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A method of constructing and optimizing service value model based on process mining

Xuequan Zhou

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POUR OBTENIR LE GRADE DE
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ECOLE DOCTORALE DES SCIENCES PHYSIQUES ET
DE L'INGÉNIEUR

Spécialité : Automatique, Productique, Signal et Image, Ingénierie cognitive

Par **Xuequan Zhou**

A Method of Constructing and Optimizing Service Value
Model Based on Process Mining

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Soutenue le 16 décembre 2022

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Une méthode de construction et d'optimisation d'un modèle de valeur de service basé sur l'exploration de processus

Résumé :

Avec l'émergence et le développement de la servitisation, de plus en plus d'entreprises se tournent vers le service plutôt que vers le produit. Le service est devenu la principale force du développement économique, et fournit le pouvoir de transformation et de mise à niveau des entreprises. Le système de service de produit est un modèle d'affaires émergent sous cette tendance. Un aspect difficile est de gérer la croissance des besoins client et ses besoins de personnalisation des services client, les fournisseurs de services ne peuvent plus compter sur eux-mêmes pour remplir tous les services, mais doivent fournir des services collaboratifs reposant sur plusieurs entreprises, coordonnant tous les participants dans la chaîne de valeur du service pour compléter les services ensemble. En même temps, l'exploration de processus reçoit une attention croissante au cours des deux dernières décennies. Il y a deux raisons principales : d'une part, de plus en plus de journaux d'événements enregistrés dans le système d'information fournissent des informations détaillées sur l'historique des processus ; d'autre part, la nécessité d'améliorer et de mieux soutenir les processus d'entreprise, dans un environnement compétitif et en évolution rapide, devient de plus en plus importante. Dans ce contexte, pouvons-nous utiliser les techniques d'exploration de processus pour décrire le mécanisme de création de valeur dans le processus de service et optimiser la chaîne de valeur du service afin de mieux répondre aux besoins des clients?

En fonction de cette motivation, cette thèse propose une méthode de construction de modèle de valeur de service basée sur l'exploration de processus. Sur la base du journal des événements des processus de services stockés dans le système d'information, la technique d'exploration de processus est introduite dans le domaine des services pour déterminer les activités et leurs dépendances dans le processus de service par le biais d'algorithmes d'exploration, afin d'extraire les participants aux services et leurs relations, ainsi que les informations sur la valeur du service à partir du journal des événements du service, et réaliser la construction automatique du modèle de valeur du service du système de service de produits. Sur cette base, compte tenu de l'impact des ressources de service sur le fonctionnement du système de service, le problème d'allocation des ressources dans le système de service et de produit est modélisé et les solutions correspondantes sont données. Le modèle de valeur du service construit dans cette thèse est capable de refléter la façon dont les acteurs du service co-crée de la valeur dans l'exécution réelle des processus de service, et peut aider à optimiser l'allocation des ressources du système de service pour atteindre ses objectifs de valeur. Enfin, un journal d'événements d'un service de réparation de climatiseurs est utilisé comme un cas pour montrer comment utiliser cette méthode pour construire un modèle de valeur de service et optimiser l'allocation des ressources.

Mots-clés : système de produits et services, besoins client, modèle de valeur du service, processus de service axé sur la valeur, algorithme d'exploration des processus, allocation des ressources.

A Method of Constructing and Optimizing Service Value Model Based on Process Mining

Abstract:

With the emergence and development of servitization, more and more enterprises are turning from product focus to service focus. Service has become the main force of economic development, and provides power for the transformation and upgrading of enterprises. Product service system is a business model emerging under this trend. A difficult aspect is that with the growth of customer scale and the personalization of customer service needs, service providers can no longer rely on themselves to fulfill services, but must provide collaborative services across enterprises, coordinating all participants in the service value chain to complete the services together. At the same time, process mining is receiving increasing attention in the past two decades. There are two main reasons: on the one hand, more and more event logs recorded in the information system provide detailed information about process history; on the other hand, the need to improve and better support business processes, in a competitive and rapidly changing environment, is becoming increasingly prominent. In this context, can we use process mining techniques to describe the value creation mechanism in the service process and optimize the service value chain so as to better meet customer needs?

With this motivation, this thesis proposes a service value model construction method based on process mining. Based on the service process event log stored in the information system, the process mining technique is introduced into the service domain to determine the activities and their dependencies in the service process through mining algorithms, extract the service participants and their relationships, as well as the service value information from the service event log, and realize the automatic construction of the service value model of the product service system. On this basis, considering the impact of service resources on the operation of the service system, the resource allocation problem in the product service system is modeled, and the corresponding solutions are given. The service value model constructed in this thesis is able to reflect how service actors co-create value in the actual execution of service processes, and can help optimizing the resource allocation of the service system to achieve its value goals. Finally, an event log of air conditioner repair service is used as a case to show how to use this method to build a service value model and optimize resource allocation.

Keywords: product service system, needs of customer, service value model, value-oriented service process, process mining algorithm, resource allocation.

Unité de recherche

IMS Laboratory, University of Bordeaux, France.

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LIST OF TERMS AND ABBREVIATIONS

BIRIS Bilateral Resource Integration Service	86–88
BPMN Business Process Model and Notation	7, 25, 75, 77, 82, 85, 103, 108, 116
IM inductive miner	61, 63–66, 68, 74, 75, 84, 112
IVC Industrial Value Chain	11, 28–32, 34–37
PSS Product Service System	8, 11, 13–15, 48, 78, 82, 86–88, 93, 101
QoS Quality of Service	16
SLA Service Level Agreement	16–18, 38, 39, 96, 105
SPM Service Process Model	3, 6, 54–56, 76
SVC Service Value Chain	8, 48, 51
XES eXtensible Event Stream	19, 20, 103, 113

General Introduction

With the emergence and development of servitization, more and more enterprises are turning from product focus to service focus. Service has become the main force of economic development, and provides power for the transformation and upgrading of enterprises. Product service system is a business model emerging under this trend. A difficult aspect is that with the growth of customer scale and the personalization of customer service needs, service providers cannot rely on their own to fulfill services. Moreover, meeting needs of customers often requires a complete and complex service. Therefore, the service provider has to provide cross enterprise collaborative services and coordinate all participants in the service value chain to complete the services together. And Service value become the goal pursued by all actors in the service process, whether it is the service provider or the service demander.

At the same time, process mining is receiving increasing attention in the past two decades. There are two main reasons: on the one hand, more and more event logs recorded in the information system provide detailed information about process history; on the other hand, the need to improve and better support business processes, in a competitive and rapidly changing environment, is becoming increasingly prominent. However, there is little attention given to value creation by activities in the business process.

In this context, we tentatively apply process mining techniques to the service domain with the aim to build up actual service-oriented value model with the help of historical data, to discover the collaborative relationships of service actors, to understand the mechanisms of service value creation and to better meet customer needs.

With this motivation, the main objective of this thesis is to develop a cross-enterprise collaborative service value model based on service process model mined from the event log stored in the information system, and optimize the service value model through resource allocation to enhance the value of service entities. Service is customer-oriented. Customer needs and customer values should be emphasised first. Then there is the service process, which is the specific step for service providers and other actors to complete service to meet customer needs, and the process of realizing customer value. The activities in the service process are the basic units of value creation.

To achieve this objective, this thesis proposes a service value model construction method based on process mining. Based on the service process event log stored in the information system, the process mining technique is introduced into the service domain to determine the activities and their dependencies in the service process through mining algorithms, extract the service participants and their relationships, as well as the service

value information from the service event log, and realize the automatic construction of the service value model of the product service system. In order to make the process mining algorithm applicable to service domain, we will adopt two ways: one is to improve the inductive miner algorithm, and the other is to propose a value oriented service process mining algorithm to extract more knowledge from the service event log while obtaining the service process model. On this basis, considering the impact of service resources on the operation of the service system, the resource allocation problem in the product service system is modeled, and the corresponding solutions are given. The service value model constructed in this thesis is able to reflect how service actors co-create value in the actual execution of service processes, and can help optimizing the resource allocation of the service system to achieve its value goals.

The thesis is structured as follows. In Chapter 1, the main objective, research problems and outline of the thesis are briefly introduced. Chapter 2 gives the state of the art including service system, process mining and industrial value chain. Chapter 3 defines the relevant concepts of service value model and the mapping relationship between event attributes and service value indicators, and puts forward the construction framework and model prototype of service value model. Chapter 4 describes two mining algorithms for automatically constructing service value model from the event log, guided by the above construction framework idea. Chapter 5 addresses the allocation of resources in the service value chain, considers the resource constraints and the historical experience obtained from mining, determines the resource allocation model, and gives the solution. In chapter 6, an air conditioner repair service is used as a case study to validate the proposals described in the previous chapters. Finally, a conclusion is given.

Keywords:

Product service system, Needs of customer, Service value chain construction, Value-oriented service process, Process mining algorithm, Resource allocation.

CHAPTER 1

Research Problem

1.1 Introduction

The main objective of the research is to develop a cross-enterprise collaborative service value model based on Service Process Model (SPM) mined from the event log stored in the information system, so that service actors on the value chain can improve service value by optimizing the service process. During the research, service system is the main research problem in the context of manufacturing. Three more problems are found and need to be solved. It is a big challenge to formalize the definition and research framework of service value model. It is also necessary to propose or improve the mining algorithm for building service value model based on process mining. At last, in order to enhance the service value, it needs to consider the resource allocation in the service process to optimize the service and validate the result by simulation.

1.2 Background

At present, in the context of industry 4.0 (Frank et al. 2019), service has become the main force of economic development, and provides power for the transformation and upgrading of enterprises. Various industries are changing from traditional business to service, which is called “servitization” Firms attracted by the potential revenue benefits are choosing to move from supplying product only, to supplying product and services (Barnett et al. 2013). More and more manufacturing companies are transforming from a product focus to a service focus in order to provide better service for customers (Baines et al. 2009). On the other hand, as the size of customers grows and customer service needs become more complex and personalized, service providers can no longer rely solely on themselves to deliver the service. The service provider has to provide cross enterprise collaborative services and coordinate other participants in the service system to complete the services together (Xu, Sheng, Zhang, Fan and Dustdar 2015). For example, when a customer buys an air conditioner in summer, not only the air conditioner product itself, but also the related after-sales services such as the installation of the air conditioner and the experience of using the air conditioner should be included. The

manufacturer should provide the service to the customer, including timely delivery of products to customers, and quick arrangement of engineers for installation, in order to enable the customer to enjoy the coolness brought by the air conditioner. Any failure in one of these links may lead to customer dissatisfaction or even return the product, such as the air conditioner taking a long time to cool down and not achieving the desired effect.

Process mining is receiving increasing attention in the past two decades. There are two main reasons: on the one hand, more and more event logs recorded in the information system provide detailed information about process history; on the other hand, the need to improve and better support business processes, in a competitive and rapidly changing environment, is becoming increasingly prominent (Aalst et al. 2011). The Process Mining Group defines it as a family of techniques in the field of process management that support the analysis of business processes, based on event logs in the information system. The idea of process mining is to discover, monitor, and improve actual business processes by extracting knowledge from event logs (Van der Aalst 2011). Some scholars have done related research in this field (de Leoni et al. 2016, Schimm 2004, Agrawal et al. 1998, Herbst and Karagiannis 2004, Günther and van der Aalst 2007, Van der Aalst et al. 2011), focusing on how to discover or extract business process models from event logs, proposing corresponding algorithms, and developing corresponding tools. These process models mainly pay close attention to control flow, resources, time, and organizations. However, there is little attention given to value creation by activities in the business process.

Value is the goal pursued by all service actors, whether it is the customer or the provider or the participant. Values are usually expressed using value indicators, which are a group of elements that are used to point to the specific value on the related scale. For example, if an air conditioner sells for \$400, \$400 is the economic value of the air conditioner, a tangible value; if the customer is satisfied with the installation service, satisfaction is the value of the customer experience, an intangible value. Some scholars have discussed service value creation, or co-creation. Wang et al. (2016) proposed the concept of a product-service value creation network from the perspective of industry, and put forward four steps in the value creation process, which include value identification, value proposal, value delivery, and value evaluation. Man et al. (2019) presented an integrated design framework for a service-centric service system, which considers the interactions between actors in the value co-creation process at a strategy level, and is integrated with techniques for executing each stage of the framework. Takahashi et al. (2020) argued that service value is affected by providers, receivers, and / or its environment, and discussed the value creation model from the viewpoint of case-based decision theory. However, these studies tend to focus on the conceptual level and in-

dustry level, with a lack of attention given to the role of customers in service, and do not pay attention to the process and activities of service performance.

In reality, services to meet the requirements of customers are basically complex services, which need to be completed by multiple enterprises or actors. Simultaneously, we also realize that customer requirement is the driving force of service, and customer value determines the value of service. Therefore, service is customer-oriented, and the creation of service value is a complex process. To describe value creation clearly at an activity level may help service actors to more easily understand and achieve their value goals.

1.3 Problem Statement

The realization of service needs the support of service system. Service systems comprise service providers and customers working together to co-create value in complex value chains or networks (Spohrer et al. 2007). Based on the definition of service systems (Maglio et al. 2006), a typical service system and its composition is shown in Figure 1.1. The relationships and actions among service provider, customer, and service target are described as follows.

- In a service system, service provider owns individual, organization and technology.
- Customer can be an individual or an organization.
- Service target is the reality to be transformed or operated on by service provider, for the sake of customer.
- First of all, service provider and customer establish service relationship through some kind of channel, put forward their respective expected value (expectations of services, needs and constraints), and then through negotiations to form service target. Then, service provider forms a collaborative production relationship with customer to create value together.
- The actual value of the service may not match the expected value in terms of the outcome of the service.

In a service system, the participants in the service can be divided into three types of actors: customers, service providers and partners (service enablers) (Basole and Rouse 2008). To provide a service to the customer, a service provider may rely on numerous partners that help create, design, initiate, deploy and complete the service. According to the complexity of the service system, the partners can be divided into several tiers. The participants in the service system and their relationships are gradually formed over

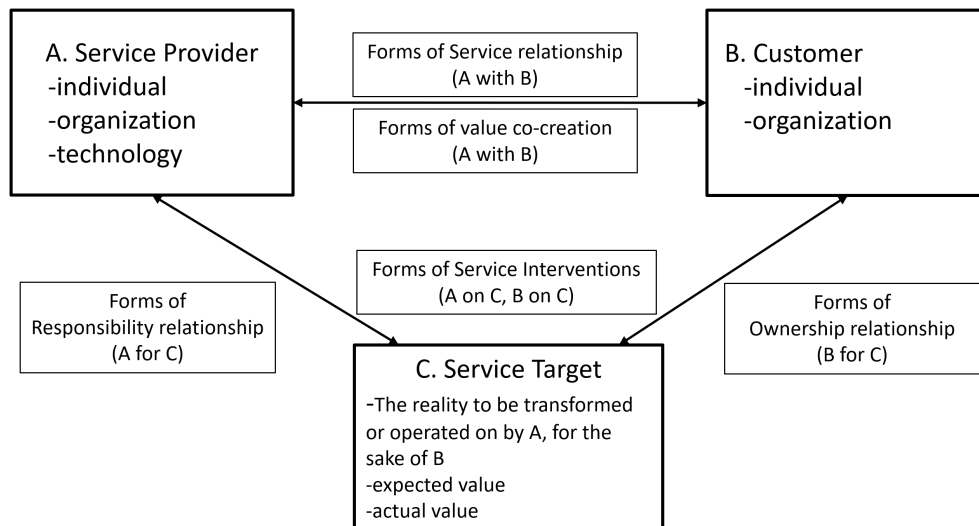


Figure 1.1 Service system and its composition, based on Maglio et al. (2006)

a period of time. Generally, service providers need to go through multiple stages in providing services to customers, which means that a service process is needed to realize the services.

The SPM describes the relationships among the behaviors of service participants, support resources, capabilities, personnel, organization, information, etc. (Weigand et al. 2008). In the service process, each atomic service will generate value, which is related to the activities of the service. When the activities in the service are executed, the corresponding logs are produced in the service system. For example, in an air conditioning repair service system, when a customer submits a service request, the information system records the event, including the name of the event and the relevant attributes of the event, such as the time of occurrence, customer information, product model, fault information, etc. Generally, the event is triggered by the activity actor, and the content of the event is recorded by the corresponding information system and saved in the system database. For example, when engineers come to repair the air conditioner and when the repair is completed, the corresponding information will be recorded in the mobile APP designated by the service provider. All events in the process should be recorded in the information system in accordance with the standard execution of the service process.

