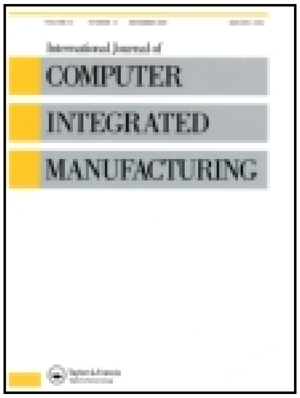

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Optimal service selection and composition for service-oriented manufacturing network

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The management of services is the kernel content of service-oriented manufacturing. However, it is difficult to realise the integration and optimisation of services in an open environment, which contains large amounts randomicity and uncertainty. The key problem is how to realise the optimal service selection and composition. In this article, the comprehensive performance evaluation metrics for service-oriented manufacturing network is proposed, which combines the key performance indicators of services in business, service and implementation level. The performance evaluation model is brought forward to analyse the local and global performance. An uncertainty and genetic algorithm-based method is developed to realise the optimal service selection and composition in effective and efficient way.

Keywords: service-oriented manufacturing; performance evaluation; service selection; service composition

1. Introduction

Interaction between manufacturing and services leads to the emergence of the service-oriented manufacturing (SOM) paradigm (Fry *et al*. 1994, Marceau and Martinez 2002, Gebauer *et al*. 2005). In the past decades, the enterprises have made the transition from a product manufacturer to a service provider. Examples of implementing this SOM strategy include IBM, GM and Intel (Karmakar 2004). Through the bundling of tangible products with associated intangible services, SOM extends the value chain and value creation for enterprises and customers.

Sun and Li (2007) defined SOM as a new advanced manufacturing paradigm where involved enterprises provide production-related services for each other to form a SOM network (SOMN). Production-related services enlarge the product connotation and realise the specialisation. A broad range of production-related services have been developed and incorporated within manufacturing (Marceau and Martinez 2002). Typical examples include engineering design and development (Hu *et al*. 2010), production management (Ahn *et al*. 2005, Phaithoonbuathong *et al*. 2010), material purchasing and transportation (Chen *et al*. 2010), repair and maintenance (Jiang and Fukuda 2001, Jiang *et al*. 2007).

In the context of global manufacturing and service outsourcing, production-related services are organised as a SOMN (service-oriented manufacturing network) (Fan and Huang 2007, Jang *et al*. 2008). SOMN realises value chain integration and cooperation among production-related services. SOMN is the alliance of professional services coming from different manufacturing enterprises that are involved in producing products. In SOMN, some services are owned by a core enterprise, while some services are outsourced to enterprises that provide the services. The capability to manage and use the manufacturing service network has direct relation to the success or failure of the manufacturer and its supply enterprises (Tao *et al*. 2009).

For example, Boeing Company has its service-oriented manufacturing network, which consists of 13,000+ professional service suppliers in more than 100 countries. Based on its SOMN, Boeing is planning to cut the construction time of its new 787 Dreamliner down to a three-day period. The SOMN ensures that Boeing gets the component products and services that are needed for building Dreamliner. However, at the same time, it also brings about some challenges. When the scales of the network become very large, the management of the network will become more difficult.

Different from the traditional manufacturing network (Shi and Gregory 1998), SOMN has its unique characteristics related to services. Compared with manufactured products, service products are featured by intangibility, inseparability, heterogeneity and perishability (Bowen *et al*. 1989, Nie and Kellogg 1999, Vargo and Lusch 2004). Some researchers studied the service operation management from

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economic view, such as service design, service quality, service marketing (Cook *et al.* 1999, Johnston 1999, Nie and Kellogg 1999).

However, the literature on the management of SOMN is limited. Early works proposed the concept of service supply chain to study service supply-demand, service purchasing, and service production in SOMN (Sampson 2000, Akkermans and Vos 2003, Ellram *et al.* 2004, Warrt and Kemper 2004).The management of service supply chain is quite different from manufacturing supply chain management where physical products are produced. Comparison has been drawn between these two types of supply chains from several aspects, such as expectations, distribution channels, contents, operation mode, architecture, controlling mechanism, evaluation methods and system dynamics (Allen and Chandrashekar 2000, Edward and Morrice 2000, Akkermans and Vos 2003, Ellram *et al.* 2004).

From the comparison, the following two technical difficulties can be observed in the management and implementation of SOMN. First, the measurement of service performance is not as easy as product functionality and tolerances (Ellram *et al.* 2004). The measurement of service performance is not only dependent on business factors but also dependent on the quality of service and service operating environment. Moreover, the performance of SOMN is related with the business logic used in service composition. All of these increase the difficulties of the performance measurement of SOMN and make it hard to establish a comprehensive performance metrics and develop the corresponding performance evaluation algorithm.

Second, there exist large complexity and uncertainty in the selection and composition of services. SOMN is a continually evolutionary system. The generation and termination of services happen more frequently. The relationship between services may be competitive and cooperative. To realise on-demand business, the SOMN system shows highly flexibility for the selection and composition of services. However, at the same time, it increases the computational complexity sharply. The selection of candidate services and the optimisation of potential composition schemes still a knotty issue.

The problems mentioned earlier have not yet been fully dealt with in a systemic and integrated way from both the academic or application perspectives. Concerning the performance evaluation of SOMN, existing methods focus on business domains and assess the performance from the strategic, tactical and operational levels (Chen and Paulraj 2004, Gunasekaran *et al.* 2005, Sengupta *et al.* 2006). However, few studies considered the relationship between business and implementation. The service element in SOM is not only a concept in economic and operational field but also corresponds to the implementation of business functionalities. Services can be realised and managed in a service-oriented manufacturing environment (Kathawala and Abdou 2003). The quality of services and the implemental environment play important roles in the management of SOMN and have become crucial factors to determine the performance of the SOMN system. It is important to analyse and optimise SOMN system from both business and implementation aspects. The integrated performance indicator framework should be established and the efficient and effective performance evaluation algorithm should be developed.

In addition, the research on the management and optimisation of SOMN is limited. The management and optimisation of SOMN is realised through the dynamic selection and composition of services. Current research on service selection and service composition is carried out from the field of computer science and based on IT-attributes of services (Li *et al.* 2007, Ko *et al.* 2008, Mabrouk *et al.* 2009, Menascé *et al.* 2010, Zhang *et al.* 2010). Most of the research does not consider the business performance being impacted by the service selection and composition scheme. Moreover, according to the customer requirements, there exist a large number of feasible schemes. The system should determine which services should be selected and what is the best service composition scheme that leads to the global optimal performance. Some intelligent methods have been proposed to cope with the problem (Aversano *et al.* 2006, Su *et al.* 2007, Cai *et al.* 2009, Liang and Huang 2009, Zhang *et al.* 2010). However, due to the dynamic business environment, service selection and composition is associated with a high degree of uncertainty. How to deal with the complexity and uncertainty to find out the optimal solution from a huge design space is the key problem in service selection and composition.

