system behaviour studies into a number of sub-areas and determine the features and the application for each sub-area.

(2) The second task is to review all published natural-inspired algorithms and determine the features and applications for each algorithm.

(3) The third task is to develop a performance analysis system to evaluate the features and applications to generate the lists of all features and possible applications against the supply chain management requirements specifications.

(4) The fourth task is to record these features and applications in a log book

4.2.2 Data presentation in XML

All features and applications in the log book should be presented in XML.

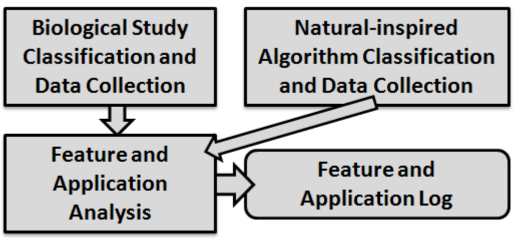

Fig. 3 The procedure of bio-inspired method data collection and presentation

4.2.3 Data collection and XML presentation samples

In this section, a sample of XML presentation of the biological behaviour of fish schooling is discussed. The fish schooling behaviour is listed in Table 1. It should be pointed out that the behaviours listed in Table 1 are based on the data available to the authors and their understanding. The data in Table 1 should not be considered as inclusive. The data can be modified and further processed with the more data available. The main purpose here is to demonstrate how to present the collected data in XML. Fig. 4 is a short version of the real XML file. This is only a sample of XML file for recording the data of the biological inspiration of fish schooling.

As for the natural-inspired algorithms, the features or the parameters used for describing these features for supply chain management are normally different from those biological behaviours listed in Table1, but XML file is the same in formats for representing the natural-inspired algorithm data.

4.3 Knowledge and Requirement Matching

After the representation of the supply chain management requirements and the biological behaviour and natural-inspired algorithm knowledge in XML, the nest step is to develop an algorithm to match them to determine a natural-inspired method for the targeted problem of supply chain management. Because the problems associated with supply chain management are diverse, so the matching algorithm can only generate a list of possible methods with a factor that describe each method's suitability. Since the requirement and knowledge data have been represented in XML, XSLT can be used to build the 'matching engine' using key words defined in the requirement and knowledge databases.

Table 1 Biological inspiration data from fish schooling

Fish Schooling				
Behaviour Name	**Biological Inspirations**	**Potential Application in SCM**		**Applicability**
		Application Area	**Management Meaning**	
defence	Defence against predators through better predator detection and by diluting the chance of individual capture	FSa	Importance of collaboration to survive	High (10)
		FSb	Group purchase or sale power enhancement	
		FSc	SMEs collaboration to compete with giant enterprises	
foraging	Enhanced foraging success	FSa	Importance of collaboration to survive	High (10)
		FSd	Group force for winning market share	
mating	Higher success in finding a mate	FSe	To have a pool of potential partners (suppliers or customers) to form the close partnerships for long term strategic business targets	High (10)
hydrodynamic efficiency	Fish possibly gain the reduced the hydraulic resistance of water to save the moving energy so that to move longer distance and fast for defence and foraging	FSd	Importance of forming collaboration to reduce the resistance of getting into a new market with reduced requirement of resources	Medium (5)
Using traits for mating	Use many traits to choose shoalmates. Prefer larger shoals, shoalmates of their own species, shoalmates similar in size and appearance to themselves, healthy fish, and kin (when recognized)	FSe	Looking for partners with similar sizes, business culture, good business performances	Medium to High (8)
		FSf	For SMEs, form collaborations with the friends or relatives' companies	
Oddity effect	Any shoal member that stands out in appearance will be preferentially targeted by predators	FSg	Avoid to be targeted by the enemy competitors	Low to Medium (3)
Ways fish school (1)	Young fish practice schooling techniques in pairs, and then in larger groups as their techniques and senses mature	FSe	SMEs or new companies to form the collaboration with the smaller number of partners at beginning and then to grow with longer time of collaboration	High (10)
Ways fish school (2)	Fish require sensory systems for schooling	FSh	An information warning system will be useful for partners to work together efficiently	High (10)
School Behaviour model	1) Move in the same direction as your neighbour 2) Remain close to your neighbours 3) Avoid collisions with your neighbours	FSa	Responding the business environment in a harmonized way	High (10)
		FSi	Agreeing the same supply chain strategy	
		FSj	Avoid the same products in the close or similar markets	
School structure	1) Fish in schools typically have a density of about one fish per cube of body length [83] 2) NND (nearest neighbour distance) is usually between one-half and one body length	FSl	The importance of the density of the companies in an industry sector for a geological region or a market sector	Medium to High (8)
Clustering algorithm	a fish school clustering algorithm to study student sectioning problem[76]	FSalg	Partner selection	Low to Medium (3)
Collective decision-making	The right balance of interdependence and independence between animals is crucial for maintaining group cohesion and achieving high decision accuracy[78]	FSm	Importance of trade-off between decision accuracy and speed	High (10)
		FSn	Importance of joining decision making but with some level of independence between partners	