For the analysis and solution of problems in the system, most researchers work on developing models. In general, most models are based on the assumptions of domain experts and the researcher's observations of the system. In this approach, the researcher can model the service process manually or using modelling tools by observing the service process and its activities and combining this with the knowledge of domain experts. However, the service process obtained in this way may be different from the actual ex-

ecution of the service process, and sometimes it is not precise enough.

Process mining is an enabling technology for supporting the analysis of business processes based on event logs. Typically, three types of process mining can be distinguished: 1) process discovery, 2) conformance checking, and 3) model enhancement (Van der Aalst 2013). In process discovery, the process mining algorithm generates a process model from the event log, which provides a potential idea for the construction of a service value model. As Gupta (2014) mentioned, “the main benefit of process mining techniques is that the information is objectively compiled”. There are a large number of event logs in the information system, which are the actual happenings of a service system and not what people think. If the event log is large enough, it is possible to cover all paths of the service process execution and to reflect the real situation, while the event attributes in the log contain a great deal of knowledge that can be extracted from the participants of the service and the related value information. For example, in a customer evaluation event in an air conditioner repair service, the customer can rate the timeliness of the service, the attitude of the engineer and the effectiveness of the repair, all of which are recorded in the log as attributes of the event and are a reflection of the value gained by the customer, an intangible value.

In order to realize the value for all actors, the service provider needs to understand what the relationships are between the actors in the service? How can the value creation mechanisms in the service process be identified? How can service processes be optimised to meet customer needs? Therefore, a service value model is needed to describe the relationships between service participants, the value creation mechanisms and to help optimise the service process. The concept of service systems and process mining techniques provide the theoretical and technical basis for the construction of service value models, but there are three issues that need to be addressed.

1.3.1 Framework of Building Service Value Model

In the process model, the results of process mining are usually represented by specific model forms such as Petri Net (Van der Aalst et al. 2004), process tree (Buijs et al. 2012*b*), Business Process Model and Notation (BPMN) (Kalenkova et al. 2015) and so on. However, these process models do not take into account the value co-creation of service participants, nor do they take into account factors such as time, resources, etc. Service is a common production process that creates and shares value. The service model describes whether services and service systems can achieve the desired value of both customers and providers, as well as the level of the expected value is realized (Xu and Wang 2008). Service value is achieved gradually with the support of various service functional elements, such as process, participants, interactive behavior, resources and information. Building the service value model from the service event log is a big

challenge. **First, how to identify the value indicators of the service is a key issue. These values may be tangible or intangible. Second, the various service functional elements need to be reflected in the service value model through some kind of rules. Third, the construction of service value model needs to consider the corresponding relationship of activities, actors and value creation in the service process.** A framework needs to be proposed to support the building of the service value model.

1.3.2 Mining Service Value Model from Event Log

In order to automatically build the service value model from the event log, the corresponding mining algorithms are needed. Although some process discovery algorithms have been proposed in process mining techniques, such as α algorithm (Van der Aalst et al. 2004), heuristic miner (Weijters, Aalst and Medeiros 2006), inductive miner (Lee-mans et al. 2013, 2018) and so on, they focus on the business process itself and do not take into account the characteristics of the service or the value creation in the service process. For example, the manufacturing process of an air conditioner in a factory is product-oriented and its goal is to produce a product that meets the standard requirements; the repair service of an air conditioner is customer-oriented and its goal is to meet the needs of the customer, and the service is necessarily triggered by the customer and the delivery of the service. There is a gap between product-centered and customer-oriented. **Mining the service value model from the event log should not only consider the service process itself, but also consider each activity in the service process and its actors, as well as the value created by the actors in completing the activities.** The implementation of the new algorithms can be considered from two aspects: one is to improve the original process mining algorithm so that it can be applied to service scenarios; another is to propose a new algorithm applicable to the service value model mining based on the characteristics of services.

1.3.3 Optimization of the Service Process Considering Resources

In service optimisation, the allocation of resources in the service process is mainly considered as the creation of service value that cannot be achieved without the use of the relevant resources. The categories of resources required may vary greatly in different service areas. From the perspective of Product Service System (PSS), manpower, vehicles, products, product parts, tools, etc. can be used as resources involved in the service process. At the same time, **the resource allocation in services is different from the traditional goal of pursuing product production efficiency and minimum cost. It is more centered on meeting customer needs and improving customer satisfaction.** As customer demand is the driving force of service, when the value of customer is optimized, the overall value of the whole Service Value Chain (SVC) will be optimized.

Based on the existing service event log, using the proposed new mining algorithm, we can discover the historical usage of various service resources.

1.4 Thesis Outline

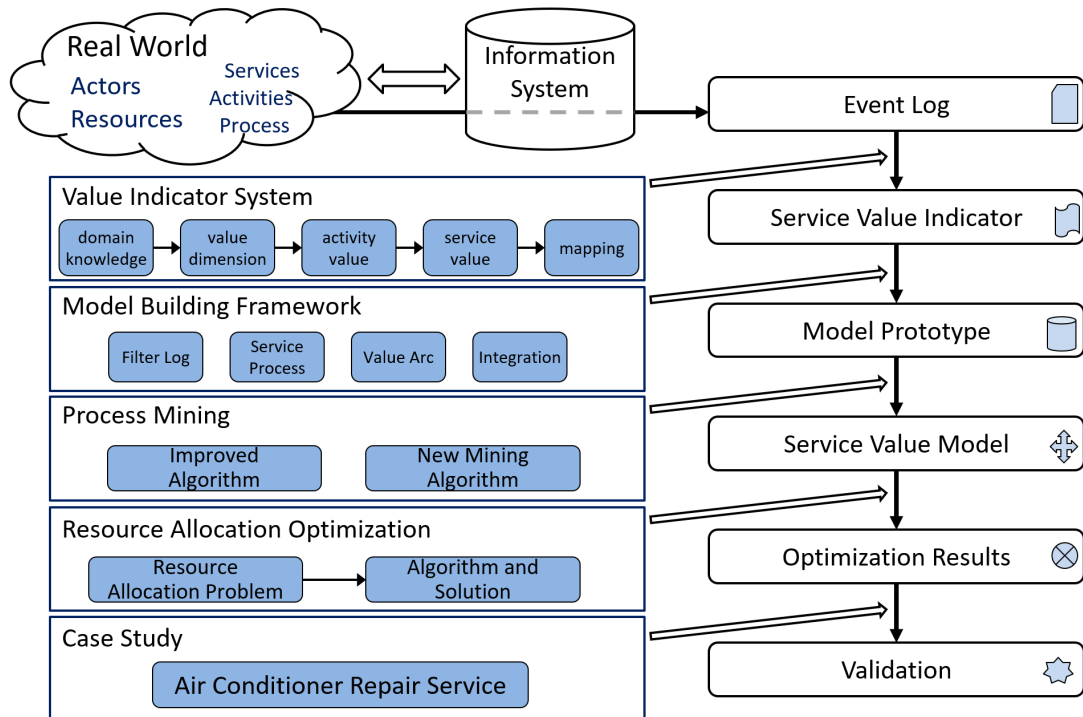


Figure 1.2 Structure of the constructing method

The rest of the thesis is organized as follows. Chapter 2 introduces the state of the art of service system, process mining and industrial value chain. The concept and formalization of service, service value and service process are explained in the service system. The traditional process modeling method, service event log and typical process mining algorithm are explained in process mining. In the industrial value chain, the notions of value chain, industrial value chain system and modeling methods are explained. As shown in Figure 1.2, the following chapters are described from top to bottom. In the service system, the execution of services is continuously recorded in the enterprises' information system, forming a large number of service event logs. Based on interviews with customers and domain experts, combined with the domain knowledge, chapter 3 defines the value creation entities of service, value dimension, activity value and service value, and determines the mapping relationship between event attributes and service value indicators, so as to build a service value indicator system. Then, the construction framework of the service value chain model is proposed and the model prototype is given. Chapter 4 describes two mining algorithms for automatically constructing ser-

vice value chain from the event log, guided by the above construction framework idea. One is an improved algorithm of inductive miner, and the other is a new value-oriented service process mining algorithm. Chapter 5 addresses the allocation of resources in the service value chain, considers the resource constraints and the historical experience obtained from mining, determines the resource allocation model, and gives the solution. In chapter 6, an air conditioner repair service is used as a case study to validate the proposals presented in the previous chapters and discuss the corresponding results. Finally, conclusions and perspectives are given.

CHAPTER 2

State of the Art

2.1 Introduction

The main objective of this thesis is to discover and optimize the service value model in service event log based on process mining techniques. This objective is involved in the fields of service system, process mining and Industrial Value Chain (IVC). Section 2.2 introduces the background of the construction of the service value model, including the relationship between services, service systems, and service value, and the concept and evolution of servitization and PSS. The service process is the concrete realization procedure of the service and is the carrier used to describe service value model. Section 2.3 gives the technical support for the construction of service value model, including the basic principles, data foundation, common algorithms and tools of process mining techniques. Process mining algorithm is the core of model discovery. In Section 2.4, the modeling scenario of the service value model is specified. The concepts of IVC, IVC system, IVC modeling and value chain analysis are described as well as value creation considered as the core issue of IVC.

2.2 Service System

At present, service has become the main driving force for social and economic development. More and more manufacturing enterprises are undergoing service-oriented transformation. At the same time, service also has attracted more and more attention in both industry and academia.

2.2.1 Service and Service System

Service is defined as the application of competences for the benefit of another, meaning that service is a kind of action, performance, or promise that's exchanged for value between provider and customers (Spohrer et al. 2007). Different with manufacturing in which values are transferred thoroughly from providers to customers, values in services are co-produced and shared between service provider and customers. In other words, the manufacturing process uses physical or chemical methods and means to transform

raw materials into a product with market value. When the product is transferred from the manufacturer to the customer, all the value generated in the manufacturing process is transferred to the customer and the customer is not involved in the manufacturing process. Services, on the other hand, are triggered by customer demand, and the service provider and the participants, as well as the customer, participate in the service process and the creation of value that results in the delivery of the service. For example, the process of manufacturing an air conditioner culminates in the sale of the air conditioner to the customer in the form of a product, while the air conditioner installation service requires the installation to be coordinated by the manufacturer with an engineer at a location and time specified by the customer, and the effectiveness of the service is verified by the customer. Each party of a service has his own expectations on values (Stabell and Fjeldstad 1998). These values are further classified into more detailed types, e.g., (1) economic values; (2) improvement on knowledge or skills; (3) improvement on experiences; (4) improvement on market competitiveness; (5) physical value, which refers to a tangible entity or product, such as an air conditioner; etc. Some of them are tangible values while others are intangible ones. Based on a well-designed service system, these values would be delivered to related parties by co-production, and the degree of value delivery relies on the design and development quality of service models and service systems to a great extent (Xu and Wang 2008). Figure 2.1 shows the relationships among service, service value and service system using UML class diagram. Service is described by a value model and a function model.

To support the implementation of services, there must be corresponding service systems to compose various service elements together. A service system is a complex socio-technological system and is defined as “a value co-production configuration of people, technology, other internal and external service systems connected by value propositions, and shared information” (Spohrer et al. 2007). A typical service system is composed of the following service elements:

- People: service customers, service providers, including their organizations, roles, human resources, professional skills and capabilities.
- Resource: including technological resources and physical material resources, e.g., software, equipment, physical environment and IT infrastructure, etc.
- Shared information: including files, data and documents that are created, transacted by and exchanged between service customers and providers.
- Behavior: physical, mental or social behaviors of people doing work in service systems. Such behaviors are usually stochastic and can't be easily modeled and simulated.

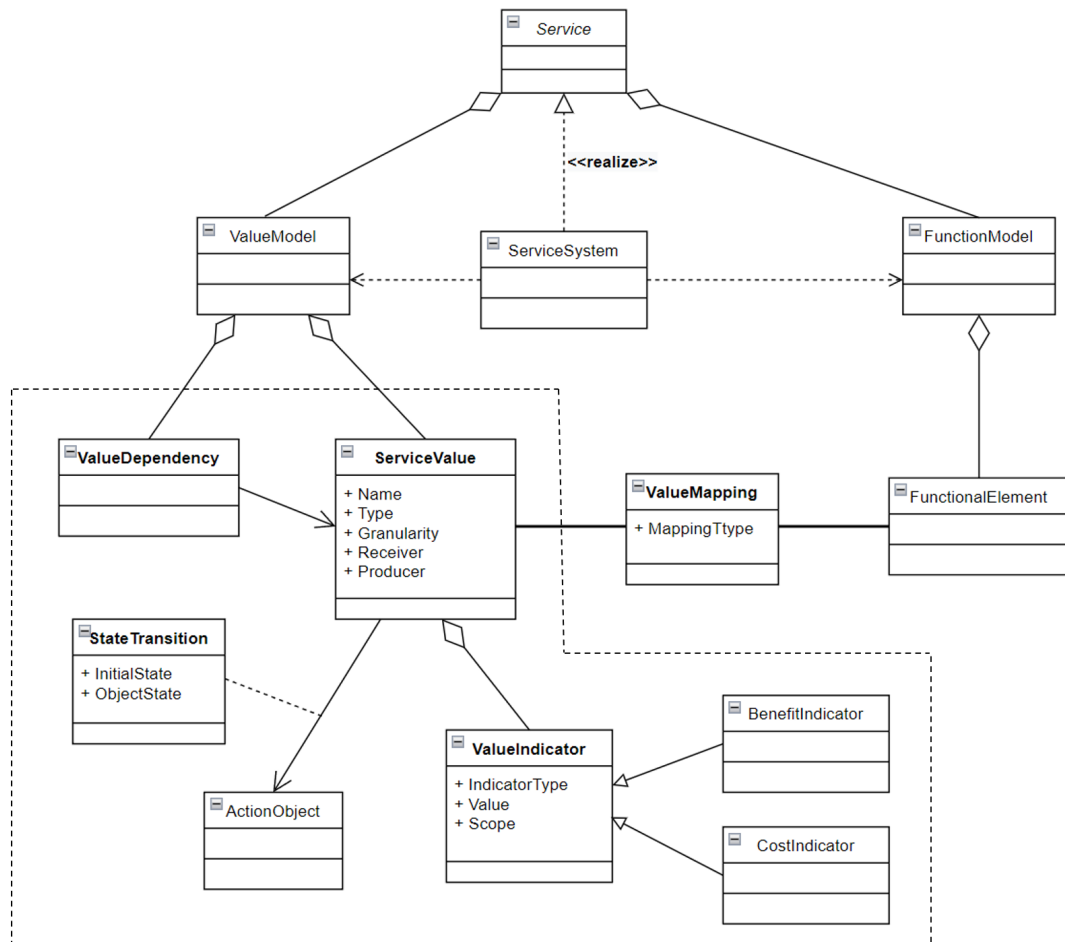


Figure 2.1 Service and service System, based on Wang and Xu (2011).

2.2.2 Product Service System

The “servitization” was first introduced by Vandermerwe and Rada (1988), which refers to an integrated product-service package offered by manufacturing enterprises in addition to physical products. The integration package is gradually dominated by services, and services become the main source of value creation. As research progresses, the main directions of servitisation research can be divided into input servitisation and output servitisation. Input servitization is concerned with the impact of service efficiency on the competitiveness of companies within manufacturing companies in terms of technical quality, operations, assets, etc. in the design and production of products. So input servitization is not the subject of this study. In the direction of output servitization, product system is gradually changing to PSS. PSS, initially considered as a competitive system composed of products, services, participant network and supporting infrastructure, can continuously meet customer needs and has less environmental impact than traditional business model (Goedkoop et al. 1999). PSS has the following characteristics: the transformation from traditional physical product design and sales to an ecosystem of organic integration of tangible products and intangible services requires a process

that does not happen overnight (Manzini and Vezzoli 2003, Wong 2004); it is customer-oriented, with the goal of delivering services to achieve customers' requirements, and the products are the carriers of services; it seeks a balance between the exchange value at the manufacturing end and the use value at the consumption end, re-conciliates the conflict between the two, realizes the synergy of interests through the integration and complementarity of resources, and realizes the win-win of value increment; it is under the service-dominant logic, the key creator of value is the customer and the core of value is the realization of use value rather than exchange value (Siddike and Hidaka 2017); and the value is created by resource integration and application between service providers and customers. According to the degree of servitization, PSS can identify three more specific types as follows (Tukker 2004): product-oriented, mainly focusing on product design, manufacturing and sales, providing some supplementary services; use-oriented, focusing on product related services or service-oriented products, providing the right to use the product rather than ownership; result-oriented, in which the product is a part of the service, delivering value to customers through a customized portfolio of products and services and with attention to the satisfaction of customer needs.