The aim of this article is to propose a comprehensive performance evaluation method for SOMN and to develop the efficient algorithm to find out the optimal solution for service selection and composition. The rest of this article is structured as follows. The following section analyses the complexity of SOMN management. 'The performance evaluation for SOMN' section establishes the preference metrics and comprehensive performance evaluation model for SOMN. 'Optimization of service selection and composition in SOMN' section proposes an uncertainty and genetic algorithm based algorithm for the optimisation of service selection and composition. 'Case study section' presents a case study for the proposed methods before concluding the article in the 'Conclusion' section.

2. Complexity analysis of service-oriented manufacturing network

2.1. The organisational structure of SOMN

In SOMN, an enterprise encapsulates its core competitiveness into services. Each involved enterprise in the SOMN provides a series of professional services. Through the composition of services, the service-oriented supply chain is created to fulfil custom requirement. Figure 1 describes the typical organisational structure of SOMN. For SOMN, due to the large number of services, the dynamic behaviour and performance of services, and the dynamic relationship between services, the management of SOMN is an arduous task (Thoben and Jagdev 2001).

2.2. The scenario for the management of SOMN

Taking the collaborative scenario of a household appliance manufacturing company as example, we can find out the management process of SOMN. The enterprise has established a SOMN, which contains 300+ manufacturing service providers, 20+ logistics service providers and 20+ financial service providers. A platform has been developed to support the management of this network. When receiving an order from the customer, the enterprise will decompose the customer requirement into a service-oriented supply chain (SOSC). The nodes in SOSC are implemented by services. There are two kinds of node in SOSC. One is physical service (PSV) node. PSVs are services, which are bound to specific functional entities directly. The other is abstract service (ASV) node. ASVs are not bound to specific functional entities. ASVs can be regarded as service requirements. There are number of potential PSVs can satisfy the requirement of an ASV. An ASV can also be satisfied by other ASVs.

Figure 2 shows the scenario of service-oriented sale process in SOMN. In the process, the nodes for receive order, check stock and assemble are PSVs, which can be bound to the functional entities of the enterprise. The department of market and manufacturing of the enterprise can provide the order service, stock service and assembling service directly. The other nodes, such as Transport 1, Making Parts, Payment, and Transport 2, are ASV nodes. Each ASV will publish its service requirement in SOMN platform. The potential service providers can register their PSVs in the platform and response to the requirements. Each ASV may be instantiated by one of the responded PSVs. For example, the node Make Parts may be instantiated by one of the PSVs provided by the 300+ manufacturing service providers and the node Transport 1 may be instantiated by one of the PSVs provided by its 20+ logistics service providers.

In the initial stage of SOMN, when the number of services is small, it is possible to manage SOMN by experience. But, when the scale of SOMN become

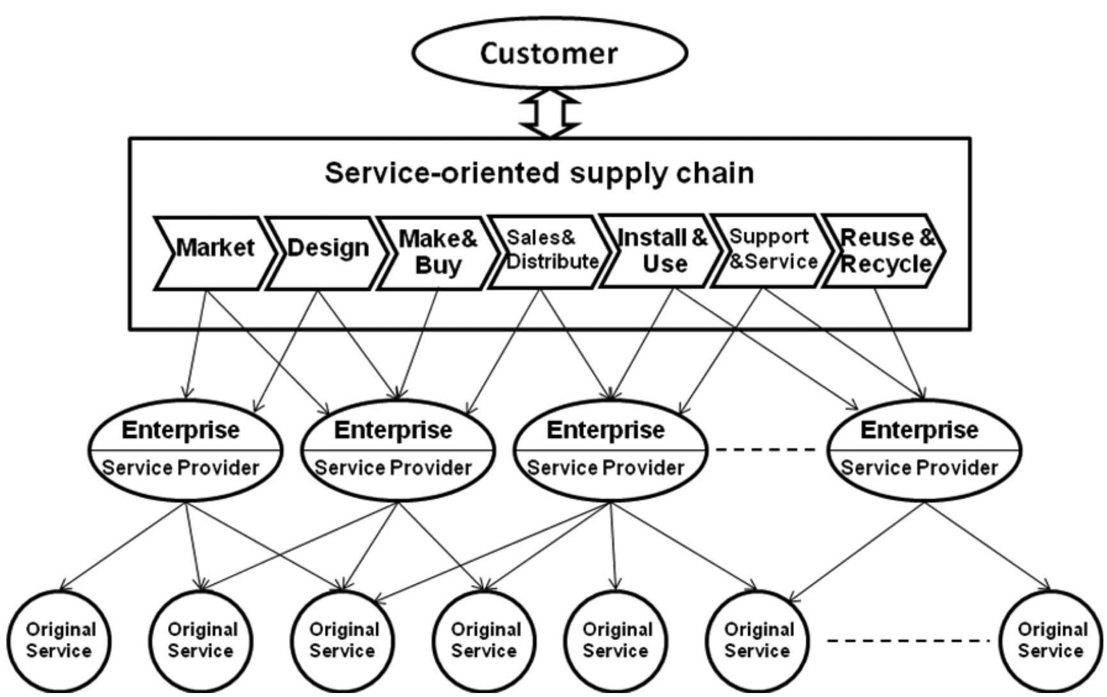

Figure 1. The organisation structure of SOMN.

larger and larger, it is unfeasible to make decision only by experience. It is also inefficient and ineffective for the selection of services and the searching for the best service composition scheme for SOMN by traversal algorithm due to the huge design space.

2.3. *Formal analysis for the complexity of SOMN*

According to Figure 2, the service supply-demand relationship in SOMN can be considered as a service-oriented supply chain system with multiechelon inventory. Figure 3 shows the topological structure of service-oriented supply chain in SOMN. Different from manufacturing supply chain, the inventory here refers to service inventory, which represents the capacity of ASVs or PSVs.

Suppose the service-oriented supply chain has K echelons, each echelon has J inventory nodes, each node has N ASVs, and each ASV contains M candidate services. The number of potential instantiated schemes for the SOSC could be calculated with Equation (1):

$$|\Theta| = (((M)^N)^J)^K. \tag{1}$$

Because services contain large number of uncertainties, we can use a simulation method, such as the Monte Carlo method (Brooks 1998) to estimate the global performance expectation for SOMN:

$$Q(\theta) \equiv E_\xi[P(\theta,\xi)] = \lim_R \frac{1}{R}\sum_{s=1}^{R} P(\theta,\xi_s) \tag{2}$$

where θ is the system parameters, ξ is the diversified randomicities of the system and $P(\theta, \xi)$ denotes the system performance.