artificial fish school swarm algorithm	applied in a combinatorial optimization problem to minimize the turnaround time of vessels at container terminals so as to improve operation efficiency customer satisfaction[79]	FSo	Optimisation of vehicle fleet in-out order and density for logistics management	Medium to High (8)

```
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             xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
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     <fishschooling>
         <fs001>
             <behaviourName> defence </behaviousName>
             <biologicalInspirations> Defence against predators through
                       better predator  detection and by diluting the
                       chance of individual capture </biologicalInspirations>
             <potentialApplicationInSCM No="1", appArea=FSa> Importance of
                       collaboration to survive</potentialApplicationInSCM>
            <potentialApplicationInSCM No="2", appArea='FSb'> Group
                       purchases or sales power enhancement
           </potentialApplicationInSCM>
            <potentialApplicationInSCM No="3", appArea='FSc'> SMEs
                       collaboration to compete with giant enterprises
           </potentialApplicationInSCM>
            <applicability> 10 </applicability>
         </fs001>
         <fs002>....</fs002>
         ....
         <fs013>...<fs013>
     </fishschooling>
</ Bio-Inspiration >
```

Fig. 4 A short version of the real XML file

The procedure of the matching is as follows, as shown in Fig. 5:

1) Select the target SCM areas from those discussed in Section 2.
2) For each selected SCM area, determine the AppArea codes from SCM requirement database.
3) Apply XSLT to search XML file as discussed in Section 4.2.3 to find all matched biological inspirartions or natural-inspired algorithms using AppArea codes.
4) Evaluate the found inspirations or algorithms using pre-determined criteria and generate an evaluation report.
5) Record the reports in Report Log.
6) Check if all SCM areas have been matched, if not, repeat Step 1 to Step 5 until all the areas have been matched.

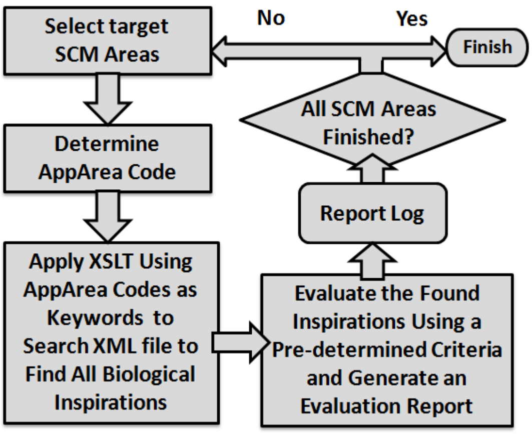

Fig. 5 The procedure of knowledge and requirement matching

4.4 The Case Study

In this paper, a case study of a sub-supply chain in the automotive industry is selected to demonstrate the proposed framework. A typical supply chain model in automotive industry is shown in Fig. 6. Due to the limitation of the length of the paper, a segment of the chain between car OEM (original equipment manufacturer) and Tier 1 part supplier is selected for the discussion. Based on the framework, the first step is to determine the SCM requirements. For this case study, the two requirements are selected: (1) the relationship management between Tier 1 part supplier and OEM and the logistics management between Tier 1 part supplier and OEM. So the strategic relationship between the partners and the cost-effective and efficient logistics management are selected as the SCM AppAreas. Using the matching algorithm discussed in Section 4.3 to search both the XML file can find the possible biological inspirations and natural-inspired algorithms, as listed in Table 2.

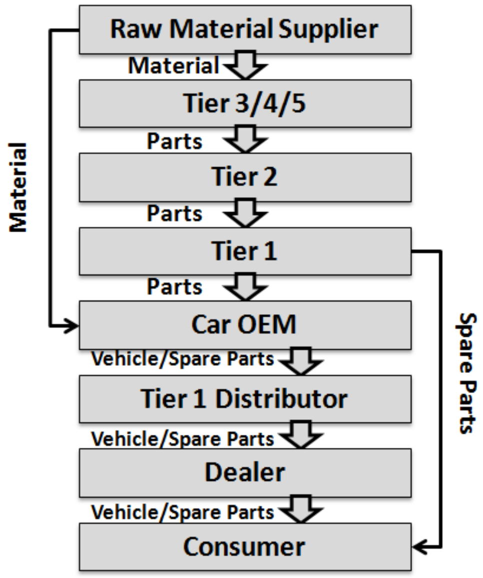

Fig. 6 A typical SCM model for automotive industry

5 Discussions of the Future Research

As discussed above, though there have been considerable amount of study of SCM, as far as the authors are aware, there have been very limited publications of applying the findings from the biological system study into SCM. This paper is only presented with purpose of introducing the principle and possibility of how to learn the biological systems' behaviours and natural-inspired algorithms for SCM and proposing a framework as a guide line for users to apply the knowledge learnt from the biological systems for SCM. But to make the proposed framework applicable in practical SCM, there is still a significant amount of research work to be carried out. The future research areas can be:

1) Supply chain business process modelling, analysis, simulation and optimisation

Through the study of the supply chain management business process modelling, analysis, simulation and optimisation, the SCM requirements can be accurately defined, which is considered as the fundamental work for building the valuable XML SCM requirement database and hence for design and develop a framework with applicable value.