With the development of the Internet, social interaction breaks through the limitations of time and space, which also provides an opportunity for the integration of products and services. Based on the background of Industry 4.0, Gaiardelli et al. (2021) argued that the development of science and technology plays an important role in the establishment and improvement of the PSS, which is embodied in the incentive effect on horizontal integration and service transformation. The massive amount of data generated by the current development of technology is both a challenge and an opportunity for enterprises. The collaborative and integrated ecosystem named big service can more effectively address these challenges (Xu, Sheng, Zhang, Fan and Dustdar 2015). In the current research, the network nature of PSS is beginning to merge with service design (Costa et al. 2018). In the field of service, scholars have begun to focus on the concept of pattern. Alexander et al. (1979) defined pattern as a set of rules that describe situations, problems and solutions. Later, researchers began to combine pattern and service, focusing on service composition of primitive services, and combining atomic services using domain knowledge to meet customer needs (Strunk 2010). Xu et al. (2019) proposed that the core of the service pattern is to combine small-granularity services into a service pattern, and quickly construct a service plan based on it. Huang et al. (2010) defined the concept of reusable process fragments similar to service patterns, which refers to service composition that meets certain constraints.

It can be found that the concept of PSS has been gradually integrated into the operating philosophy of management, and gradually penetrated into the subdivision of

enterprises. Also, PSS is an important theoretical support for enterprise service transformation.

2.2.3 Service Value

Value is the goal pursued by all stakeholders involved in the service. In traditional research, value is usually regarded as an economic concept, with money as a means of measuring value. However, there are still a lot of non-economic values in the services. Scholars have made great progress in research on the service value and the cooperative relationship among participants. Owing to different concerns, different people may define value from different perspectives. Allee (2008) argued that there are two types of value, tangible and intangible value. Haksever et al. (2004) argued that service value includes not only the traditional economic value, but also non-economic value. Basole and Rouse (2008) pointed out the influencing factors of service value, they considered that service value is affected by political, economic, social, technological and other factors. van Heck and Vervest (2009) considered that emerging technologies foster collaboration and value co-creation. Enterprises are nodes in the service value network and they must identify and create value, and integrate a competitive value proposition (Lusch et al. 2010). Shamah (2012) pointed out the importance of knowledge sharing among participating stakeholders for value co-creation. From the perspective of serving ecosystems, Chandler and Vargo (2011) paid attention to the impact of the interaction between the dynamic social environment and economic agents. The scope of participants in value co-creation has been expanded by Vargo and Lusch (2016), and they argued that the value co-creation network is customer-centric, but the scope of the network is not limited to the binary relationship between enterprises and customers. They believe that all economic participants and resource integration can participate in the creation of value. Xing et al. (2013) proposed a sustainability-oriented value assessment model to measure the sustainable part of service value. Yang et al. (2017) divided uncaptured values into four categories, value surplus, value absence, value missed and value destroyed. Akaka et al. (2017) presented that services should consider the multi-level cultural environment, institutional environment and social environment from the dynamic and complex macro-situation. Matschewsky et al. (2020) studied the value creation in the service process from the perspective of suppliers, and proposed two stages: provider value analysis and provider value evaluation. Zhao and Wang (2021) proposed a neuroscience methodology for value co-creation that represents the perceived value creation process during customer decision making and PSS deployment.

From the opinion of Wang and Xu (2009b), service value can be divided into two categories: value transfer by exchanging certain “things” between service participants; value brought by improving the status of participants. Wang, Xu, Chu and Ma (2010)

argue that Value has three granularity levels: root value v^R , interim value v^I and atomic value v^A . v^R is the value directly expected by the user, with the largest granularity; v^A is the smallest granularity value, which can be created by the execution of one and only one service component; v^I is the value between the two. The root value proposed by users cannot be realized immediately. It needs to be gradually decomposed into interim value and atomic value, and finally realized by specific service function elements. Service value is defined as:

$$v = (Name, Type, Granularity, ao, s^I, s^O, P^B, P^C, Receiver, Producer),$$

where *Name*, *Type* and *Granularity* represent v 's name, type (such as resource use value, transfer value, information value, etc.) and granularity level, respectively; *ao* is an action object (entity) which v is attached to, that is, the effect of v is reflected by the improvement performance or state transition of *ao*, which can be an actual service entity for people, resources, information, etc. s^I and s^O are the initial state and expected final state of *ao*, and only when the state of *ao* changes to s^O , v is fulfilled. *Producer* and *Receiver* represent the producer and receiver of v respectively. P^B is a set of indicators used to measure the value of the recipient's benefit; P^C is a set of indicators used to measure the cost of value recipients in order to obtain v ; P^B and P^C measure the degree of value from the perspective of benefit and cost respectively. The component relationships of the service value model are shown in the section surrounded by dashed lines in Figure 2.1.

2.2.4 Service Process

Service process is an integral part of service, and it is the actual procedure, mechanism, and operation flow of service provision. The service process can be viewed as a chain or constellation of activities that allow the service to function effectively (Bitner et al. 2008). In general, the execution of service process is constrained by the Service Level Agreement (SLA) between service provider and customer (Zappatore et al. 2015), or the Quality of Service (QoS) requirements of customer. The SLA specifies the metrics of the customer, used to monitor and verify the contract. QoS can be regarded as a part of SLA, mainly considering the parameters related to customer requirements, such as response time, availability, security, etc. Customers may not only care about the functionality of the service, but also want to achieve some specific service quality objectives, such as the fastest response or the most reliable service (Netto et al. 2007). The current research on service process is mainly about the reconfiguration of service process, and the management of service process. Zhai et al. (2009) presented a reconfiguration region identification algorithm and middleware components to support the service reconfiguration based on end-to-end QoS constraints. Li et al. (2011) proposed an adaptive QoS-aware service process reconfiguration approach based on supplement-

tary services and a region-based reconfiguration algorithm, to solve the problem efficiently with low reconfiguration costs. Zappatore et al. (2015) proposed a contract template and a directed tree-graph model for SLA specification definition to manage service delivery. Nan et al. (2006) argued that service process management is a way to effectively manage publication, discovery, negotiation, deployment, and implementation of services, and presented an SLA-based service process management approach for service-oriented architecture (SOA). Yang et al. (2015) argued that the scope of process management consists of process design, process execution, process mining, and process intelligence, and a petri-nets based service process management method was introduced for workflow verification. Antosz and Stadnicka (2018) propose to implement the Six Sigma methodology to collect and analyse data, elements of the Lean concept to identify wastes and Industry 4.0 concept in order to improve the maintenance service processes. From the above literature review, it can be found that the research on service process focuses more on service composition, service process configuration and improvement, and less on the process itself and activities in the process.

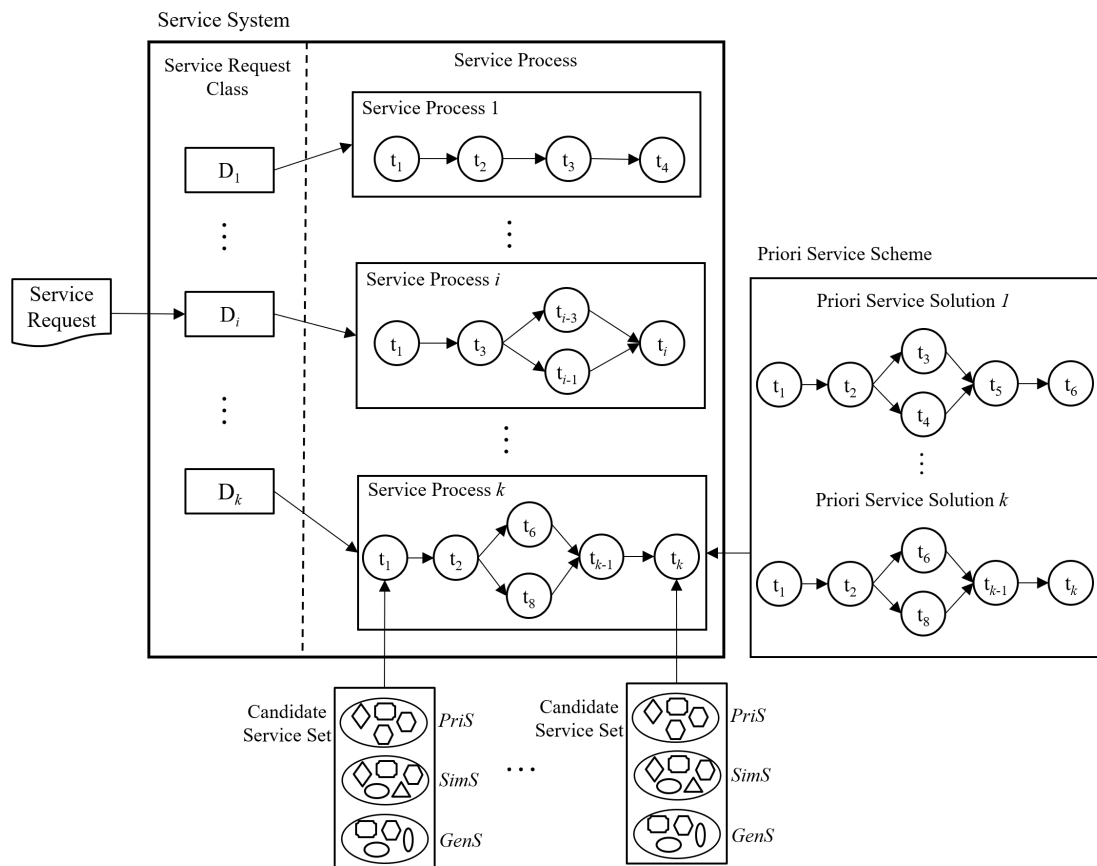


Figure 2.2 Service process and service composition, based on Xu, Liu, Wang, Min, Liu and Wang (2015)

In a service system, services are interacting, for example, by exchanging messages. By combining basic services more complex services can be created. Orchestration is

concerned with the composition of services seen from the viewpoint of single service. Choreography is concerned with the composition of services seen from a global viewpoint focusing on the common and complementary observable behavior (Van der Aalst 2013). Through orchestration and choreography, services would be integrated to create end-to-end service processes. When constructing service process, we need to consider the impact of some characteristics of service domain on service process. In the service domain, the service ecosystem has formed its unique service domain characteristics in its long-term development and evolution process, mainly including priori, correlation and similarity (Xu, Liu, Wang, Min, Liu and Wang 2015). They are described as follows.

- Priori refers to the experience knowledge generated in the long-term service application, that is, for a typical service application request class; there are usually some services (or service schemes) with high frequency and satisfactory users. This feature is called a priori in the service field.
- Correlation refers to the relationship between service and service (service and resource) in business collaboration. The relationship between services usually includes business association, statistical association, service quality association and so on.
- Similarity refers to the existence of a large number of services with the same functions and similar quality of service in the service domain.

Because of the large number of services available in the service system, each task in the service process has a candidate service set. Under the SLA of user, according to priori and similarity, the candidate service set of each task can be divided into priori service set and similarity service set and general service set, and the service process meeting user's requirements can be constructed quickly. As shown in Figure 2.2, a service process considering service domain characteristics is presented.

2.3 Process Mining

Process mining is a relative young research discipline that sits between machine learning and data mining on the one hand and process modeling and analysis on the other hand (Aalst et al. 2011). Process mining is a family of techniques in the field of process management that support the analysis of business processes based on event logs. The idea of process mining is to discover, monitor and improve actual business processes by extracting knowledge from event logs (Gupta 2014). There are three types of process mining as shown in Figure 2.3.

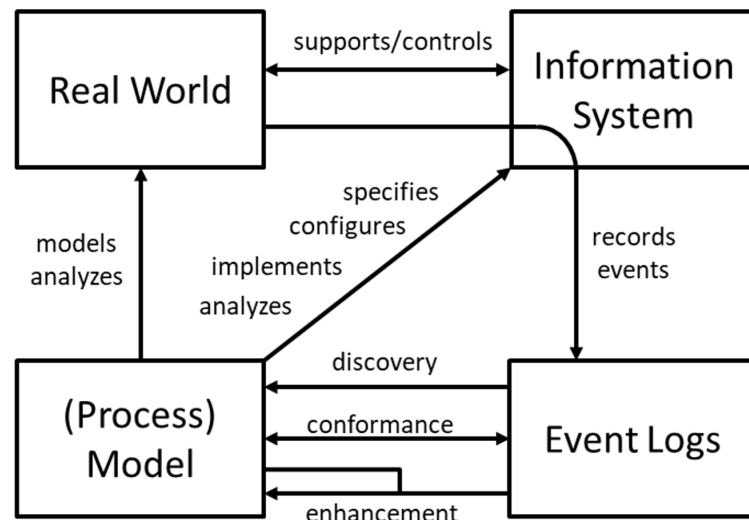


Figure 2.3 The framework of process mining based on Van der Aalst (2011)

- The first type of process mining is discovery. Discovery techniques can extract process models from an event logs, and the results are not limited to control flow discovery, but can also discover relevant organizational models, case models and time constraints.
- The second type of process mining is conformance. Conformance techniques can be used to compare the mined models (event logs) with the existing models. The results of the checking show the deviations between model and log.
- The third type of process mining is enhancement. Enhancement techniques can be used to extend or improve an existing process model using the other information recorded in same event log such as the time or resource. Enhancement usually occurs after the conformance checking.

2.3.1 Event Log

Event log is the information accumulated in the process of information system operation about the logical relationship between business, the access and utilization of resources, the attributes of business activities and so on. Event logs are necessary resources for process mining, and the quality of log data determines, to some extent, the quality of model mining results. eXtensible Event Stream (XES) was adopted in 2010 by the IEEE Task Force on Process Mining as the standard format for log events (CW Günther and Verbeek 2014). It is now in the process of becoming an official IEEE standard. XES is an XML-based log file format. XES itself does not have a predefined meaning for any particular tool or application area. Figure 2.4 shows a complete meta-model of the XES standard using UML 2.0 class diagram. An XES document contains one log which is

related to one process instance. XES uses the three-level structure of Log, Trace and Event to represent logs. Log is the top-level node, representing one log object related to one specific process, which contains multiple Traces, i.e. a set of specific instances or cases of the logged process. Trace is the second-level node that represents a specific instance object and contains multiple Events, i.e. a collection of specific event objects. Event is the three-level node representing a specific event object which is an atomic granules of activity observed during the execution of a process. The Log, Trace, and Event objects contain no information themselves. They only define the structure of the document. Attribute is used to describe the information of the log. Logs, traces and events each may have an arbitrary number of attributes. XES supports six types of attributes, including list, container, string, date, float, boolean, and ID, and it supports nesting of attributes. XES uses the classifier tag to identify events. An extension defines an attribute set of XES log. It mainly provides semantics for a set of attributes defined on each element to make up for the ambiguity of XES in describing specific concept. For an Event, the name and the time of occurrence are essential attributes, which are represented by attributes with the keys “concept:name” and “time:timestamp” respectively. The name of the event is used to distinguish between different events, while the time of occurrence is used to determine the temporal order of the different events in order to determine the dependencies between them. Other attributes are optional for the Event and are used to describe other information related to the event, such as actor, resource, value information, etc.

At present, some literature assumes that the log data is correct when using the log. But in fact, the log data in the information systems may contain some noise, such as wrong or incomplete log data. For example, in the air conditioner repair service, due to the communication network failure, the engineer could not submit the event of starting the repair but submitted the event of completing the repair, which would result in incomplete log data. This is very unlikely to happen, but still exists. Therefore, the log data used for mining must contain complete data about the process, especially the various scenarios of the process, so as to ensure the correct implementation of the follow-up work.

2.3.2 Process Mining Algorithms

Process mining algorithm is a method to discover the activities by the whole process runtime through the process log, so as to establish the process model. At present, many process mining algorithms have been proposed, which come from different research projects and represent several different research directions. And each algorithm has its own solution for solving some difficult problems in process mining. For the current main process mining algorithms, they can be described in the following categories.