The expectation of Equation (2) is as to all the randomicities of the SOMN and the last item is a

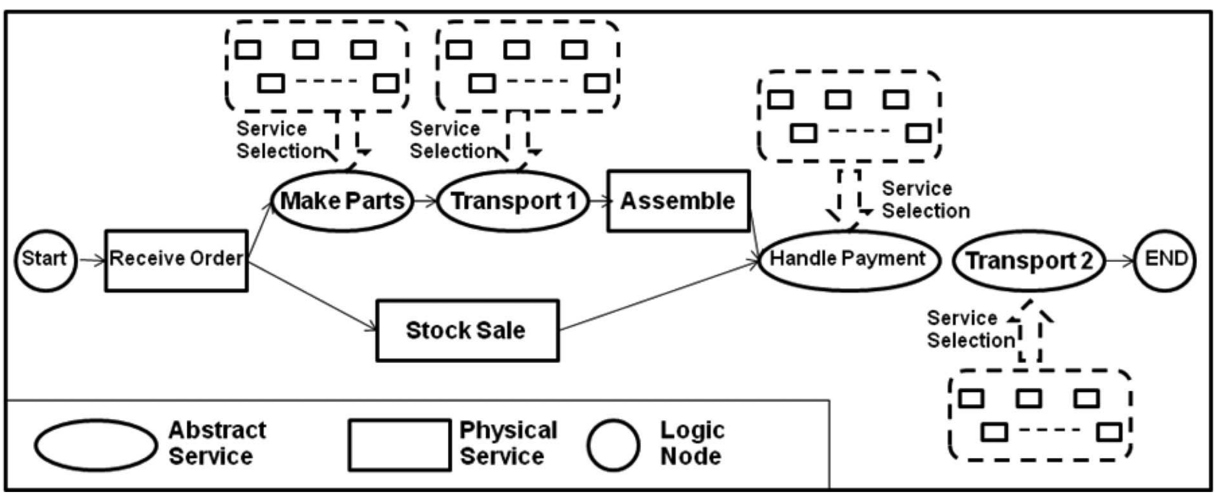

Figure 2. The scenario of service-oriented sale process based on SOMN.

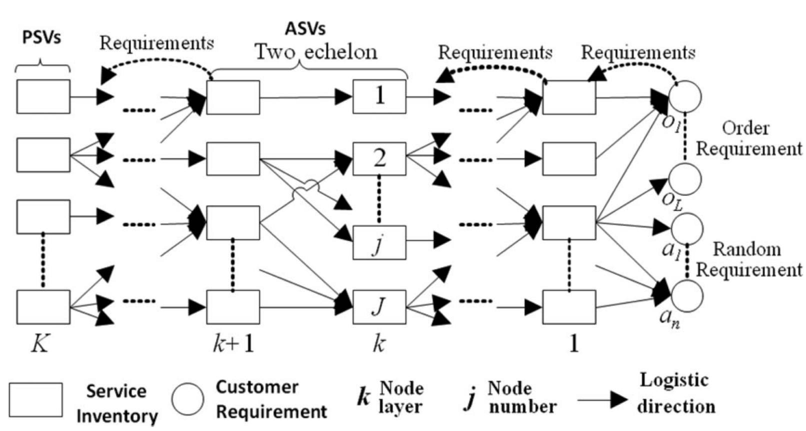

Figure 3. The topological structure of service-oriented supply chain in SOMN.

limitation. When R is sufficient large, the limitation is approximately as below:

$$\frac{1}{R}\sum_{s=1}^{R} P(\theta, \xi_s). \tag{3}$$

Therefore, the problem of management and optimisation for SOMN can be defined as to search the possible scheme $\theta \in \Theta$ to maximise the system's performance $Q(\theta)$. Here Θ is the system design space that contains all the possible θ. If Monte Carlo simulation takes too much time, it is difficult to search for the best scheme in the whole design space by infinite enumeration method. One valuable solution is to minimise the design space and to develop intelligent algorithms for service selection and composition under the premise of guarantee for performance.

3. The performance evaluation for SOMN

As the basic unit of SOMN, services have significant influence on the overall performance of SOMN. Because of the intangible, inseparable and dynamic nature of services, it is not easy to understand and measure the service performance (Ellram *et al.* 2004). It is also hard to define the relationship between service performance and business performance to build up the comprehensive evaluation framework for SOMN (Moorsel 2001). In this article, through the combination of business performance metrics and service performance metrics, a multilayer performance evaluation metrics model for SOMN is proposed. It synthetically considers the factors from business, service and implementation aspects and fits to the real operating situation of enterprises. Based on the performance metrics model, the analytic hierarchy process (AHP)-based performance evaluation method is proposed. The AHP method is a powerful and flexible multicriteria decision-making method for complex problems and has been widely used in the field of business performance evaluation (Saaty 2008). The article improves traditional AHP by defining the correlation of performance metrics to calculate the local and global performance of SOMN.

3.1. *Performance evaluation metrics for SOMN*

Because SOMN realises some business functions, manifests as service, and is implemented in service-oriented IT environment, its performance indicators consist of three layers (Figure 4).

(1) Business layer indicators: From business view, SOMN can be looked as a business ecosystem, which fulfills the objectives of business operation and strategy. The business level indicators describe the business performance metrics of SOMN.

- Business reliability ($\text{Reli}_{\text{busi}}$): $\text{Reli}_{\text{busi}}$ denotes the reliability of the business performance promised by the service providers. $\text{Reli}_{\text{busi}} \in (0,\ 1]$ and $\text{Reli}_{\text{busi}} = 1 - (\sum_{i=1}^{n} |x_i - y_i|/x_i)/n$, where x_i is the promised value of the indicator provided by the service providers and y_i is the real value of the indicator ascertained from the assessments provided by the consumers.
- Business time ($\text{Time}_{\text{busi}}$): $\text{Time}_{\text{busi}}$ denotes the completion time for a business process promised by the service providers. It is issued by the providers and may range from certain time period with a specified randomness, for example two to 5 days.
- Business cost ($\text{Cost}_{\text{busi}}$): $\text{Cost}_{\text{busi}}$ denotes the business cost promised by the service providers in a range with a specified randomness, for example 200–500 dollars.
- Business flexibility ($\text{Flex}_{\text{busi}}$): $\text{Flex}_{\text{busi}=}F_{\text{fun}} \otimes F_{\text{perf}}$ denotes the business flexibility, where F_{fun} denotes the number of ASVs optional implementation schemes with the same function, e.g. a function named TRANSPORTATION may be implemented by a train, by a car, or by a plane, then $F_{\text{fun}} = 3$. F_{perf} denotes the number of optional performance schemes for a certain function scheme, e.g. the function named BY TRAIN may have the performance schemes: 10 days, 100 dollars or 1 day, 500 dollars, thus $F_{\text{perf}} = 2$. Symbol '$\otimes$' here indicates an operator and its operation result is the combinatory number of the function schemes and the performance schemes.
- Business organisation relationship ($\text{Org}_{\text{relation}}$): $\text{Org}_{\text{relation}} \in$ (0,1] denotes the business organisation relationship between the service providers in SOMN at the business level. It is used to weigh the correlations for the different services at the business level.

(2) Service layer indicators: Service level indicators describe the ability of the service when an ASV is bound to specific PSV or a service-oriented business process is being composed by PSVs.

- Service response time (Q_{time}): $Q_{\text{time}} = \sum_{i=1}^{n} T_{q.i}/n$, denotes the time span between the time when the service provider receives the request and the time when it outputs the corresponding outcomes. T_{q} can be predicted from existing records.