2) SCM requirement analysis

SCM covers a variety of management issues as discussed in Section 2. It is required to have the systematic study to generate a reliable and valuable XML SCM requirement database. To achieve this, various SCM performance evaluation methods and indicators should be investigated.

3) Study of biological system behaviours and natural-inspired algorithms to gain the inspirations for SCM

Though there are a large amount of publications on biological system behaviours by biology scientists and some publications on applying them for business management, but there is little work on systematic review of the published work from knowledge engineering point of view to obtain the useful data that can be used for business management, especially for SCM. The data should be designed with information to describe the bio-inspirations' features and their potential application areas. This is the area with both theoretical meanings and practical application values.

4) Design and development XML files, XSLT files and the other required program files for matching and report presentation

Though XML has been applied extensively in various industries for information sharing and system integration for business management, as far as the authors are aware, there are no reported work on represent SCM requirements, biological system behaviours and natural-inspired algorithms in XML. Some study should be carried out in this area as well. In addition, various algorithms should be developed for data mining or matching purpose. Especially, the algorithms can be implemented using XSLT.

Table 4.2 The possible biological inspirations and natural-inspired algorithms identified using the proposed framework

SCM Requirements	Possible Applications in SCM		Identified Bio-Inspirations			
	Application Area	Management Meaning	Behaviour Name	Biological Inspirations	Applica-bility	Biological Behaviour Category
Good Strategic Relationship between OEM and Tier 1 Part Supplier for Automotive Industry	FSa	Importance of collaboration to survive	defence	Defence against predators through better predator detection and by diluting the chance of individual capture	10	Fish Schooling
	FSa	Importance of collaboration to survive	foraging	Enhanced foraging success	10	Fish Schooling
	FSd	Importance of forming collaboration to reduce the resistance of getting into a new market	Hydro-dynamic efficiency	Fish gain the reduced the hydraulic resistance of water to save the moving energy so that to move longer distance and fast for defence and foraging	5	Fish Schooling
	FSg	Avoid to be targeted by the enemy competitors	Oddity effect	Any shoal member that stands out in appearance will be preferentially targeted by predators	3	Fish Schooling
	FSa	Agreeing the same supply chain strategy	School Behaviour model	Remain close to your neighbours	10	Fish Schooling
	FSi	Responding the business environment in a harmonised way	School Behaviour model	Move in the same direction as your neighbour	10	Fish Schooling
	FSm	Importance of trade-off between decision accuracy and speed	Collective decision-making	The right balance of interdependence and independence between animals is crucial for maintaining group cohesion and achieving high decision accuracy	10	Fish Schooling
	BFa	Importance of collaboration to survive	Flocking Behaviour model	Working together. Following rules. Providing safety in numbers	10	Bird flocking
	SYa	Joint ventures, collaborations, competition, co-operation	Mutualism	two species cooperated such that both species benefitted	10	Symbiosis
	......	......	......	......	......	......
Cost-effective and efficient logistics Management for Automotive Industry	FSo	Optimisation of vehicle fleet in-out order and density for logistics management	artificial fish school swarm algorithm	applied in a combinatorial optimization problem to minimize the turnaround time of vessels at container terminals so as to improve operation	8	Fish Schooling
	ACalg	Vehicle routing design and optimisation	Ant colony optimisation	the ants' social behaviours in finding shortest paths	7	Ant Colony
	BCalg	Vehicle routing design and optimisation	Bees Algorithm (BA)	the food foraging behaviour of honey bees in multiple directions simultaneously to exploit a large number of food sources	7	Bee Colony
	FLalg	The optimisation of transportation system design of a logistic system	Firefly Algorithm (FA)	Fireflies produce luminescent flashes as a signal system to communicate with other fireflies, especially to prey attractions	5	Firefly colony
	......	......	......	......	......	......

6 Conclusions

This paper presented the principle and possibility of how to learn the biological systems' behaviours and natural-inspired algorithms for SCM and proposed a framework as a guide line for users to apply the knowledge learnt from the biological systems for SCM. In particular:

1) Various supply chain management issues and requirements have been discussed.
2) Some typical biological system behaviours and natural-inspired algorithms have been evaluated for the purpose of SCM.
3) A framework has been proposed for users to match the bio-inspirations and SCM requirements so that they can apply those bio-inspirations to their SCM.
4) In the framework, a number of the procedures have been presented for using XML to represent both SCM requirement and bio-inspiration data.

5) A case study has been presented to demonstrate how the proposed framework can be used as a guide for users to find the bio-inspirations for some particular SCM problems.

The authors would like to point out that the framework has only proposed without fully developed. To make the proposed framework applicable in practical SCM, there is still a significant amount of research work to be carried out, as discussed in Section 5.

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