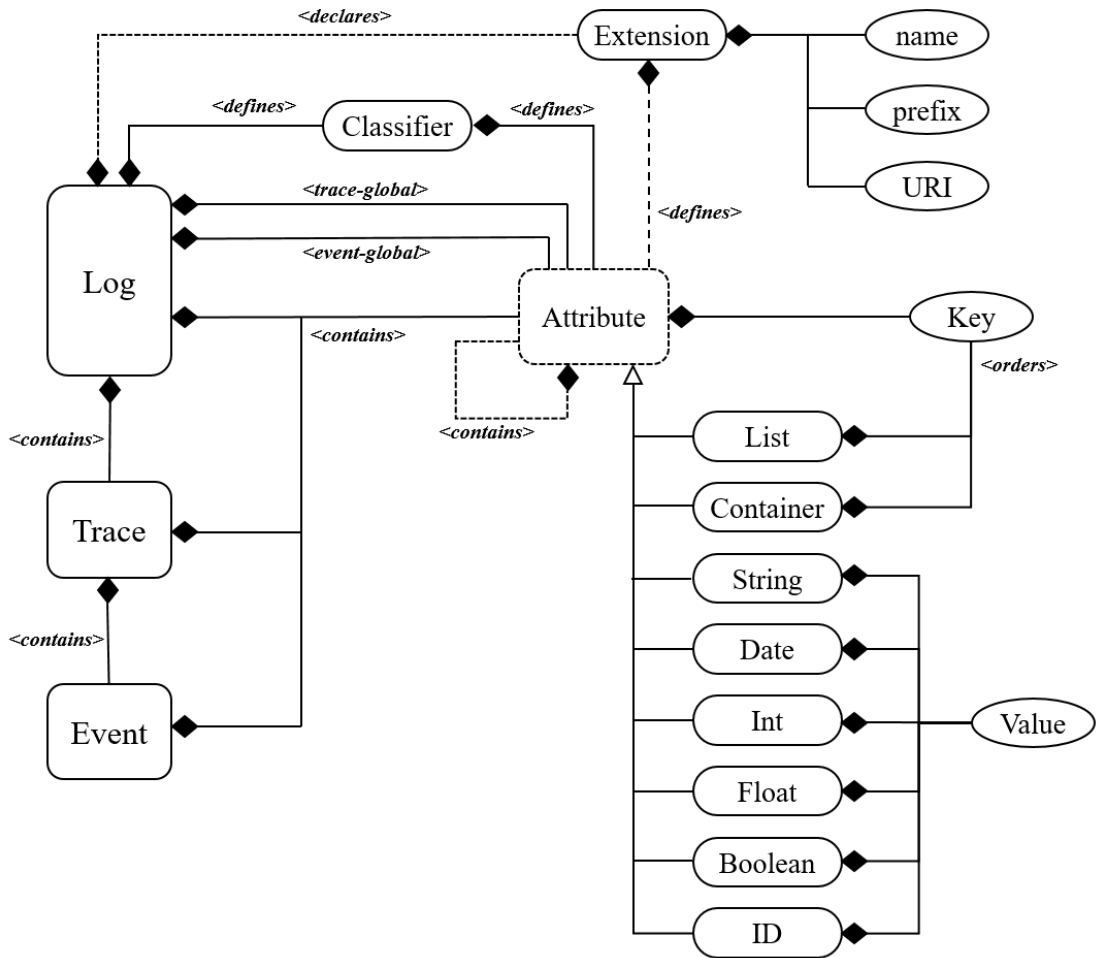


Figure 2.4 The UML class diagram of XES based on CW Günther and Verbeek (2014)

(1) alpha and its derivative algorithms

The first algorithm of process mining is α algorithm proposed by Van der Aalst et al. (2004), which was the mining approach allowing to discover a Workflow network from event log. Based on the order of occurrence of Events in the event log, the α algorithm reasoned about the dependencies between Events to discover the four structures of sequence, causal, choice and parallel among them and to obtain a sound Workflow-net. The result of mining was expressed as Petri net. Petri net is one of the most popular models to represent the results of process mining. As a tool for describing concurrent processing and simulating parallel systems, Petri net plays an important role in computer and engineering technology, automatic control and other fields. Because Petri net has a strict mathematical theory foundation, it is helpful for formal verification and analysis of workflow model. Since it is a mining technology based on Petri net, the α algorithm can detect the log changes, and it can easily rediscover the workflow. This algorithm can find corresponding substitutes for And-split and And-join structures by extending Petri net, but the relationship among activities is limited to the relationship

between two of them. The algorithm has some shortcomings in the construction of the workflow process model, such as the inability to correctly handle duplicate activities, invisible activities, loops, synchronous aggregation, etc. Invisible activities are tasks that are not visible, i.e. such tasks that exist in the process model but not in its event log (Wen et al. 2010). For invisible activities and one-step cycle problems, the mining method for workflow model based on synchro-net can handle them very well (Huang et al. 2006). For duplicate activities, an extended α algorithm based on Petri net is proposed, which can discover and solve the problems (Li et al. 2007). Wen et al. (2009) considered that the activities in the event log are not atomic activities, that is, each activity is composed of a *START* and a *COMPLETE* activity. The rules in the α algorithm are modified by the overlap relationship between the activities, which makes the algorithm more rigorous. A process mining algorithm based on statistical α algorithm is proposed, which can distinguish the rename activities and non-free-choice constructs, and the algorithm has good robustness and correctness (Yu et al. 2018). As a basic approach based on Petri net for process mining, α algorithm has been developed as a series of algorithms, and can solve most of its limitations in process discovery.

(2) Heuristic process mining algorithm

Weijters, van der Aalst and de Medeiros (2006) first proposed a heuristic algorithm for process mining, called heuristic miner (HM). The sequences of events in a case are derived from the timestamp in the event logs and then calculating related frequency-based metrics to determine the dependencies between activities. For this, it can find the frequent and infrequent paths in the process, being more robust in relation to the process frequencies. To avoid explicit modeling of invisible activities, the process models are represented as causal nets in the algorithm. The HM algorithm consists of three main steps. First, the dependency between two events is calculated by Equation 2.1. The calculated \Rightarrow_W values between the events of an event log are used in a heuristic search for the correct dependency relations. $|a >_W b|$ is the number of times $a >_W b$ occurs in the log. the value of $a \Rightarrow_W b$ is always between -1 and 1. The closer the value of $a >_W b$ is to 1, the stronger the dependency between event a and event b . Conversely, the closer it is to 0, the weaker the dependency between the two events. For example, let $W = \{ \langle A, B, C, D, H \rangle^{10}, \langle A, C, E, H \rangle^4, \langle A, B, C, E, B, D, H \rangle^5 \}$, then $|A >_W B|$ is 15 and $|B >_W A|$ is 0. We can get $A \Rightarrow_W B$ as 0.9375. Next, a threshold is set to construct the dependency graph. Some edges with low dependency caused by noise will be filtered out at this point. Finally, the parallel and selection branches in the model are further determined by calculations based on the dependency graph.

$$a \Rightarrow_W b = \left(\frac{|a >_W b| - |b >_W a|}{|a >_W b| + |b >_W a| + 1} \right) \quad (2.1)$$

Since HM only focuses on the main behavior and can automatically filter some

anomalous information (e.g., noise), the initial version has many shortcomings. Weijters and Ribeiro (2011) further proposed Flexible Heuristics Miner (FHM) in 2011, which extends the dependency graph of the original HM algorithm, trying to find a representation with good performance in practice while easily understandable. Then a parallelized heuristic process mining algorithm was proposed in 2015, which not only improves the computational performance of the algorithm, but also optimizes the computation of long distance dependencies in the HM algorithm and the 2-degree loop structure (Lu et al. 2015).

(3) Region-based mining algorithm

Region-based process mining algorithms include two categories: state-based region and language-based region. State-based regions can be used to construct a Petri net from a transition system. Transition system is the most basic process modeling notation. It is used to describe the potential behavior of discrete systems. It consists of states and transitions between states. Language-based regions can be used to construct a Petri net from a prefix-closed language. A language L is prefix-closed if, whenever a word w is in L , then every prefix of w is also in L (Brzozowski et al. 2010). Synthesis approaches using language-based regions can be applied directly to event logs. To apply state-based regions, a transition system needed to create firstly (Van Der Aalst 2016). The language-based regions construct a process model by computing the minimum linear basis of integer points from the event logs (Bergenthum et al. 2007). This method guarantees the optimal Fitness value, but does not consider the Precision value of the model, and the time complexity of the proposed algorithm grows exponentially with the log size. On the basis of language-based regions, Van der Werf et al. (2009) propose a process discovery algorithm using Integer Linear Programming (ILP). The ILP Miner presented the objective function of integer linear programming and constructs the constraints. The main idea is that places restrict the possible firing sequences of a Petri net. Therefore it searches as many places as possible so that the Petri net obtained are consistent with the log. Van Zelst et al. (2018) present an ILP-based process discovery approach, based on region theory, that guarantees to "discover relaxed sound workflow nets". The method not only improves the objective function, but also proposes how to handle low-frequency behavior, thus improving the precision of the obtained model.

(4) Divide-and-Conquer-based mining algorithm

The idea of divide-and-conquer is to try and break the problem into smaller ones and solve them one by one. Inductive Miner (IM) algorithm proposed by Leemans et al. (2013) is one of the best algorithms based on divide-and-conquer method. The process tree and the model of block-structured workflow net can be mined from event logs, with guarantee of the robustness and adaptability (Leemans et al. 2013, 2018). Such block-structured process model is generally more understandable than other mod-

els. Moreover, block-structured models are sound, provided that the gateways at the entry and exit of each block match (Augusto et al. 2017). Leemans et al. (2013) defines an Inductive Miner direct-follows framework (IMD framework), which discovers process models using the idea of divide-and-conquer and recursion. A process model is represented by a process tree, with leaf nodes representing the activities in the process and non-leaf nodes representing the structure of the process. The process structure is represented by the process tree operators \oplus , including \rightarrow , \times , \wedge , \oslash , which respectively indicate the relationship between its subtrees as sequential execution, exclusive choice, parallel execution and loop execution for a given log L . Its directly-follows graph (DFG) is $G(L)$. According to $G(L)$, the IMD frame judges the relation among activities and divides the activity set into a subset of activities, then, based on the subset, L is cut into smaller sub-logs, which can be combined with \oplus to restore the log L . Then, the sub-process trees are recursively obtained in the sub-log, and the sub-process trees are combined into a complete process tree through \oplus . When L can no longer be split, the recursion ends.

The IM algorithm has good noise resistance and can discover the basic model structure. The discovered process models performs well in all four dimensions of quality, including fitness, precision, generalization and simplicity (Bolt et al. 2016). Verbeek et al. (2017) introduce a tool framework, called Divide And Conquer that can support generic approach for process mining. This approach offers formal guarantees for the results obtained by it and makes existing algorithms also tractable for larger logs.

(5) Computational Intelligence mining algorithm

These algorithms originate from the field of computational intelligence for solving data mining, nonlinear optimization and other problems, such as genetic algorithms, bee colony algorithms, ant colony algorithms, simulated annealing algorithms, neural networks, etc. These techniques have in common that the log is not directly converted into a model but uses an iterative procedure to mimic the process of natural evaluation (Van Der Aalst 2016). de Medeiros et al. (2007) first applied genetic algorithm to process mining and proposed Genetic Miner. Through well-defined fitness function and genetic operators such as crossover and mutation, Genetic Miner can obtain a C-net model that is consistent with the event log. Vázquez-Barreiros et al. (2015) propose a new mining method based on genetic algorithm called ProDiGen. ProDiGen includes new definitions for precision and simplicity, and specific crossover and mutation operators. And it can guarantee to find complete, precise and simple models for the given logs. Based on genetic algorithm, a new process mining algorithm called Evolutionary Tree Miner (ETM) is proposed (Buijs et al. 2012a,b). The input of the algorithm is an event log. In the initial step, a population of random process tree is generated, where each activity occurs exactly once in each tree. Next, four quality dimensions are computed for each

candidate in the population. Using the weights of each dimension, the overall fitness of the process tree is calculated. In the next step, certain stopping criteria are tested, such as finding the tree with the desired overall fitness. If none of the stopping criteria are met, the candidates in the population are changed by swapping subtrees between them (crossover) or by changing, adding or removing nodes (mutation). Then the fitness will be calculated again. This will continue until at least one stopping criterion is met, and then the most suitable candidate is returned. Figure 2.5 illustrates the above steps. The ETM algorithm is one of the most effective algorithms based on computational intelligence, and instead of using the traditional causal net model, it uses a process tree as the structural model for the result.

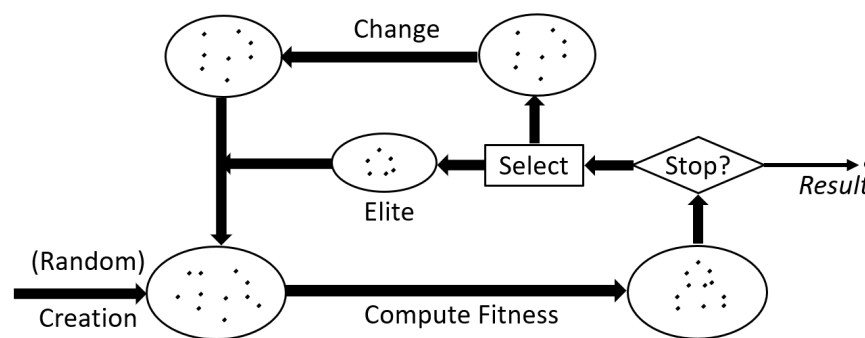


Figure 2.5 Steps of EMT, based on Buijs et al. (2012a)

Many process discovery algorithms and techniques have been developed, and various process models have been used to represent mining results, such as Petri net, C-net, P-tree, BPMN model (Kalenkova et al. 2015), YAWL model, etc. It is not easy to determine the quality of a process mining result, which needs to be described in terms of different dimensions, including four main quality dimensions: precision, fitness, generalization and simplicity.

- Precision, the resulting model should not allow for behaviour that is completely unrelated to that reflected in the event log.
- Fitness, the model of exposed allows for the performance realized in the event log. Performance checking in the event log model has allowed to fitness.
- Generalization, the model discovered should generalize the event compoment realized in the event logs.
- Simplicity, the simpler the model obtained, the better.

Based on the above review, region-based mining algorithm, Divide-and-Conquer-Based mining algorithm, and Computational Intelligence mining algorithm have received more attention in recent years in terms of effectiveness. The representative algorithms in these three categories are Hybrid ILP Miner, IM, and ETM. The simple

comparison of Hybrid ILP Miner, IM, and ETM is shown in Table 2.1. It can be found that all three algorithms perform well in general, and their disadvantages are: the process model mined by Hybrid ILP Miner with low generalization; the IM cannot handle non-free choice and long distance dependence, and the EMT is defective in rediscovering the model and has a long execution time.

Table 2.1 Comparison of algorithms

Algorithm	Hybrid ILP Miner	IM	ETM
Model	Petri net	Process tree	Process tree
Precision	X	X	X
Fitness	X	X	X
Generalization		X	X
Simplicity	X	X	X
Deal with loop	X	X	X
Long distance dependency	X		X
Non-free-choice	X		X
Deal with noise	X	X	X
Rediscovering	X	X	
Time consume	short	short	long

2.3.3 Process Mining Tools

In order to assist users to realize process mining, many process mining tools have been developed. The most famous process mining tools include ProM, Apromore, Disco, Celonis, PM4Py and so on.

ProM is an Open Source framework for process mining algorithms which was developed by the Process Mining Group, Eindhoven Technical University (Van Dongen et al. 2005). ProM provides a platform to users and developers of the process mining algorithms that is easy to use and easy to extend. Plugins are provided for different mining algorithms, for analysis, conversion and export modules. ProM has provided over 3,000 process mining and analysis plugins (Dakic et al. 2019), including α algorithm, genetic algorithm, social network mining, decision mining, fuzzy mining, cloud mining and so on. Plug-ins can be used in a variety of ways and can be applied combined in real-life situations. ProM supports event logs document with the XES, MXML or CSV formats and can load process model definitions in different standards (Yasmin et al. 2020). Developers can develop their own plug-ins and make them run in the ProM framework according to their needs, guided by the ProM plug-in development specification. With the upgrade of the version and the increase of the number of plug-ins, the storage space occupied by ProM is increasing, and the number of plug-ins that need to be loaded is also increasing.

Disco (Günther and Rozinat 2012) is a commercial process mining software offered

by Fluxicon. It supports a wide range of event log import formats including CSV, MS Excel, MXML, XES, FXL Disco Logs and DSC Disco project files. Disco provides an automatic process discovery mapping once the event log is imported in to the system. In Disco, after the necessary filter is applied, a process model is easily discovered with all the required information attached. The Disco is based on the Fuzzy miner. Fuzzy Miner was the first mining algorithm to introduce the “map metaphor” in process mining, including advanced features such as continuous process simplification and highlighting frequent activities and paths (Gomes et al. 2022). As a professional commercial software, Disco is powerful enough and has good performance, but it does not provide an interface for developers.

In a perspective of a process mining software that is easily extensible, allows algorithmic customization and easily allows to conduct large-scale experiments, the Process Mining for Python framework (PM4Py) appears (Gomes et al. 2022). PM4Py provides a new process mining library for large-scale applications, and the library integrates with state-of-the-art data science libraries such as pandas, numpy, scipy and scikit-learn (Berti et al. 2019). For the developers, the mainstream process mining techniques that the PM4Py library can provide include:

- Process discovery: Alpha Miner, Heuristic Miner and Inductive Miner.
- Conformance Checking: Token-based replay and alignments.
- Measurement of fitness, precision, generalization and simplicity of process models.
- Filtering based on time-frame, case performance, trace endpoints, trace variants, attributes, and paths.
- Case management: statistics on variants and cases.
- Graphs: case duration, events per time, distribution of a numeric attribute’s values.
- Social Network Analysis: handover of work, working together, subcontracting and similar activities networks.