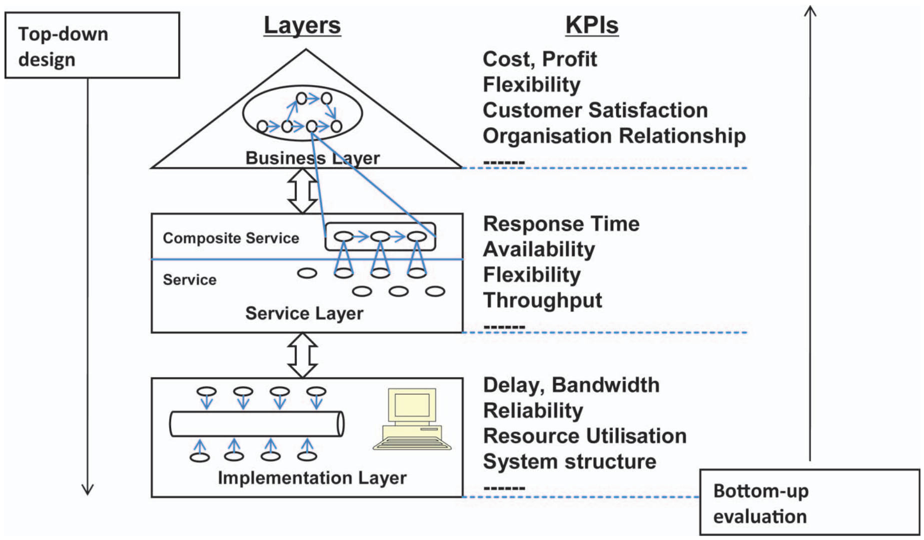

Figure 4. Performance evaluation architecture for SOMN.

- Service availability (Q_{avail}): $Q_{avail} = T_s/T_t$ denotes the time ratio that means the mean available time (T_s) in a specified interval (T_t). Success here means that the service will provide a correct output in an expected interval.
- Service organisation relationship ($Qorg_{relation}$): $Qorg_{relation} \in (0,1]$ denotes the organisational relation between the service providers from the service perspective, such as Qos. It can be used to weigh the relationship among services.
- Service flexibility (Q_{flex}). Q_{flex}=f($Flex_{busi}$) denotes the service flexibility that is related to the implementation of a service such as its function and interface descriptions. It is the technical base of the indicator $Flex_{busi}$.
- Service throughput (Q_{throu}): $Q_{throu} = N/T_{total}$ denotes the transactions handled by a service per unit time.

(3) Implementation layer indicators: the implementation indicators describe the relationship of SOMN performance with the implementation environment, such as softwares, hardwares, networks.

- IT environment reliability (IT_{reli}): $IT_{reli} = T_{work}/T_{total}$ denotes the ratio of the time span of the IT environment working correctly (T_{work}) in a given interval (T_{total}).
- IT resources utilisation (IT_{utili}): $IT_{utili} = T_{use}/T_{total}$ denotes the ratio of time that IT resources (e.g. Database, Application Server, Network Bandwidth) being used (T_{use}) in a given interval (T_{total}).
- IT environment configuration and structure (IT_{config}): $IT_{config} \in (0,1]$ denotes the comprehensive evaluation of the IT environment structures, scheduling policies, work patterns, etc. It can be analysed by quality analysis methods, benchmarking, etc.

3.2. *Performance operators for SOMN*

The performance of SOMN is not only associated with the services but also related to the business logic structure in the service composition. There are four basic business logic structures, i.e., sequential, concurrent, alternative with probabilities, and iterative structures. According to these structures, four-performance calculation operators are defined as follows, where n is the quantity of services involved in the business logic, q_i and w_i denotes the value and weight of ith performance indicator of the service.

(1) *Linear operators*: $L(q_1, q_2, \ldots, q_n) = \sum_{i=1}^{n} w_i q_i$, including:

- *Summation operators*: $L_{sum}(q_1, q_2, \ldots q_n) = \sum_{i=1}^{n} q_i$, used by the composition of cost, time of services, where $w_i = 1$, $1 \le i \le n$
- *Average operators*: $L_{avg}(q_1, q_2, \ldots, q_n) = \frac{1}{n}\sum_{i=1}^{n} q_i$, used by the composition of reliability and availability of services, where $w_i = 1/n$, $1 \le i \le n$.
- *Probability operators*: $L_{psb}(q_1, q_2, \ldots, q_n) = \sum_{i=1}^{n} p_i q_i$, used by the composition of services with alternative structure, $w_i = p_i$ is the probability the service may be executed, $1 \le i \le n$
- *Numeral multiplication operators*: $L_{tim}(q) = kq$, usually used in the composition of

services with iterative structure, k is the times of iteration.

(2) *Extremum value operators*: $\bar{M}(q_1, q_2, \ldots, q_n) = \max_{i=1}^{n} q_i$ or $\underline{M}(q_1, q_2, \ldots, q_n) = \min_{i=1}^{n} q_i$, usually used in composition of services with concurrent structure.

(3) *Multiplication operators*: $T(q_1, q_2, \ldots, q_n) = \prod_{i=1}^{n} q_i$, e.g. the calculation of availability of services with sequential structure.

(4) *Power operators*: $P(q) = q_i^k$, usually used in the composition of services with iterative structure, k is the times of iteration.

With the value of performance indicators of services and the performance calculation operators, the comprehensive performance of SOMN can be calculated on the whole. For example, the performance indicators such as cost, time and availability is denoted in Table 1.

Table 1. Performance operators for different service composition structures.

Performance indicators	Sequence	Alternative	Concurrent	Iteration
Cost	L_{sum}	L_{psb}	L_{sum}	L_{tim}
Time	L_{sum}	L_{psb}	$\bar{M}$	L_{tim}
Availability	T	L_{psb}	$\underline{M}$	P

3.3. Performance evaluation for SOMN

The performance evaluation of SOMN includes two stages. In the first stage, the performance of all candidate PSVs for each ASV will be calculated. The candidate PSVs of each ASV will be sorted by the results. In the second stage, all the potential service composition schemes will be evaluated.

3.3.1. Performance calculation for PSVs

(1) Determination of the performance indicators set.

Each indicator in 'Performance evaluation metrics for SOMN' section will be assigned a weight w_k, $k = 1, \ldots, K$. K is the number of all indicators selected by users. Suppose the service-oriented supply chain consists of m ASVs. The ith ASV$_i$ has p_i PSVs (PSV$_j$, $j = 1, \ldots, p_i$). PSV$_{i,j}$ denote the jth candidate PSV of ASV$_i$. Denote the performance indicator set of ASV$_i$ as P_i, the PSV$_{i,j}$ s $P_{i,j}$, and their kth dimensional performance indicator as P_i^k and P_{ij}^k.