In summary, ProM allows you to develop your own plugins or use existing ones; Disco is user-friendly but does not allow any specific development; and the Python library, PM4Py, contains basic process mining algorithms that can be used in a development environment.

2.4 Industrial Value Chain

A value chain is a set of activities that a firm operating in a specific industry performs in order to deliver a valuable product or service for the market. The theory of value chain comes through business management and has been proposed by Porter (1985). The concept of value chain is based on the process view of the organizations, which regards the provision of products or services to customers as a process of a series of activities. The value chain theory was originally applied to a traditional manufacturing firm. With the development of social division of labor, production specialization and globalization, the IVC and global value chain (GVC) were formed (Piboonrunroj et al. 2017). The IVC applies the ideas and methods of value chain to the industrial level, and considers the organizational form of value creation in a more macroscopic way (Du and Li 2004). The GVC (Gereffi et al. 2005, Antràs and Chor 2013) is a global cross-enterprise network that links production, sales and recycling processes to achieve the value of goods or services. GVC is similar to IVC, the former emphasizes geographical characteristics, and the latter emphasizes industry characteristics.

2.4.1 IVC System

Industrial chain is a concept in industrial economics. It is a chain-like relationship formed objectively among various industrial departments based on certain technological and economic linkages, and according to specific logical relations and spatial-temporal distribution relations (Du and Li 2004, Fan et al. 2018). Industrial chain is a chain formed to realize value in order to meet the needs of users. The relationship among IVC, industrial chain and value chain lies in using the analysis method of value chain to investigate the industrial chain. A series of activities carried out in the industrial chain and in the enterprise competition are analyzed and studied only from the point of view of value, which is called the industrial value chain. Based on the industrial chain, it analyzes the value creation activities of each phase in the industrial chain and the core factors that affect the value creation from the overall point of view. In the current competitive environment, the competition in industry is not only the competition among individual enterprises, but also the competition among industrial chains.

The formation of IVC effectively realizes the value of the whole industrial chain and reflects the transfer and creation of value in various industrial phases. Base on the opinion of Du and Li (2004), the features of IVC can be described as follows:

- The IVC provides a systematic method to divide the enterprises in the industrial chain into some separate activities. The value chain can be used to study what these activities are and how they are organized.

- The IVC provides a systematic approach for integration of value in the industrial chain. Through opening up the value chain of each enterprise, the industrial chain forms a smooth, unified and coordinated value chain system.
- The IVC makes synergistic effect between enterprise value chains. The industrial chain strategy integrates the value chains of enterprises, links up the value chains of enterprises, and creates value and competitive advantages.

The system of IVC is integrated by the value chain of each enterprise in the industrial chain, as shown in Figure 2.6, the value chains of the enterprises are connected by the connecting points. Before the industrial chain was formed, the value chains of enterprises are independent of each other, and the value links connection them are loose or even unrelated. Through industrial integration, enterprises are bound to an IVC system, and the IVC on the industrial chain is formed accordingly. The IVC opens up the value barriers among enterprises, links up the various value chains by connection points, and forms a smooth value channel. Through the unified layout and planning, the IVC straightens out the relationship among the various intra-firm value chains and coordinates the value activities of enterprises, so that the value created by the whole industrial chain far exceeds the sum of the value created by individual enterprises. IVC is an interactive and interdependent activity system. When the benefits of executing one enterprise's value chain affect the benefits of other enterprises' value chain, the value connection point among enterprises will become the value decision point. In order to maximize the benefits of the whole IVC, trade-off effect appears.

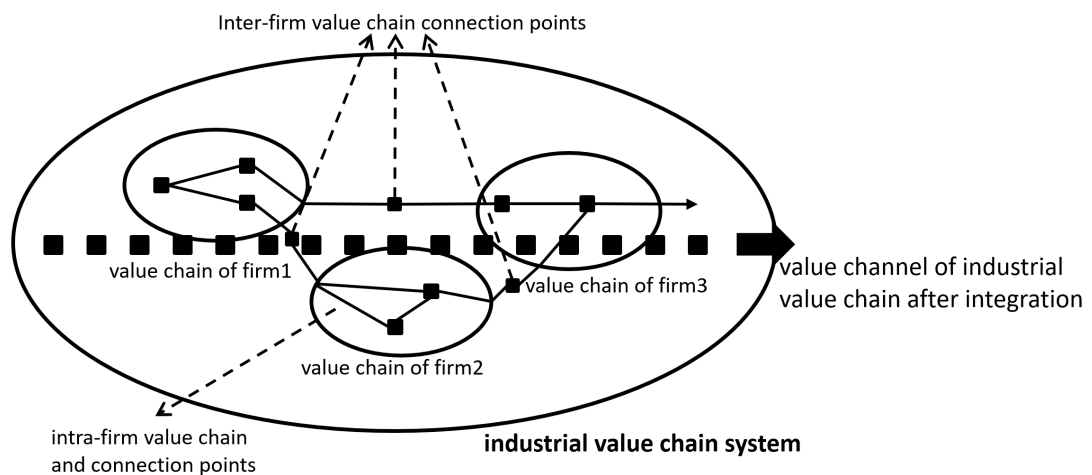


Figure 2.6 Structure of industrial value chain, based on Du and Li (2004)

2.4.2 IVC Modeling

Some research has already been done on IVC modelling by some scholars. Typical modeling methods mainly include IVC system structure diagram (Du and Li 2004),

IVC modeling based on industrial value matrix (Wang et al. 2008), IVC model based on IDEF0 (Wang, Tang and Li 2010), game model of industrial value chain (Yan and Tan 2016) and model structure of digital economy value chain (Miao 2021), etc. In addition, the value stream mapping (VSM) is a language widely used in the manufacturing industry for modeling. It is typically developed to understand value-added and non-value-added activities from both information and material flow in a value stream (Shou et al. 2017). Some government departments and standardization organizations have released the “Graphical symbols for process chart” standard for process modeling and analysis for the manufacturing industry, such as JIS Z8206 in Japan and JB/T 9170-1998 in China. The model related to this thesis is the IVC modeling based on value matrix, and we will use the idea of this participation matrix as a basis for identifying the relationship between the actors and the activities in the service process.

(1) Model elements of IVC

In order to construct model for IVC, some basic modeling elements are defined as follows:

- Industrial phase: is the smallest module of product (or service) which is subdivided into all activities in the whole process from raw material supply, production to sales. The industrial phase is the embodiment of the hierarchy of value activities in the IVC.
- Industrial node: refers to a specific industrial phase in which an enterprise participates, which is the instantiation of the industrial phase. There may be multiple enterprises involved in the same industry phase. There must be at least one industrial node in any industry phase.
- Node link: refers to the “upstream and downstream relationship” between two industrial nodes located in adjacent industrial phases. If there is such a “supply and demand” relationship between the two industrial nodes, it is said that there is a node link between them.
- Value channel: is a complete path from raw material supply to final consumer.

In capacity network, an origin point and a receipt point are usually specified, and other points are called intermediate points. For a network with multiple origins and receipts, a total origin point and a total receipt point can be assumed separately, and connected with each origin and receipt respectively, which can be transformed into a network with only one origin and one receipt. Drawing on the above viewpoint, a total origin point and a total receipt point are set up at both ends of the industrial chain, but these two points are not fictitious, but the aggregation of the original large number of nodes.

- The total origin point is defined as a virtual supplier. The supply of raw materials may be provided by a number of enterprises. For the convenience of research, it is assumed that all raw materials are supplied by the virtual supplier.
- The total receipt point is defined as a virtual consumer. Consumers in reality may be hard to count. Similarly, for the convenience of research, it is assumed that all consumption activities are performed by the virtual consumer.

The length of the value channel is defined as the number of arcs on any channel connecting the virtual supplier and the virtual consumer. The characteristics of value channel are as follows:

- All value channels are equal in length. Since any industrial phase in the whole path from virtual supplier to virtual consumer is irreversible and cannot be crossed, the length of all value channels is one plus the number of the industrial phases in the IVC.
- There are no loops in all value channels. Because of the irreversibility of industrial phases in the real environment, any value channel can only extend from low-level industrial phases to high-level industrial phases.
- Any value channel intersects with other value channels. If a value channel does not intersect with any other value channels, all nodes of the channel will form an independent IVC. Therefore, one value channel intersects other value channels with at least one node.

(2) Concept model of IVC

In the process of socialized division of labor, according to the track of industrial evolution, from the opinion of Wang et al. (2008) that it is divided into three stages: pre-industry, initial-industry and mature-industry. For different stages, different IVC models can be constructed. The pre-industry model of IVC is shown as Figure 2.7. During the monopoly period, there are only a few giant enterprises in an industry, which divide up the market. In essence, IVC in this period belongs to the enterprise value chain. The “raw material supply” in Figure 2.6 represents the virtual supplier, while the “terminal consume” refers to the virtual consumer. The initial-industry model of IVC is shown as Figure 2.8. With the gradual refinement of industrial division of labor, many enterprises begin to focus on their respective advantages under the pressure of market competition and cost. As a result, there is a real “chain” within the industry. During this period, the enterprises outsourced their own weak phases, which were fulfilled by other specialized enterprises with obvious advantages.

The mature-industry Model of IVC is shown as Figure 2.9. Industrial division of labor has entered a mature stage, and the market has developed into a monopolistic

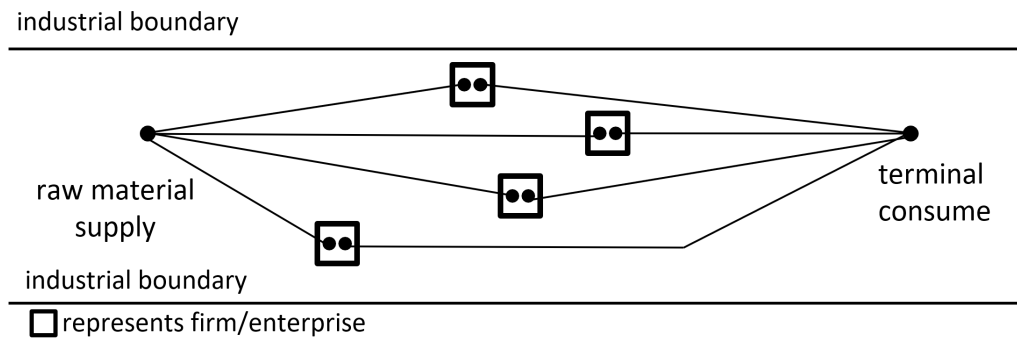


Figure 2.7 Pre-industry model of IVC

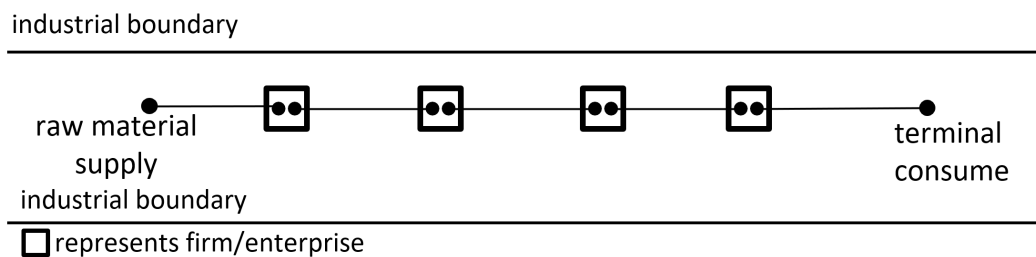


Figure 2.8 Initial-industry model of IVC

competition stage. Many enterprises may participate in competition in any phase, and the structure of industrial value chain tends to mature. As can be seen from the figure, a phase can be participated by many enterprises, and an enterprise can also participate in several phases. As can be seen from the figure, a phase can be participated by many enterprises, and an enterprise can also participate in several phases. For example, in phase 1, there are four enterprises involved; Enterprise A participates in phase 3 and phase 4, and Enterprise B covers phases 4, 5 and 6. The mature IVC model has the following characteristics:

- The IVC model is a directed connected graph. Although the arrow line is not used in the figure, the irreversibility of the industrial phases shows that each node link is directed, which is from the low-level industrial phase to the high-level industrial phase.
- The industrial value chain model is a hierarchical structure chart. It is not difficult to draw this conclusion from the hierarchy of industrial phases. All adjacencies occur between adjacent nodes.

(3) Industrial Value Matrix

It is assumed that the production process of an industrial target product consists of N phases (N is a natural number, without calculating virtual suppliers and consumers), and at most M enterprises participate in the competition in each phase. Then a $M \times N$

R is a square matrix with rows and columns $M \times N$. Because the upstream and downstream correlations are symmetrical and each phase is not correlated by itself, the elements on the diagonal line of matrix R are all 0, and it is a diagonal symmetrical square matrix. Since $p_{i,j}$ in Formula (2.2) becomes the $[(i-1)N+(j-1)]_{th}$ element after expansion, each element of the supply and demand matrix R is calculated as follow: $r_{u,v} = 1$, if p_{i_1,j_1} is associated with P_{i_2,j_2} upstream or downstream; $r_{u,v} = 0$, if p_{i_1,j_1} is not associated with p_{i_2,j_2} upstream or downstream; where $u = (i_1 - 1)N + j_1$, $v = (i_2 - 1)N + j_2$, $i_1, i_2 = 1, \dots, M$, $j_1, j_2 = 1, \dots, N$, and $|j_1 - j_2| = 1$. For example, if the participation matrix P is shown in Formula (2.4), the corresponding supply and demand matrix R is shown in Formula (2.5).

$$P = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \quad (2.4)$$

$$R = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (2.5)$$

The IVC matrix includes “participation matrix” and “supply and demand Matrix”, and combines with the concept model of IVC to form the theoretical basis of IVC model.

2.4.3 Value Chain Analysis

At first, value chain analysis is a tool to seek to determine the competitive advantage of enterprises, that is, to decompose the activities of enterprises, and to determine the competitive advantage of enterprises by examining the relationship between these activities and activities themselves (Porter 1985). With the development of value chain theory, value chain analysis is more used in IVC or GVC that across enterprise boundaries. We argue that GVC is also an IVC in essence. Under these circumstances, the value chain analysis is to investigate the “economics” of the IVC in depth, and to make an in-depth study of its impact and the degree of impact, so as to fully weigh the pros and cons in order to obtain the best value chain structure. Each activity in the chain will have an impact on the ultimate value realization of the enterprises. The value chain

analysis focuses on the value creation in the business of enterprises, and its emphasis is on the value-added behavior analysis of activities in the value chain to enhance the competitive position of enterprises. Traditionally, value is the price that the user is willing to pay for the products or services provided by the enterprise. It also represents the realization of customer demand satisfaction. Value-added activities are activities in which the physical and technical boundaries of a company are clearly defined. They are the cornerstone for enterprises to realize products or services of value to Users.

There is a dependence of the value chain with Lean Management (LM). LM is an integrated socio–technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer and internal variability (Camacho-Miñano et al. 2013). LM requires the use of “Lean Thinking” in all activities, i.e., the creation of as much value as possible with minimal investment of resources, including people, equipment, money, materials, time and space, to provide new products and timely services to customers. The implementation of LM enables the detection and analysis of “waste” in value chain processes, the establishment of control and measurement mechanisms aligned to objectives and the implementation of improvement actions to achieve these objectives (Prado-Prado et al. 2020). For value chain analysis, the LM must go beyond the scope of a single enterprise to view all the industrial activities necessary to produce a specific product, which is an improvement of all links along the IVC (Sinha and Matharu 2019). However, it mainly focuses on the waste in the supply chain and the general management in the enterprise. This study focuses on service and the construction of service value model. Therefore, lean management is not very closely related to this study.

There are also some researches oriented to IVC that analyzed the value chain from different perspectives, such as cost, resources, influencing factors, etc. For example, from the perspective of cost management, value chain analysis is a strategic approach (Donelan and Kaplan 1998). Two generic strategies for achieving a competitive advantage are price leadership and differentiation. Whichever strategy is selected, value chain analysis can help the company focus on its chosen strategic plan and thus, achieve a competitive advantage. And some studies focus on specific industries, using value chain analysis to solve problems such as structure optimization, partner selection and so on. For example, for the logistics industry, a value chain analysis method for smart logistics based on fuzzy theory is present to help to analyze and construct multi-objective model of smart logistics, and multipurpose optimal theory is used to achieve the maximum value under constraints (Pan 2012). For the purpose of reducing Bull-whip effect of the fourth party logistics (4PL), Zheng et al. (2010) propose the value chain framework, introduce the value chain analysis method for manufacture, and design a business process operation model for 4PL value chain integration simulation. In order to best serve

customers and achieve business excellence, a multi-criteria decision-making approach is proposed to evaluate e-logistics-based strategic alliance partners and a fuzzy logic approach is adopted for the selection decision (Büyüközkan et al. 2008).