Let P_i denote the performance of ASV$_i$. P_i is a two-dimensional matrix:

$$P_i = (P_{i,j}^k;\ 1 \le j \le p_i, 1 \le k \le K). \tag{4}$$

Let $P_{i,j}$ denote the performance of the j_{th} PSV, $P_{i,j}$ is

$$P_{i,j} = (P_{i,j}^k;\ 1 \le k \le K). \tag{5}$$

(2) Determination of the weights of all indicators based on AHP

Once all the performance indicators are decided, the overall performance of services can be measured based on the AHP. The AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. By using the AHP, the problem should be modelled as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives. Then, the priorities among the elements of the hierarchy are established by making a series of judgments based on pairwise comparisons of the elements. Through synthesising these judgments, a set of numerical weights or priorities for the hierarchy is generated. The consistency of the judgments should be tested to check whether the weight distribution is reasonable (Saaty 2008).

While it is a general consensus that the AHP is both technically valid and practically useful, the method does have its critics. Especially, because of vagueness and uncertainty in the decision-maker's judgment, the conventional AHP seems insufficient and too imprecise to capture the decision-maker's judgments correctly. In this article, the fuzzy set theory is introduced to compensate for this deficiency in the conventional AHP. The use of fuzzy set theory allows incorporating unquantifiable, incomplete and partially known information into the decision model (Duran and Aguilo 2008).

In this methodology, we first compare the indicators' importance one by one and give a value for each. Then the judgment matrix $\boldsymbol{A}$ is solved to get the weight set $\boldsymbol{W}$. If the calculation consistency evaluation of $\boldsymbol{W}$ can be verified, the $\boldsymbol{W}$ is the needed weights vector. To cope with the vagueness and uncertainty in the decision-maker's judgment, the fuzzy set theory is introduced to determine the fuzzy relation and fuzzy comprehensive evaluation model. We can define a fuzzy remarks set $\boldsymbol{V}$ with elements v_l, $l = 1, \ldots, m$. For example, the fuzzy remark set $\boldsymbol{V}$ could be {good, medium, bad}. Then, the remarks of each indicator in Equation (5) can be denoted as r_{kl}. So, we can get the fuzzy relation matrix $\boldsymbol{R}$ from $\boldsymbol{P}_{i,j}$ to $\boldsymbol{V}$: $\boldsymbol{R} = \{r_{kl},$

$1 \le k \le k,\ 1 \le l \le m\}$. Finally, the overall performance of PSVs can be calculated by $\boldsymbol{W}$ and $\boldsymbol{R}$ according to the value of $\boldsymbol{B} = \boldsymbol{WR} = \{b_1, \ldots, b_m\}$.

3.3.2. *Comprehensive performance evaluation for SOMN*

Denote performance indicator set of SOMN as P. With the performance operators, we can calculate the kth dimensional performance of P. Let $\boldsymbol{P^k}$ denote the kth dimensional performance indicator of P.

Once each ASV has selected a PSV, e.g. the ASV_i has selected the $PSV_{i,ji}$, the service composition scheme of SOMN $S_h = (PSV_{1,j1}, PSV_{2,j2}, \ldots, PSV_{N,jN})$ is determined, where $j_i \in [1,M_i]$ and $h \in [1,H]$, $H = M_1 \times M_2 \times \cdots \times M_N$. The value of the kth dimensional performance of S_h can be calculated as below:

$$p^k(S_h) = \Psi_k(p^k_{1,j1}, p^k_{2,j2}, \ldots, p^k_{N,jN}) \tag{6}$$

Here ψ_k depends on the performance operators of service composition structure.

For some indicators, the larger values indicate the better performance (increasing indicators). While for other indicators, the lower values mean better performance (decreasing indicators). The increasing indicators and decreasing indicators can all be transformed into unified values. Equation (7) is for increasing indicators and Equation (8) is for decreasing indicators.

After, we calculate the performance for all dimensions, the overall performance of SOMN can be calculated by AHP method presented in 'Performance evaluation for SOMN' section.

$$U(p^k(S_h)) = \begin{cases} \frac{p^k(S_h) - \min_{l=1}^{H}(p^k(S_l))}{\max_{l=1}^{H}(p^k(S_l)) - \min_{l=1}^{H}(p^k(S_l))}, & \max_{l=1}^{H}(p^k(S_l)) - \min_{l=1}^{H}(p^k(S_l)) \neq 0; \\ 1, & \max_{l=1}^{H}(p^k(S_l)) - \min_{l=1}^{H}(p^k(S_l)) = 0 \end{cases} \tag{7}$$

$$U(p^k(S_h)) = \begin{cases} \frac{\max_{l=1}^{H}(p^k(S_l)) - p^k(S_h)}{\max_{l=1}^{H}(p^k(S_l)) - \min_{l=1}^{H}(p^k(S_l))}, & \max_{l=1}^{H}(p^k(S_l)) - \min_{l=1}^{H}(p^k(S_l)) \neq 0; \\ 1, & \max_{l=1}^{H}(p^k(S_l)) - \min_{l=1}^{H}(p^k(S_l)) = 0 \end{cases} \tag{8}$$

The objective of the optimisation of service selection and composition in SOMN is to search for the best service composition scheme S^* to maximise the following objective function, where K is the number of the concerned performance dimensions and S_l. is the lth instance of S_h

$$U(P(S^*_h)) = \sum_{k=1}^{K} w_k \times U(p^k(S_l)). \tag{9}$$

According to Equation (1), if the structure of SOMN is complex, and the quantity of ASVs and PSVs is large, the searching space for S^* will be extremely huge. It is infeasible to search S^* in the whole searching space by the method of infinite enumeration. The efficient and effective method for service selection and composition in SOMN should be developed.

4. Optimisation of service selection and composition in SOMN

For the optimisation of complex system having large amount of dynamics and uncertainty, it is hard to find the optimal solution for the system. The common method in engineering is to find the approximate optimal solution, which satisfies the requirement. Recent years, uncertainty theory has drawn wide attention in complex system optimisation field. Uncertainty theory consists of probability theory, credibility theory and trust theory. It provides the general framework for stochastic programming, fuzzy programming, and rough programming (Liu 2007).

In this article, the uncertainty method is used to determine the number of candidate PSVs to minimise the design space. A Genetic Algorithm (GA)-based intelligent algorithm is developed to search for the best service composition scheme in effective and efficient way. Figure 5 shows the main stages in the optimisation of service selection and composition. The first stage is the optimisation of service selection based on the optimal waiting number of PSVs according to the predefined requirement and performance distribution of PSVs. The second stage is the searching for the optimal solution in all the potential service composition schemes based on genetic algorithm. The detailed process will be introduced in the following sections.

4.1. *Optimisation of service selection based on uncertainty methods*

In the process of service selection, when a service request is published, the services, which meet the requirement will arrive and respond to the request successively. The arrival and response process of services is similar to the randomly queuing process in queuing system (Gross and Harris 1998). The expected performance of service follows certain probability distribution. So, the optimisation of service selection can be seen as a class of uncertainty problem. In this article, the uncertainty method is adopted to determine the minimum number of candidate services with some probability condition.

Using the denotation in 'The performance evaluation for SOMN' section, let ASV_i denote the ith ASV of the service-oriented business process, $\text{PSV}_{i,j}$ denote the jth PSV of ASV_i, and P_{ij}^k denote the kth dimensional performance indicator of $\text{PSV}_{i,j}$. Once ASV_i has published its request, numerous $\text{PSV}_{i,j}$, $j = 1,2, \ldots,$ will successively respond to the request of ASV_i. Based on the value of performance indicator P_{ij}^k, the ASV_i can determine its candidate PSVs number m_i according to the arriving rule and the performance distribution function of PSVs.

Similar to queuing system (Gross and Harris 1998), the arrival and response process PSVs can be regarded as a Poison process $\{N(t),\ t \geq 0\}$, with parameter λ_i, where $N(t)$ stands for the number of PSVs arrived in the time span [0, t]. The performance distribution function $F(X_i)$ for the arriving $\text{PSV}_{i,j}$, $j = 1,2,\ldots,m_i$, follows the exponential distribution function with the parameter u_i:

$$F(X_i) = 1 - e^{-x_i/u_i}. \tag{10}$$

In Equation (10), x_i means the performance expectation for ASV_i. For example, $x_i = 10\%$ means the performance expectation should fall into the top 10% performance distribution. And u_i means the average performance estimation for ASV_i. The agonic estimation of u_i is

$$\overline{u_i} = \frac{1}{m_i}\sum_{j=1}^{m_i} u_{i,j}. \tag{11}$$

In Equation (11), $u_{i,j}$ denotes the overall performance of the $\text{PSV}_{i,j}$, $j = 1,2,\ldots,m_i$. The value of $u_{i,j}$ can be calculated by the performance evaluation model in 'The performance evaluation for SOMN section.

If the performance requirement of ASV_i is larger than or equal to x_i, the probability that there is at least one PSV among the arrived m_i PSVs, which meets the requirement is

$$P\{\max(X_{i,1}, X_{i,2}, \ldots, X_{i,m_i}) \geq x_i\} = p. \tag{12}$$

With Equation (10), the value of m_i is

$$m_i = \left\lceil \frac{\ln(1-p)}{\ln(1 - e^{-x_i/u_i})} \right\rceil. \tag{13}$$

Namely, it has p probability to ensure that there exists one PSV that satisfies the ASV_is design requirement among its m_i having arrived PSVs.

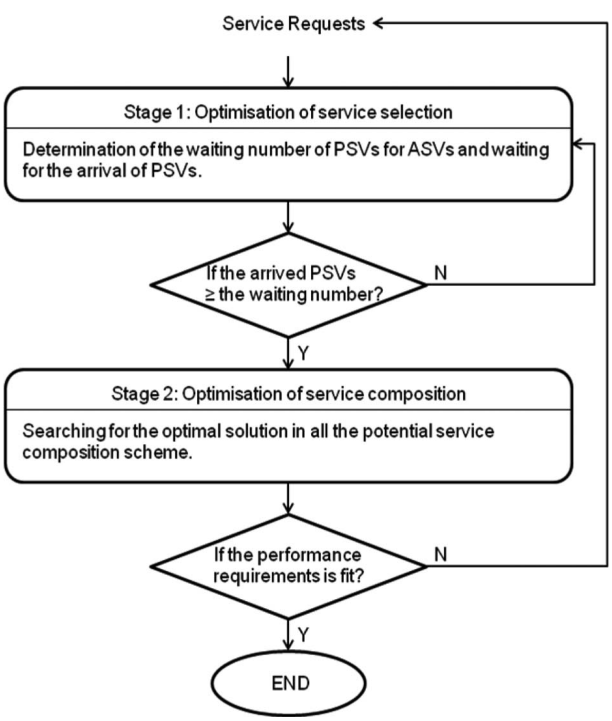

Figure 5. The optimisation of service selection and composition.

4.2. Optimisation of service composition base on genetic algorithm

Using uncertainty method, we can get a limited search space for the service composition. However, the complexity degree of the search space is still in exponential level. It is necessary to develop the intelligent algorithm to search for the best service composition scheme in effective and efficient way.

GA, as an adaptive and intelligent method, has been widely used to solve search and optimisation problems, especially in large scale and multi-objective problems (Koza 1995). In this article, the genetic algorithm is used to search for the best service composition scheme. The characteristic features of our algorithm are the selection procedure and elite preserve strategy. The fitness function in individual selection of our algorithm is determined by the overall performance calculation of service composition scheme [Equation (9)]. The elite preserve strategy is used to keep the fit individuals from the previous generation into the next generation. The elite preserve strategy can guarantee the GA converging to local optimal point globally optimal (or near-optimal) point (Rudolph

1998). The main steps of our algorithm are listed below:

Step 1: To code the gene of the genetic algorithm

When using genetic algorithm to search the optimal service composition scheme, the length of the gene is related with the number of ASVs and the number of candidate PSVs for each ASV. If there are N ASVs, let M_i, $i = 1, \ldots, N$ denote the number of candidate PSVs for ASV_i. We can use a binary code to identify all the PSVs for ASV_i. Let b_i denote the length of the binary code. Then $b_i = \left|\log_2^{M_i}\right|$, $i = 1, \ldots, N$. In this way, the service composition scheme S_h can be coded as a binary character string $\boldsymbol{X}$ that stands for the hth instance in all potential service composition schemes. The length of $\boldsymbol{X}$ would be

$$b_h = \sum_{i=1}^{N} b_i \tag{14}$$

Step 2: To select the initial population

Suppose the size of the population is D. The initial individuals $\boldsymbol{X}^{(1)}, \boldsymbol{X}^{(2)}, \ldots, \boldsymbol{X}^{(D)}$ are generated randomly. Let g denote the evolution generation. The initial evolution generation is 0 and the upper limit of the evolution generation is $g_{\max}$.

Step 3: To select the fitness function

In genetic algorithm, the fitness function provides the mechanism for evaluating the status of each individual. This is an important link between GA and the target system. In SOMN, once each ASV_i selected one PSV, the corresponding service composition scheme is set as $S_h = \{\text{PSV}_{1,j1}, \text{PSV}_{2,j2}, \ldots, \text{PSV}_{N,jN}\}$. The S_h will be a potential service composition scheme for the system. The performance measurement of S_h can be calculated by Equation (9). So, Equation (9) can be set as the fitness function for our genetic algorithm. Using Equation (9), each service composition scheme in SOMN can be assigned a fitness value. The objective of our algorithm is to search for the scheme S_h^*, which has the best performance in all the service composition schemes of SOMN.

Step 4: To choose the genetic operations

There are three genetic operations included in genetic algorithm, which are selection, crossover and mutation (Koza 1995). In the selection operation, an individual is probabilistically selected from the population based on its fitness. The operation of crossover and mutation allows new individuals to be created. The crossover operation produces two offspring. Each offspring contains some genetic material from each of its parents. The mutation operation changes the chromosome of an individual randomly and creates a new individual to alter the old one. In our algorithm, the 'selection' operation adopts the tournament selection method, the crossover operation adopts the intercross of the double sequential locations method, and the mutation operation adopts the interchange variation method.