2.5 Conclusion

Service system theory provides related concepts and models in service domain. Service is described by value model and function model. To support the implementation of services, there must be corresponding service systems to compose various service elements together. Service process is the actual procedure, mechanism and operation flow of service provision.

The idea of process mining is to discover, monitor and improve actual business processes by extracting knowledge from event logs. There are many different process mining algorithms. And in order to assist users to realize process mining, many process mining tools have been developed. Therefore, process mining theory, the related algorithms and tools can provide strong support for the mining of service process models.

Although the value chain theory optimizes the activities of enterprises from the perspective of economics, it also can be used in the field of service. IVC can help to analyze the value creation activities of each phase in the industrial chain and the core factors that affect the value creation from the overall point of view. The conceptual model and value matrix model of IVC are similar to service process model. The idea of value chain analysis can provide more perspectives for service value optimization.

From the state of the art review, it can be concluded:

- The existing process mining approaches don't deal efficiently with the value co-creation process involving various actors in the service system. Furthermore, the relevant elements of time and resources were not well integrated in the generated process models.
- The existing process mining techniques are mainly focused on the product manufacturing, with less research on service systems. They were not developed for mining service value creation and delivery processes. There is a necessity to develop an approach that allows to mine service value model from the event log taking into account for each activity in the service process, its actors and the value created by the actors.
- The existing approaches dealing with value chain are oriented to product manufacturing in which allocation of resource to maximize efficiency and minimize cost. While in a customer-oriented service process, different resource allocations may result in different ways to meet customer's needs and satisfaction. This issue

is a very important to build a service value model but it not well considered in existing theories and approaches such as IVC and so on.

CHAPTER 3

Construction Framework of Service Value Model

3.1 Introduction

Based on the above literature review, this chapter puts forward the construction framework of service value model in the context of manufacturing. Driven by the raw data and an event log of service activities and processes in the real world, stored in the information system, the method uses process mining techniques and combines domain knowledge to describe the construction steps of the service value model at the conceptual level. We focus on the specific processes and activities in the service, and mainly consider the value creation of the activity. The model proposed in this chapter aims to reflect how service actors co-create value in the actual execution of service processes, and to help service actors achieve their value goals.

3.2 Service Process and Service Entity

3.2.1 Service Process and Activity

Service systems use processes and activities that differ from a business process. Processes and activities cover a full range of situations that might involve highly structured workflows and flexible processes, the sequence and content of which depend on the skills, experience, and judgment of the primary actors (Alter 2008). As mentioned in Section 2.2.4, SLA is the guarantee of the service provider to provide service for customers. Under the constraint of the SLA, the candidate primitive services in the repository for each service can be divided into different service sets, and the service process and activities matching the requirements of the customer can be constructed quickly. Customer requirements are the driving force of a service system, and services, including processes and activities, are dynamically constructed. As shown in Figure 3.1, for customer service requirements with the same function and different SLAs, the provider will select different primitive services from the service repository to form different service processes and activities. Usually, a primitive service is used to complete an activity in the service process, and there is a one-to-one relationship between them.

When a process contains a sub-process, the sub-process can be regarded as an activity of the parent process, and the service used to implement the sub-process may be a primitive service or complex service. Since the structure of the parent process and sub-process are consistent, we can ignore the sub-process and treat it as an activity. For example, if a customer wants to send a package to a destination, taking the postage and delivery time as SLA parameters, the delivery time will be longer if the price is lower. Then, for a low postage package, a vehicle should be used to transfer it from one station to another station until it reaches the destination; for the package with high postage, air transfer should be used to reduce the delivery time. From the perspective of the customer, what he wants is a complete service, and he does not care about the service process and activities. Therefore, if the customer pays \$5, the package should arrive at the destination within 5 days; if the customer pays \$10, then the package should arrive at the destination within 3 days. From the perspective of the service provider, they need to understand the whole service process and activities, and the appropriate primitive services should be selected to complete the corresponding activities or tasks, which may be the provider's own or outsourced to other participants. So in order to deliver the customer's package to the destination, the service provider may use a logistics company's vehicle to transport the package from one place to another until it arrives at the destination; it may also rent space on an aircraft flight to transport the package to the destination.

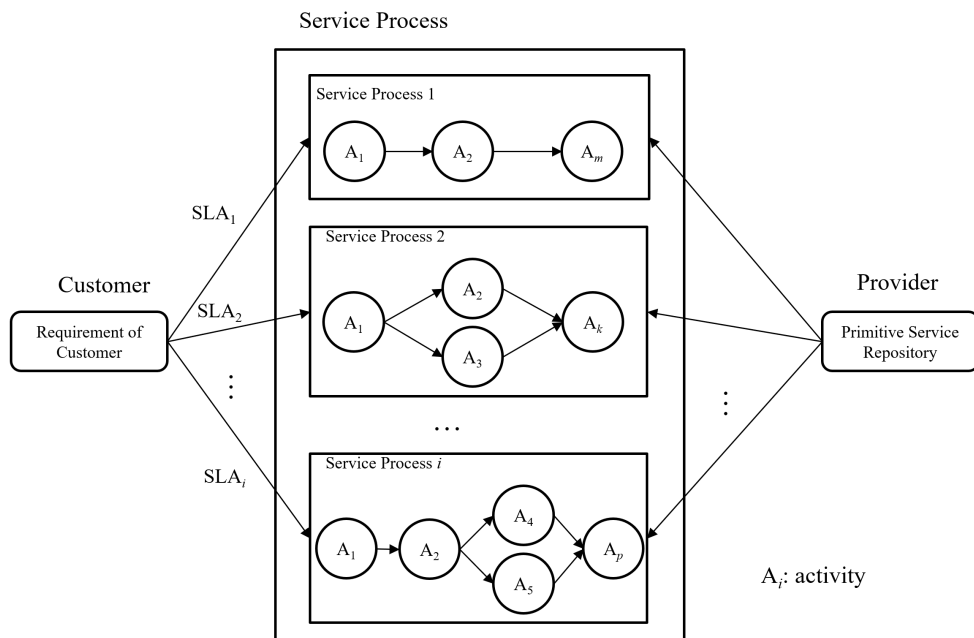


Figure 3.1 SLA and service process.

To meet the need of the customer, each service needs to combine different primitive services, which represent specific activities or tasks in the service process. Therefore,

a service process is composed of different activities, which are executed to complete the whole service. In a service process, each activity needs to be fulfilled by at least one actor, including customer, service provider, and other participants. By completing these activities together, the actors (co-)create value, exchange value, and meet their own value expectations.

Based on the above description, in this thesis, some concepts related to the service value model are defined as follows:

Definition 3.1 Business process is a series of activities completed by people, organizations, or automated resources to achieve specific goal.

Definition 3.2 Service process is a series of activities completed by people, organizations, or automated resources to provide specific service to the target customer.

The similarity between service process and business process is that there are not only strict sequence restrictions among activities, but also the contents, methods, and responsibilities of activities must be clearly arranged and defined, so that the activities in process can be transferred between different actors. An activity in a business process, and a service process, can represent a sub-process, and the process can be nested. Business process is generally used to describe the collaborative production process of products, while service process describes how to deliver services to customers, to meet their requirements. For example, the production process of air conditioners is a business process. Multiple air conditioners are being assembled on the air conditioner production line at the same time. Each step of the process is standardized, the materials used are the same, and the goal is to produce high-quality products that meet the specifications; while the air conditioner repair process is a service process, which is triggered by the repair request initiated by the customer, and the service process activities are executed according to specific customer needs to complete the service delivery (troubleshooting). Usually, the customer is not involved in the manufacturing process of the air conditioner; while the customer may be involved in the repair process of the air conditioner, such as, when replacing the air conditioner fixing bracket, the engineer will ask the customer which bracket he needs to use: iron or stainless steel? The result of the customer's answer will determine the part to be used; a customer who rents a house will use a cheap iron bracket, while a customer who owns the house will use a more expensive stainless steel one. From this perspective, business process is product-oriented, and service process is customer-oriented.

With the gradual evolution of servitization and development of cloud computing, the differentiation between products and services is increasingly blurring (Vargo and Lusch 2004). Lusch et al. (2010) argued that products can be seen as service distribution or provisioning mechanisms. Based on Banerjee's argument of "everything as a service" (Banerjee et al. 2011), some studies (Lynn et al. 2014, Woitsch and Utz 2015,

Gzik 2020) consider business process as a service in the context of business process management and cloud computing. We further argue that if the business process is customer-oriented, a business process can be a service process. For example, when a manufacturing company does not have orders, it can offer its manufacturing processes as a service to other partner companies, which increases the utilisation of resources and benefits both the service and the served parties, in the context of cloud manufacturing (Zhan et al. 2011).

Therefore, for non-customer-oriented business processes, based on the MDA method mentioned in (Zacharewicz et al. 2017), we can transform a business process into a service process. When constructing a service process model, we also need to consider the impact of some characteristics of the service domain on service process. In the service domain, the service ecosystem has formed its unique service domain characteristics in its long-term development and evolution process; mainly including priori, correlation, and similarity (Xu, Liu, Wang, Min, Liu and Wang 2015).

3.2.2 Entities in Service

In the service system, the activities in the service process are the carriers of value, and all the actors who participate in the completion of the activities create value. As shown in Figure 3.2, these entities involved in value creation can be divided into three types: customer, service provider and its partners.

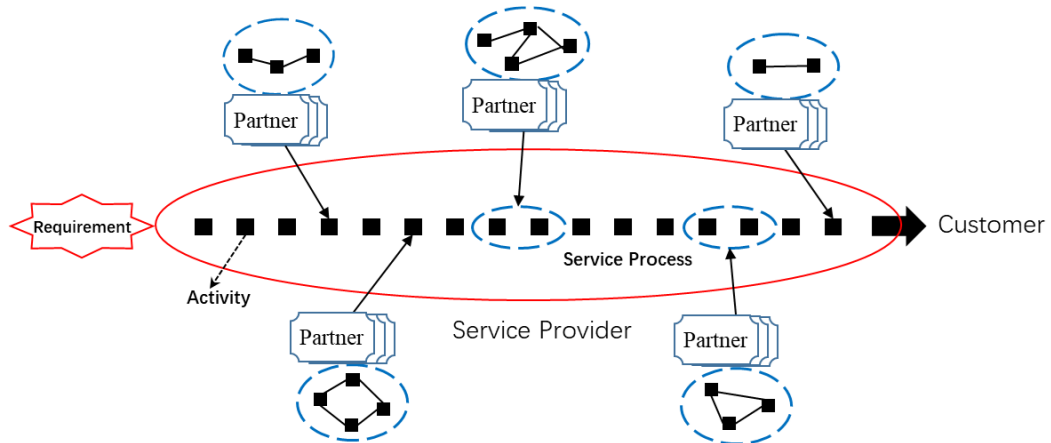


Figure 3.2 Entities and service process.

(1) **Customer.** The customer refers to the consumer individuals or organizations in the service system, the proposer of the service demand, and the ultimate realization of the value. Service demand is the expectation and goal that customers expect to achieve, and the realization of value includes not only tangible products, but also customer perception and situational experience. Customers are not just waiting for service delivery after putting forward service requirements, but constantly interact with the service system elements in the service process to better realize value creation. At the same time,

the behaviour of customers will have an impact on the surrounding people or organizations.

(2) Service Provider. The service provider is the provider of product services in the service system, and it is the core enterprise to complete the service process and meet customer service needs. It controls the whole process of product service life cycle, such as customer interaction, product design, production and manufacturing, transportation and transfer, use and maintenance, etc. It can connect many partners, and has the ability to integrate the primitive services, capabilities and resources of itself and its partners to form a complete service for customer. The provider can put forward value proposition to market or customers, and is the main creator of value, but it can't create value alone.

(3) Partners. The partners, or service enablers, are the organisations, systems or individuals involved that assist service providers to complete the service together, including suppliers, logistics service providers, maintenance service providers, etc. They have specialized production or service capabilities and can provide primitive services and corresponding resources to complete specific links in the service process. The relationship between partners and service providers is not fixed. Generally, service providers will make dynamic selection during service process execution according to the performance or availability of partners. On the other hand, partners can also participate in different service systems according to their own actual situation and value expectations. In a service system, the service provider's partners can also be considered as enablers.

The identities of customers, service providers and partners can be changed, especially for enterprises. In one service system, it is a customer, while in another, it may become a service provider or partner. Similarly, service providers and partners may play different roles in different service systems.

3.3 Value in the Service

Value is the goal pursued by both sides, the service demander and service provider. Both sides create value through working together in the service process to meet their respective value expectations. Generally, different service actors have different value expectations.

3.3.1 Dimension of value

Owing to different concerns, different people may define value from different perspectives. Allee (2008) argued that there are two types of value, tangible and intangible value. Therefore, we further argue that value is multidimensional, and that the value creation and value expectation of each actor may only contain some of these dimensions. For example, value can be defined from the perspective of economic benefits,

product acquisition, resource used, and customer experience, etc. In this thesis, in order to distinguish between the value creation of different actors in the service process and service activities, and to summarise the previous literature on the subject, we define service value in terms of three dimensions: time and space, profit, and experience, as shown in Figure 3.3

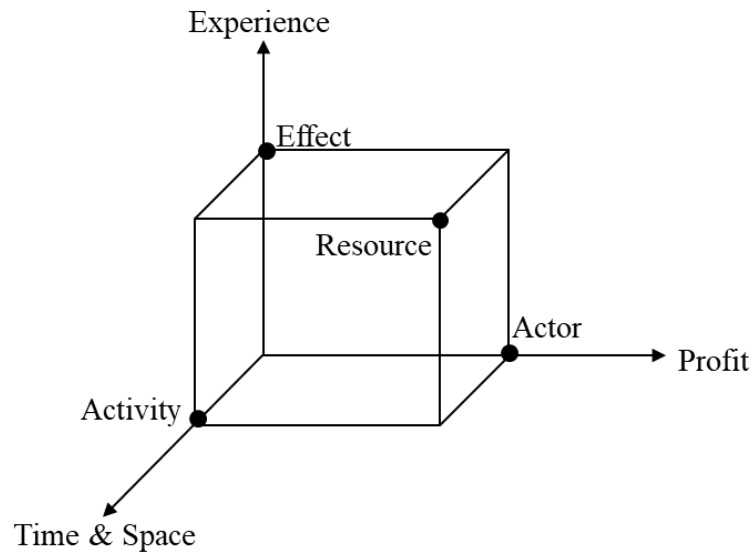


Figure 3.3 Dimensions of value.

The time and space dimension refers to the requirements of service value creation in time and space, which can be realized only by meeting the requirements. It is closely related to the activities in the service process. For example, in a logistics service process, a certain amount of time is spent to transfer a package from one place to another; in a product manufacturing process, it takes a certain amount of time to turn some materials into parts. The time and space dimension reflects the time consumption, and the change of location or status, in activities. The profit dimension refers to the benefits obtained by actors in the service activity, including economic benefits, physical products, information, etc. It is related to the service actors because each actor in the service process, including the customer, benefits from it. For example, in logistics service, the customer's package arrives at the destination, the logistics company gets the freight, and the truck driver gets the reward; in product service, the customer gets the product he wants to buy, and the manufacturer and the material supplier gain the sales income. The experience dimension refers to the intangible value or impact of the service process or service results, including knowledge, corporate reputation, social impact, customer satisfaction, experience, and skills, etc. The experience dimension is related to the effects of the service process or service result. For example, in a logistics service, without considering the storage of package, as the logistics company delivered the package to the destination earlier than expected, customer usually improve his service satisfaction

because he can get the goods he needs faster, and the reputation of the logistics company can also be improved. In addition, the cube symbolizes three dimensions of the value, and the creation of value is inseparable from the use of resources in the process of service. These resources can be people, vehicles, tools, materials, spare parts, products, data, etc.