Step 5: To generate a new population

In this article, the elite preserve and immigrant randomly is combined to generate a new population. The individuals of the parent and child generations are put together. The best E ($1 \leq E < D$, D is the size of the population) individuals will be saved in the new population unconditionally. Then select (D-E) individuals randomly from all of the individuals belonging to the parent and child generations. The rapidity of convergence would be accelerated by the keeping of the better individuals, and the diversities of population are remained too.

Step 6: To determine the iterative ending conditions

The ending condition of GA can be set as maximum number of iterations, the threshold value of solution, and the degree of saturation for fitness. Because the design space of SOMN is changing dynamically. It is hard to determine what the best performance of the system is. In this article, we combine the maximum iteration number and the degree of saturation for fitness as the ending conditions. Proved by lots of experiments, Li and Zhu (2006) found the genetic algorithm used in multitask scheduling would be convergence in polynomial time and the maximum iteration number is $2 \times N \times M$ (N refer to the number of task and M refer to the number of candidate resources). The searching for optimal service composition scheme has similarity with Li's research. To ensure convergence effect, we set the maximum iteration number as $3 \times N \times M$. Simulation results in the 'Case study' section prove which is effective and feasible. The GA can converge to an optimal solution within the maximum iteration number in the case study.

5. Case study

To validate the feasibility and correctness of the methods proposed in this article, a case study is developed based on the scenario presented in the second section.

In the case study, the enterprise has established a SOMN and set up a service-oriented supply chain to support the sale process of the enterprise. There are four ASVs nodes in this process: Transport 1, Making Parts, Payment and Transport 2. In its SOMN, there are lots of PSVs can meet the requirements of ASVs. For the enterprise, it is hard to know what is the proper quantity of candidate PSVs they need to guarantee the enterprise can get at least one PSV which meet the predefined requirements. It is also hard for the enterprise to search for the optimal service composition scheme in all the potential composition schemes. Here, we can use the uncertainty and GA-based method proposed in this article to optimise the selection and composition of service.

First, we should set the performance evaluation model for SOMN of the enterprise. In the case study, the enterprise mainly concern about the service performance from two aspects: time and cost. The weight for the two performance indicators is same. The fuzzy evaluation criterion for the two performance indicators is good, medium and bad. We can set the performance indicator set $\boldsymbol{P}=\{u^1,u^2\}$, where u^1 denotes business time and u^2 denotes business cost. The weight set is $\boldsymbol{W}=\{w_1,w_2\}$, where $w_1 = w_2 = 0.5$. The fuzzy remark set is $\boldsymbol{V} = \{\text{good, medium, bad}\}$.

According to the historical statistics, the performance expectation of ASVs follows the exponential distribution with the parameter 0.8. The agonic estimation of time and cost for each ASV is shown in Table 2. U_i^k means the kth dimensional performance indicator for ith ASV.

By Equation (6), the kth, $k = 1$ or 2, dimensional performance values of service composition are calculated as follows:

$$P^1(S_h) = \max\left((P^1_{1,j} + P^1_{2,j}), P^3_{3,j}\right) + P^4_{4,j}$$
$$P^2(S_h) = \sum_{i=1}^{4} P^2_{i,j} \tag{15}$$

Unifying Equation (15) with Equation (8), we get the unified performance values such as $U(P^1(S_h))$ and $U(P^2(S_h))$. According Equation (9), the general objective of our method is to search for the best service composition scheme to maximise the following objective function:

$$U(P(S_h*)) = \max{}_{h=1}^{H} \sum_{k=1}^{2} w_k \times U(P^k(S_h)). \tag{16}$$

Table 2. Parameters of the ASVs.

ASV_i	U_i^1	U_i^2
ASV_1	30	200
ASV_2	60	500
ASV_3	30	300
ASV_4	200	1000

As shown in Figure 5, two stages are included in our method. The first one is the optimisation of service selection. We can calculate the optimal number of candidate PSVs to guarantee the ASVs have received the enough PSVs, which can meet the performance requirements in some probability.

In this case study, for all ASVs, the enterprise requires having 90% probability to ensure that among the having arrived PSVs, there exists at least one PSV whose performance is lie in the better 10% of all the potential PSVs.

With Equation (10), if we expect the performance of ASV among the better 10%, the best performance among the arrived PSVs should be larger than $2.3u_i$. The u_i is the performance probability distribution parameter of ASV_i. According the predefined performance requirement and the probability range, based on Equation (13), the quantity for candidate PSVs will be 22.

In the simulation of the arriving process of PSVs for ASV_1 (Figure 6), the 7th arrived physical service, $PSV_{1,7}$, satisfies the design requirement with the overall performance$u_{1,7} = 2.49 = 3.1u_1$ that is better than $2.3u_1$. Although the best PSV in the 200 samples appears in the 36th PSV, we can stop the waiting process for PSVs when we received 22 PSVs. Because it can guarantee that we have got a PSV whose performance is in the top 10% of all potential PSVs with the probability of 90%.

After the number of candidate PSVs is determined, the GA-based method is used to search for the optimal service composition scheme in all potential composition schemes. In the case study, because of the limited quantity of ASVs and candidate PSVs, it is more direct to use decimal coding system for the genes. For example, the string of (1, 1, 1, 1) denotes that the four ASVs select their PSVs with the sequential number $j = 1$, respectively. In genetic operations, let the size of the population $D = 20$, the selection probability $p_e = 0.2$, the selection number at one time $E = 5$, the crossover probability $p_f = 0.6$, the mutation probability $p_m = 0.02$, the elite preserve probability $p_f = 0.2$. According the ending condition in 'Optimization of service composition base on genetic algorithm' section, the number of the maximal iterative generation is $3 \times N \times M$. In this case study, the number of ASVs and candidate PSVs is 4 and 22. So, the maximal iterative generation number is 264.

In initial population, all individuals generate randomly. The actual values of the kth, $k = 1,2$, dimensional performance and the unified overall performance of each individual (service composition scheme) within the initial population are shown in Figure 7. Obviously, the individual with the maximal unified overall performance is the third individual. Its

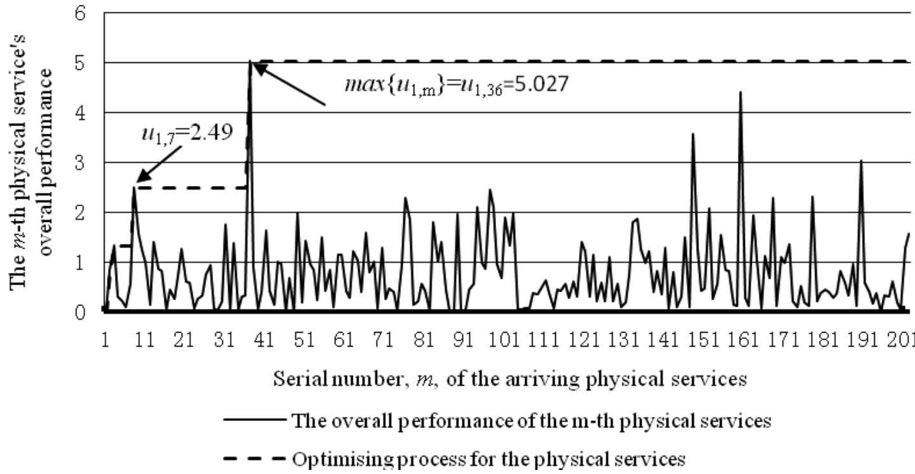

Figure 6. The overall performance of the arriving PSVs for ASV_1.