3.3.2 Granularity of Value

As we mentioned previously, services are customer-oriented. The service process is implemented around the requirements of customers. The process of the provider providing services to the customer is shown in Figure 3.4. The activities in the service process may be parallels, loops, etc., which will not be considered here, but only the process of service completion as it progresses over time towards the customer. We can find that the value of service has a different granularity. Value in the service economy is driven and determined by the customer (Basole and Rouse 2008). From the perspective of the whole service, the entire service process is customer-oriented, so it is the maximal granular value. In the service process, the activity for completing every specific task will create value, which is the minimum granularity of value. Some activities are fulfilled by the service provider itself, and some activities are outsourced to other participants. As shown in Figure 3.4, six activities are outsourced to other participants, and the number of activities completed by each participant may be different. How participants complete these activities is transparent to the service provider. Service providers do not need to know how, but the participants themselves should know. These activities can be regarded as sub-processes in the service process. For example, a service provider wants to transport a package from one place to another. It can outsource the activity to a transportation company. It does not need to consider how the transportation company completes the activity. Then, we can take the value generated by activities which are completed by participants as the medium granularity value. Therefore, there are three kinds of granularity value in the service, that of large granularity value for the customer, medium granularity value for the participant, and small granularity value for the activity. From the perspective of the whole service, the value granularity of the service provider is the same as that of the customer. There is a composition or decomposition relationship between values of different granularity. The value of customers can be composed of the value of each activity, and the value of participants can be composed of the value of the activities they completed.

In the actual service process, an activity may be completed by multiple actors, and each actor completes different parts of the activity. Due to the complexity of some activities, a single actor is unable to complete them. For example, in the air conditioner installation service, from the user's point of view, two engineers are needed to complete

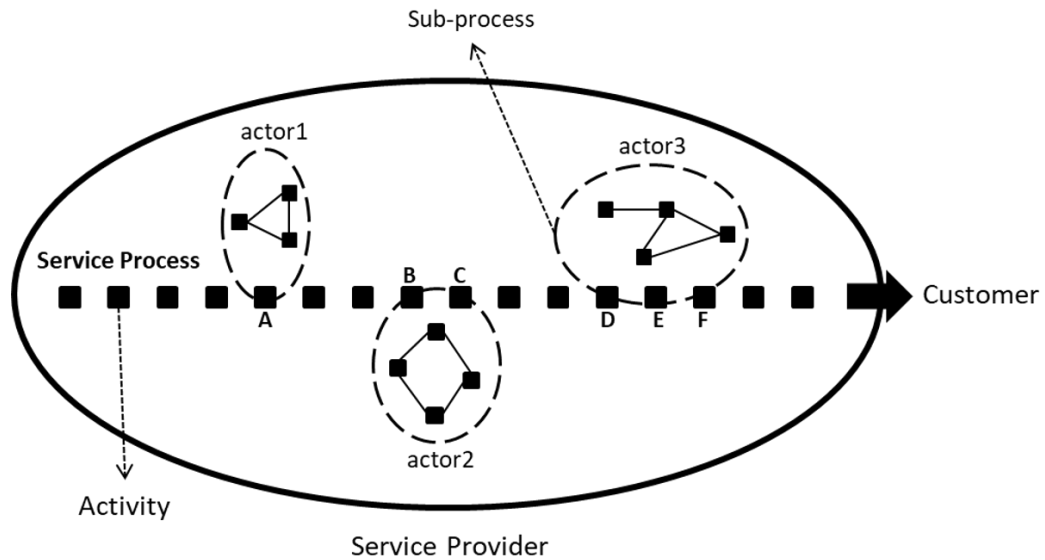


Figure 3.4 Granularity of value.

the external unit installation; in the air conditioner maintenance service, when the spare parts need to be replaced, the spare parts provider and engineer need to participate in the activity together.

3.3.3 Value of Activity

Activity is the basic unit of the service process, which completes the specific task in the service. Activity is also the basic unit of value creation in the service. If an activity does not generate value, then it does not need to exist in the service process. As shown in Figure 3.5(a), from the perspective of only one actor in the service, each activity has an input value and an output value. v_{in} represents the input value of the activity, and v_{out} represents the output value of the activity. In normal circumstances, the output value of an activity should be greater than the input. From an economic perspective, the input value is the cost of completing the activity, and the output value should be the cost plus the added value created by completing the activity. As mentioned in Section 3.2.1, the value of activity may be tangible, intangible, or both. Therefore, we can use the time and space, profit, and experience dimensions to express each specific value, whether it is input value or output value.

An activity can be completed by a single actor, such as one of the service provider, customer, and other participants, or it can be done by multiple actors. For the same activity, its input value and output value may be not the same in different situations. That is to say, the value of v_{in} and v_{out} will be different when the performers of an activity are different. For example, if a product is sold by a manufacturer or by a retailer, the cost will be different, and the price of the sale may be different. Therefore, the value creation of activities is inseparable from the actors. In essence, it is the actor

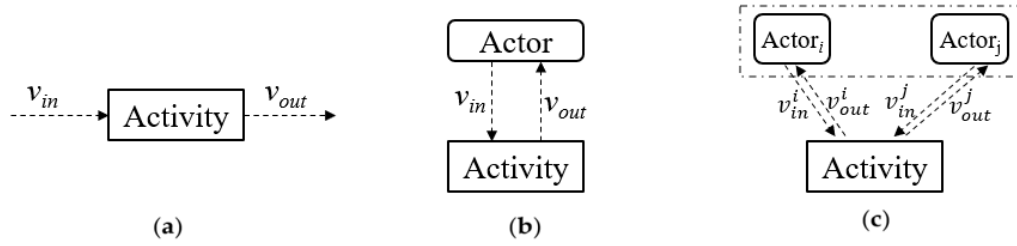


Figure 3.5 Value of activity.

who achieves value creation in the process of performing the activity. As shown in the Figure 3.5(b), each actor has an input value and an output value on the activity they participate in. If multiple actors participate in the same activity, each actor creates their own value through the activity. As shown in Figure 3.5(c), $Actor_i$ and $Actor_j$ work together to complete the activity, the input and output values of $Actor_i$ are v_{in}^i and v_{out}^i , and those of $Actor_j$ are v_{in}^j and v_{out}^j . For example, there are two actors, the manufacturer and the customer, in the activity of selling products directly by a manufacturer. For the manufacturer, the input value of the activity is the product, the output value is the money paid by the customer; and for the customer, the input value is the money, the output value is the product. Of course, both actors involved in the activity need a certain amount of time to complete it. These values are the only tangible values that we can observe. Since the service provider can improve its reputation through the product quality, and the customers get the products, they also get spiritual satisfaction at the same time. Hereby, the output value of the manufacturer may also include corporate reputation, and the output value of customer should also include the satisfaction of the requirement.

In an activity, both input and output values can be described in terms of the three dimensions of value from the previous section. Thus, the input value v_{in}^i can be expressed as $v_{in}^i = \{v_{its}^i, v_{ipro}^i, v_{iexp}^i\}$, and the output value v_{out}^i can be expressed as $v_{out}^i = \{v_{ots}^i, v_{opro}^i, v_{oexp}^i\}$. Then, we can determine the corresponding value indicators from each of the dimensions, and for those that can be quantified the corresponding arithmetic operations can also be performed. At the same time, the value of one activity is influenced by others. For example, from a time perspective, in a sequentially executed chain of activities, there is no way to start a later activity without the previous one completing, and the time of the entire service (process) varies due to the timing of the activities. Also changes in the value of the time dimension can cause changes in the value of other dimensions, for example the length of time taken to repair service can affect customer satisfaction.

3.3.4 Value of Service Process

The service process is composed of activities in a certain order to fulfill the requirements of customer. Then, based on activity value, we can get the value of the service process. The value of a service process is also described using three dimensions and can be expressed as $v_{sp} = \{v_{ts}^{sp}, v_{pro}^{sp}, v_{iexp}^{sp}\}$. The value of each dimension of a service process is not obtained by adding up the value of each dimension of all the activities in the process, as some value indicators can be calculated and others cannot be mathematically manipulated. For example, the time to complete the service process can be obtained by adding up the time to complete each activity, while the knowledge and skills acquired by the actors are related to the service entity itself and cannot be calculated.

In addition, service systems are complex adaptive systems, and they are dynamic and open (Aalst et al. 2011). As such, the service processes are dynamic, and the activities in the service process are also dynamic. In the current market competition environment, the division of labor and cooperation is very common. Since the customer wants a complete service, the service provider needs to integrate the primitive services of other actors into a complex service to meet the needs of the customer. In other words, under the coordination of the service provider, different actors will participate in the completion of different activities, and each activity may have multiple actors competing for participation. Therefore, the customer-oriented service process needs to be completed by multiple actors. As shown in Figure 3.6, there are five activities in the service process. An activity in the process can be executed by different actors, and an actor can also participate in different activities. For example, in Figure 3.6, on activity *A*, there are three actors involved; the service provider or *Actor*₃ can complete the activity *C*, activity *D*, and activity *E*, *Actor*₁ is in competition with *Actor*₂ on activity *B*, and *Actor*₁ can cover activity *B* and activity *C*. We only show the three participants in the figure, and of course there are others. We just ignore them for the convenience of the figure display and introductory purposes. Since the value of the activity will be different when the performer of the activity is different, the value of the service process also will be different. For example, in an air conditioner repair service, engineers with different levels of proficiency in that type of repair service take different amounts of time to complete the repair activity, with Engineer A taking one hour and Engineer B taking two hours, then the value in the time and space dimension is different, leading to a different value for the entire service process. Moreover, depending on the service variant, the service value delivered by one activity might be different, as in the case of logistics services described in section 3.2.1, and the value of the service process may also be different. Hereby, the service provider can dynamically adjust the service process, according to the customer's value expectation, to meet the requirements.

Another important feature of the service process can be found in Figure 3.6, which

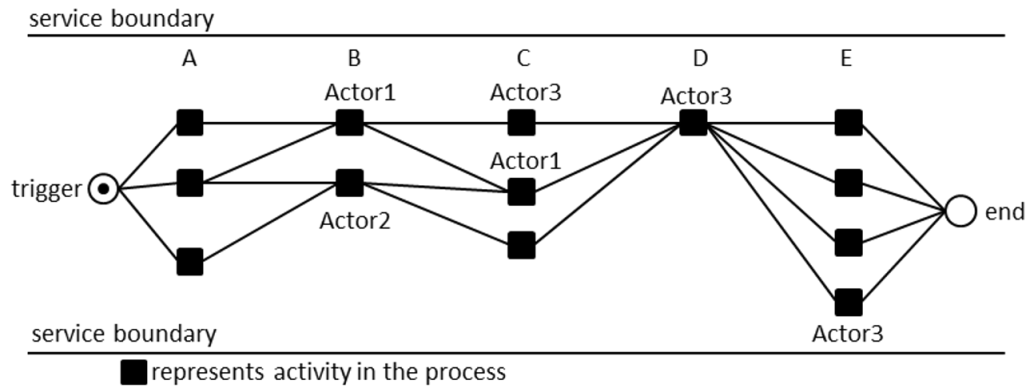


Figure 3.6 Service process and activity.

is that the service process is triggered by the customer and ends with the delivery of the service to the customer. This is one of the important differences between service process and business process, because the starting point of service is to meet the requirements of customers. It is also possible that the service provider needs to do some aftercare work, after the service is delivered to the customer, such as archiving the service-related information.

3.4 Service Value Indicators from Event Log

3.4.1 Value Indicators

Value indicators is a group of elements that are used to point to the specific value on the related scale. In the traditional commodity economy, the value indicators are a kind of total index to measure social wealth or labor achievements with money as the value measure, such as commodity sales, total industrial output value, profit, debt, etc. However, with the development of servitization and the expansion of value category, value indicators have been constantly expanded and enriched. Anderson et al. (1992) believe that when a product is purchased, all costs are perceptible to the customer, and cost is a part of service value. These costs include not only money costs, but also labor, time, logistics and other costs. Haksever et al. (2004) made clear the customer attributes of service value and added time factors and non-economic factors into the service value. He argued that service value not only includes economic value in the traditional sense, but also reflects the non-economic value of service. Basole and Rouse (2008) considered that products are tools for carrying out and delivering services, and service value is affected by political, economic, social, technological and other factors. Shamah (2012) explains the knowledge sharing among stakeholders and explains the benefits of knowledge sharing to the value co-creation of the whole SVC. From the perspective of PSS, Liang et al. (2015) divided the value index into environmental value, economic value,

functional value and emotional value, and considered that the potential variables related to service value include enterprise contact and customer contact, reputation, profit, efforts for service, etc.

3.4.2 General Value Indicators

General knowledge refers to the common understanding among people in a social environment. The general value indicators are the common characteristics of the value created by the service entities in the product service system, not affected by the type of products and services, and can be found based on general knowledge. These indicators mainly include time, space (status), deliverable, price, cost, etc. Time is the most basic indicator, which reflects the service entity to complete the service process or activity must consume a certain amount of time, and also reflects the timeliness of service performance. Any service demand from customer needs time to respond and complete. In the service process, with the completion of activities, the service will inevitably change in space or status, such as the change of package position in logistics service and the update of product state in manufacturing service. Deliverable is a combination of products and services to meet the needs of users. In the manufacturing industry, physical products, as an important part of product service system, are usually included in the deliverable. Price is an economic indicator of value exchange between service demander and service provider. Both products and services need to be represented by price when they are traded. Cost is the cost of each entity participating in the service in order to complete the task, which can be reflected as its input value. In fact, with the change of social form and times, the definition of general knowledge will also change, which will affect the understanding of general value.

3.4.3 Domain-related Value Indicators

Domain knowledge refers to a set of interrelated knowledge, which is often associated with the understanding, ability and information of a specific topic, profession or activity. Domain-related value indicators are the value created by entities in the product service system and the characteristics related to products and services. They can be found by using domain knowledge. In different fields, the value indicators of product service system are also different. For example, in the service system of household appliances, both refrigerators and air conditioners have refrigeration energy efficiency ratio (EER), but air conditioners also have coefficient of performance (COP), so the service value indicators for refrigerators is different from that for air conditioners. In the manufacturing product service system, domain-related value indicators mainly include characteristics of the product itself, the conformity degree of product quality, the standardization degree of service quality and the corresponding risks. Product charac-

teristics mainly include product brand, product model, product type, product parts, etc. related to the product itself. The conformity of product quality is mainly reflected in whether the product parameters are consistent with the claims of the provider, such as whether the EER and COP of the air conditioner mentioned above meet the industry or national standards, and whether the actual parameters are consistent with the nominal ones. The standard degree of service quality reflects whether the service provided by the provider meets the standard specifications or agreements of the service. For example, the installation specification and maintenance specification of air conditioning should be consistent with the corresponding service specification or standard. Quality is the basic requirement for products and services, and all stakeholders in the product service system will have corresponding standards or requirements for quality. In addition, affected by the characteristics of products and services, there will be different service types and different service complexity in the product service system, which will also affect the value indicators related to the domain. There may be risks in the process of service, such as cooperation risk, technology risk, shortage risk, etc. In the market economy, there is no service activity without any risk. As risks are not only related to the service process but are also influenced by other external factors that cannot be included and reflected in the event log, they are not explored in depth in this thesis.

3.4.4 Entity-related Value Indicators

As the customer is the proposer of service demand and the final determinant of service value, it is necessary to first analyze the value indicators related to customer, and then determine the value indicators of service provider on this basis, and then determine the value indicators of partners participating in the service according to the principle of profit allocation. Service provider and service demander will consider the actual situation of themselves and each other in the process of participating in the service, and these factors will have an impact on the service value.

(1) customer-related value indicators

For customers, the value associated with them comes mainly from the satisfaction of their requirements, the use of the product and the experience of the service. The degree of satisfaction of demand indicates the difference between the actual situation and expectation. The better degree of satisfaction, the higher the value customers get, and vice versa. The friendliness of the product indicates whether the actual situation is consistent with the using expectation, which is closely related to the scene where the customer uses the product, such as the easy operation and fast cooling characteristics of the air conditioner. Service experience is mainly reflected in the standardization of service and the contact between customers and service personnel. Usually, the measurement of these values can be obtained through the evaluation of the corresponding

indicators of customers, such as using the Likert Scale to score the attitude of service personnel and the timeliness of service.

(2) service provider-related value indicators

For service providers, reputation, customer evaluation, knowledge sharing, service coordination ability and service effort are their main value indicators. Brand and reputation need to be obtained by long-term operation. When the brand and reputation of service provider have certain influence, it is easier to get the good feeling of target customers and bring considerable market value. Customer evaluation is an important factor to determine the actual value of the service provider, because the customer is the value determiner of the whole SVC. Knowledge sharing, service coordination ability and service effort are mainly used to measure the contribution of service providers to the service process. For example, service providers share knowledge to partners through training, coordinate the whole service process, ensure the timeliness and quality of services, and make every effort to meet the needs of customers.