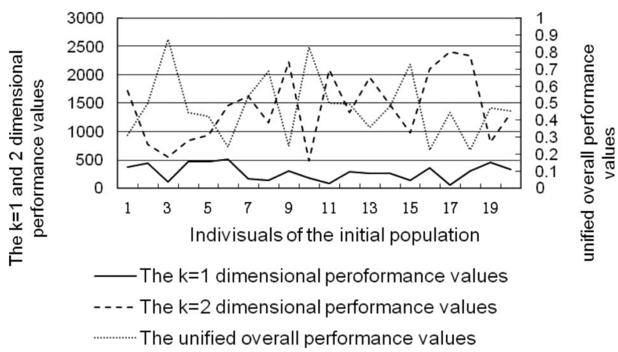

Figure 7. The actual values of the kth, $k = 1$, 2, dimensional performance and the unified overall performance of each individual of the initial population.

corresponding maximal overall performance is $U(P(S_h)) = 0.8767$; the k_1 dimensional performance $p^1(S_h) = 107.6$, the k_2 dimensional performance $p^2(S_h) = 553.2$. And the corresponding S_h composition scheme is (1, 8, 6, 20), namely $S_h = (PSV_{1,1}, PSV_{2,8}, PSV_{3,6}, PSV_{4,20})$. Their actual performance values are shown in Table 3.

The search process for the optimal service composition based on genetic algorithm is shown in Figure 8. The maximal overall performance of service composition scheme appears in the 104th generation. After the 104th generation, the performance of the individual does not increase any more. This implies that the genetic algorithm converges to an optimal solution. In this case study, the corresponding unified overall performance for the optimal solution is $U(P(S_h)) = 0.9313$, the k_1 dimensional performance value is $P^1(S_h) = 52.03$, the k_2 dimensional performance value $P^2(S_h) = 304.8$. And the corresponding service composition scheme is (12, 10, 8, 20), namely $S_h = (PSV_{1,12}, PSV_{2,10}, PSV_{3,8}, PSV_{4,20})$. Their actual performance values are shown in Table 4.

Table 3. Actual performance values of the service composition scheme (1, 8, 6, 20).

Performance indicators	$PSV_{1,1}$	$PSV_{2,8}$	$PSV_{3,6}$	$PSV_{4,20}$	S_h
$k = 1$	2.991	72.68	64.73	28.37	107.6
$k = 2$	73.38	151.1	85.42	92.60	553.2

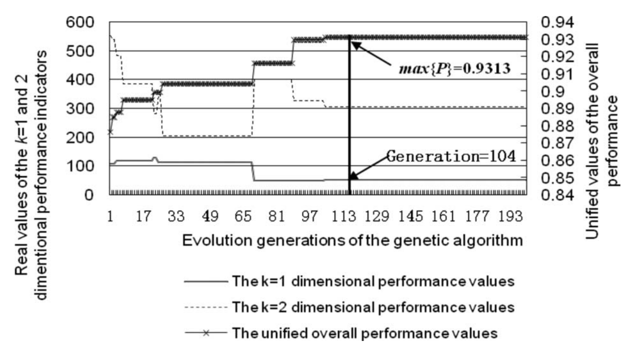

Figure 8. The searching process for the optimal service composition scheme based on genetic algorithm.

Table 4. The actual performance values of the optimal service composition scheme.

Performance indicator	$PSV_{1,12}$	$PSV_{2,10}$	$PSV_{3,8}$	$PSV_{4,20}$	S_h
$k = 1$	3.929	16.36	23.65	28.37	52.03
$k = 2$	39.28	87.51	85.42	92.60	304.8

6. Conclusion

This article has addressed the management of SOMN from two aspects. One is the performance measurement of SOMN that includes the performance metrics and evaluation model for service and service composition. The other is the optimisation of service selection and composition in SOMN, which is featured by its open, dynamic and large-scaled characters.

The article has made a few contributions to the integrated evaluation and optimisation for service selection and composition in SOMN. The comprehensive performance metrics has been established which synthesises multiple factors from business, service and implementation aspects in an operating situation. The correlation of performance metrics and the performance operators has been defined to deal with the complexity of service performance evaluation. The improved AHP method has been proposed to calculate the performance of service and service composition. Base on the performance evaluation model, a two-stage method has been developed based on the uncertainty and genetic algorithm to realise the optimisation of service selection and composition. The uncertainty method is used to determine the quantity of candidate PSVs to minimise the design space according to the predefined requirement and performance distribution of PSVs. The GA method is used to search for the optimal solution in all the potential service composition schemes in effective and efficient way.

Compared with the QoS-based service evaluation (Li *et al*. 2007, Ko *et al*. 2008, Mabrouk *et al*. 2009, Menascé *et al*. 2010, Zhang *et al*. 2010),the performance metrics of this article is much more comprehensive and hierarchical. Aiming at the problem of traditional intelligent search algorithm (Aversano *et al*. 2006, Su *et al*. 2007, Cai *et al*. 2009, Liang and Huang 2009, Zhang *et al*. 2010), the introduction of uncertainty method can reduce the design space sharply and enhanced the effectiveness and efficiency of the optimisation process for service selection and composition.

Future work is needed to improve the practicality of the performance evaluation model and optimisation algorithm for SOMN. First, the performance metrics is just concerned with the key performance indicators of SOMN. The real world problem is much more complex than the case study demonstrated in the article. It is therefore more difficult to select appropriate performance indicators and quantify their values. Further studies should be carried out to establish the specific metrics according to different domains.

Second, the evaluation model proposed in the article is based on AHP method. However, AHP has its own defects, such as the hard satisfaction of consistency of judgment matrix and the subjectivity of the scoring by experts. Future efforts could be dedicated to improving AHP to make it more quantifiable and computable. The uncertainty theories, such as fuzzy theory, rough theory, credibility theory, could be introduced to enhance the mathematical foundation of the evaluation of SOMN.

Finally, the searching algorithm proposed in this article for the optimal scheme of service selection and composition is based on a GA method. The ability to solve uncertainty and large complex system is limited. For example, there are eight million service providers from more than 240 countries and regions worldwide in the world largest B2B platform Alibaba.com with nearly 2000 new service providers joining the network every day. This type of large-scale problem requires new method of hybrid intelligent algorithms and heuristics for service selection and service composition.

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