(3) partner-related value indicators

The relevant value indicators of partners mainly include rank or level, customer evaluation, service performance and service effort, etc. Partners with high rank or high level will be preferentially selected by service providers when they compete with other participants to complete the activities. Rank and level also need a long time to accumulate. Some service providers will conduct relevant assessment and certification for partners and issue corresponding certificates. Part of the customer's evaluation is for the partner, and the implementation of the partner will have an impact on the whole service, such as the evaluation of logistics distribution in the air conditioner installation service. Service performance not only includes the efficiency of services, such as the time consumed to complete services, but also includes the rework rate, which refers to the probability that partners repeat activities when providing services, and the probability that other participants need to replace them to provide services to customers. Service effort is used to measure partners' positive or negative attitude towards solving problems in the service process.

3.4.5 Mapping between Value Indicators and Event Attributes

Based on the above analysis, we can describe the service value indicator system from the perspectives of general knowledge, domain knowledge and value creation entity, as shown in left side of Figure 3.7. Service value indicators are composed of general value indicators from general knowledge, domain-related value indicators from domain knowledge and entity-related value indicators from value creation entities. The domain-related value indicators mainly include quality, service type, service complexity, service specification and risk. Service value creation entities are divided into customers, service

providers and partners. Customer-related value indicators include demand satisfaction, usability of product and service experience; service provider-related value indicators include coordination ability, service effort, service level, knowledge sharing, and customer evaluation; partner-related value indicators include customer evaluation, service performance, service effort and rank/level. In the actual service process, each activity or entity cannot have all these value indicators, which need to be determined according to the actual situation, and these value indicators will be affected by the service environment. For example, rainy day will affect the consumption time of outdoor maintenance activity. These external factors will not be considered in this thesis.

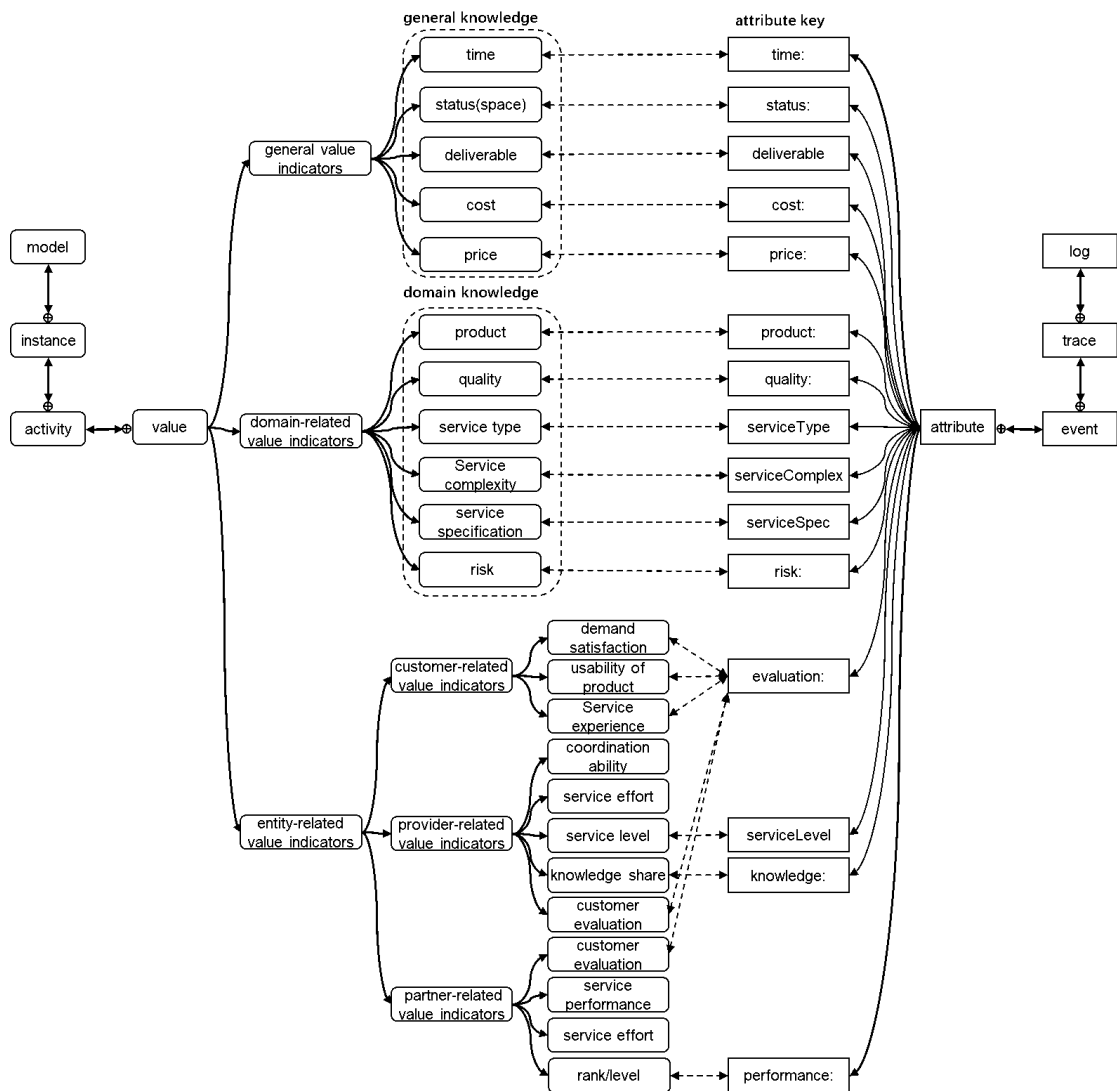


Figure 3.7 Mapping between value indicators and event attributes.

Each attribute represents the item related to the Event through a key, and the attribute value is the specific value of the item. The attributes in the Event are not necessarily related items used to represent the value created by the service entity, but may also be some characteristics of the event itself. For example, the attribute with the

key “concept: name” is used to represent the name of the Event. In order to map the value indicators to the attributes of the event, prefixes for the different attribute keys in the Event need to be predefined. For example, a time indicator is mapped to an attribute with the key begins with “time:”; a price indicator is mapped to an attribute with the key begins with “price:”. Figure 3.7 shows the mapping relationship between the value indicators described above and attributes of the events, and the attribute key is the core to determine this relationship. Some value indicators correspond to multiple attribute keys, and some value indicators correspond to attribute keys one by one. In other words, some of these value indicators can be directly mapped to the attributes of Event in the log, while some cannot be directly mapped. They may be obtained through relevant calculations. For example, the time consumption of an Event is obtained by subtracting the corresponding Event end time from the Event occurrence time; The average time consumption of an Event can be obtained by calculating the total completion time of each Event instance and dividing it by the number of event instances, i.e. $averagetime = SUM(timevalue)/N$. An Event generally contains multiple attributes. According to the actual scenario or activity, it includes “time:timestamp” to represent the start or end of an event, “time:appointment” to represent the time reservation of an event or activity, and “time:contact” to represent the contact time between both entities, etc. While the service type indicator directly corresponds to the attribute whose key is “ServiceType”. In addition, in Figure 3.7, value indicators that do not have a mapping relationship with event attributes cannot be obtained directly, such as coordination ability indicator of the service providers. This indicator is used to measure the ability of service providers to coordinate other service entities to complete services in the service process, reflecting the fluency of the service process. It can generally be expressed in the completion time of the whole service. The shorter the completion time of the same service, the stronger the coordination ability of service provider. Another problem is Quantification of the intangible values. Here we use Likert summated rating scale to represent some of the experience values. For example, the evaluation of the service, indicators such as timeliness of service, service attitude and usability are used to rate the service, with each indicator being scored from 0 to 5 and the customer scoring each indicator based on their experience. Knowledge sharing is commonly described in air conditioning repair using two attributes, one is the knowledge content shared, such as a video of the replacement process for a part; the other is the rating of the usefulness of that content by the engineer using it. Rank for a partner, such as the engineer level can be classified as junior, intermediate, senior, etc. There are two ways of upgrading: firstly, training and skills tests organised by the service provider; and secondly, the success rate of repairs and the number of repairs accumulated. Likewise for organisations that work together, there is a corresponding ranking approach to evaluation.

In practice, an Event cannot contain the attributes corresponding to all the value indicators, that is, the value created by each activity is different. When mapping value metrics, they can be attributed to different value dimensions as in Figure 3.3 based on the characteristics of the value. For example, a time indicator can be attributed to the time and space dimension; a certain error of a certain product type that an air conditioning repair engineer has fixed can be attributed to the engineer's experience dimension.

In addition, considering value and performance, we argue that the systems for measuring performance and value will be the same and the data points that they contain will be the same. Take these two points of view that show the different thinking depending on the extent to which the firm is focused on performance or focused on value. The performance-focused companies tend to be more inward-looking, focusing on the measurement of people, teams, practices and office performance. The value-focused companies are generally more concerned with perception and feedback, focusing on the value that customers receive from the services provided. This thesis focuses on not just one enterprise, but more on the entire industry value chain. Therefore, it is mainly to understand and analyze the service system from the perspective of value.

3.5 Construction Framework of Service Value Model

In general, we can build the service process model by observing the service process and activities in the service system, and by combining them with domain knowledge, manually or using modeling tools. However, the service process obtained in this way is relatively rough and may be different from the actual implementation of the service process. The observation is not accurate enough, and many hidden details may not be obtained through observation.

3.5.1 Modeling based on Process Mining

To describe the model more accurately, we use a method based on process mining to build the service value model. Normally, many raw data and event logs related to services are stored in the information systems. If there are enough traces in the event log, the process and activities obtained by process mining will cover a full range of situations. As shown in the dotted box in Figure 3.8, there are two ways to build service process using process mining, based on raw data and event logs: one is from the business process model (BPM) to the service process model (SPM); the other is from the enriched event log to the SPM.

(1) From BPM to SPM

The raw data and event logs stored in the information system are the basis for building models. As mentioned in Section 2.3, the event logs need to be pre-processed and

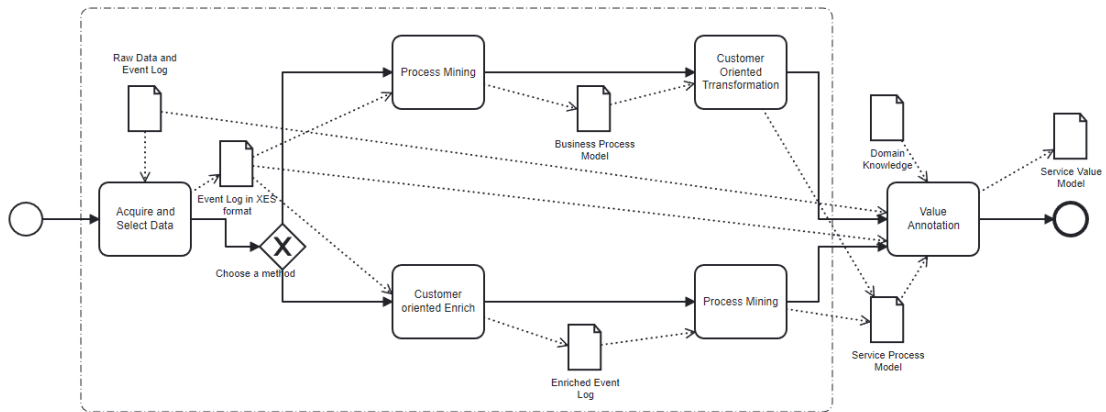


Figure 3.8 Modeling framework based on process mining.

saved in XES format. By using the corresponding algorithm in process mining, such as the HM or IM algorithm, we can get the business process model (control flow model), represented by Petri net. Since a business process is not customer-oriented, we need to transform it into a service process. In this way, we first get the business process model and then transform it into a service process model. In the transformation of the models, domain knowledge and domain characteristics should be considered.

(2) From enriched event log to SPM

In this way, since the raw data and event logs may not contain the behavior information of customers in the event or activity, we also need to pre-process them, and supplement the customer-oriented information with domain knowledge and domain characteristics. Hereby, we get the formatted enriched event log. Then we can directly extract the service process model by mining the log. Since the model we get is already customer-oriented, it is a service process model, and it does not need to be transformed again.

The difficulty with these two approaches to build service process models lies in the transformation of the model and in the handling of event log. Model conversion requires a mastery of different models, the establishment of corresponding conversion rules and the corresponding domain expertise, which is more difficult. In practice, if an organisation has a well-developed information system and the service processes are standardised and strictly enforced, then the log information will be rich in content. Therefore, we prefer to use the second approach.

In this section, we just consider process mining techniques as a necessary tool to help in building a service process model. Many scholars also have done a lot of research on how to extract the process model from the event logs, through process mining, which is mentioned in Section 2.3. And we will describe in detail how to extract the service process model from the event logs in the next chapter.

(3) From SPM to service value model

The SPM is a transition model that prepares for the service value model. So, after getting the SPM, we need to construct the service value model based on it. As shown in Figure 3.8, combined with the additional value information captured in the raw data and event logs, and the knowledge of domain experts or human experience, the value annotation is attached to the service process and it is converted into a service value model. In fact, value is annotated onto the activities of the service process, because value is created through activities. In addition, domain knowledge is closely related to the field of service. For example, for the maintenance of mobile phones, customers usually send the mobile phones that need to be fixed to a designated maintenance point for repair; while for air conditioner repair, maintenance engineers are required to provide repair services on site. Although they are all maintenance services, there may be great differences in domain characteristics. Therefore, domain knowledge has an important impact on the value of activities.

Hereby, the service process value is based on SPM, and it not only focuses on the cooperation relationship among actors in the activities or process, but also emphasizes the value creation of actors in the activities. Value is the core of service process, and activities are the concrete steps that support the realization of value. In other words, satisfying the customer's value expectation is the core of the service value model, and service process is the basis to realize the value expectation. Our focus is on how to add value information to the activities in the service process.

3.5.2 General Form of the Service Value Model

Based on the above analysis, we can describe a general form of the service value model. To describe the service value model in a formal way, in this section we use Petri net as a tool to define the service value model. Petri net here is just a formal representation form of the service value chain, other formal description languages or tools can also be used for the description of the service value model, such as BPMN, etc. The business process model, service process model and service value model are defined as follows:

Definition 3.3 Business process model is a business petri net $N = (P, T, F)$, where

- P is a set of places;
- T is a set of transitions, representing activities;
- $F \subseteq (P \times T) \cup (T \times P)$ is the flow relation describing the arcs between places and transitions (and between transitions and places).

Definition 3.4 Service process model is a service petri net $SN = (P, T, F, t_s, t_e)$, where

- $P, T,$ and F are the same as in the business petri net N ;

- $t_s \in T$, t_s is the first activity of the service process and triggered by the customer;
- $t_e \in T$, t_e is the activity of service delivery completion, and the customer must be the actor of it.

Definition 3.5 Service value model is a service value annotated petri net $SVM = (P, T, F, a_s, a_e, A, V)$, where

- P, T, F, t_s , and t_e are the same as in the customer-oriented service petri net SN ;
- A is a set of actors, $\forall a \in A$, a can participate in at least one activity t_i ;
- V is a set of values, $V \subseteq (A \times T) \cup (T \times A)$ is the input value and output value between actors and activities.

As mentioned in Section 3.5.1, no matter which way is used to build the service process model, the related event log of the service and process mining algorithms are the necessary foundation. For the event log, if it has been saved in XES format, we can use it directly, otherwise, we need to process it according to the standard of the XES format, so as to prepare for the subsequent work. For the process mining algorithms, there are many algorithms for process mining, which have been mentioned in the relevant literature, and we will not repeat them here. Here we mainly use the algorithm, or its improved algorithms, for mining. To extract the actor(s) and the corresponding value of each activity from the raw data and event log, we need to add new functions to the existing algorithm tools or develop a new tool. At the same time, we need to combine domain knowledge or user experience, such as the apriority of service, that is, experience knowledge generated in over the long-term service process (Xu, Liu, Wang, Min, Liu and Wang 2015). Since the service process model is the abstraction of many concrete service processes, the value of each activity may be an average value, or a value range. Furthermore, as the model obtained by process mining is described as a Petri net, activities in the service process are mapped to the transitions in it. We need to add the actor(s), the input value, and output value of the activity to the corresponding transition, as shown in Figure 3.5(b) and (c).

As shown in Figure 3.9, it is an example of the general form of the service value model. There are five activities and six actors in the model. The first activity is A , which is completed by two actors, that of the *Customer* and $Actor_1$. We used a dashed box to enclose the *Customer* and $Actor_1$ to indicate that they are working together to complete the activity and are in a cooperative relationship. Since the customer's service requirement is the trigger of the process, we put the *Customer* in front of $Actor_1$. Both the *Customer* and $Actor_1$ have input and output value on the activity A . Activity B is completed only by $Actor_2$ and activity C is done by $Actor_3$ and $Actor_5$ working in

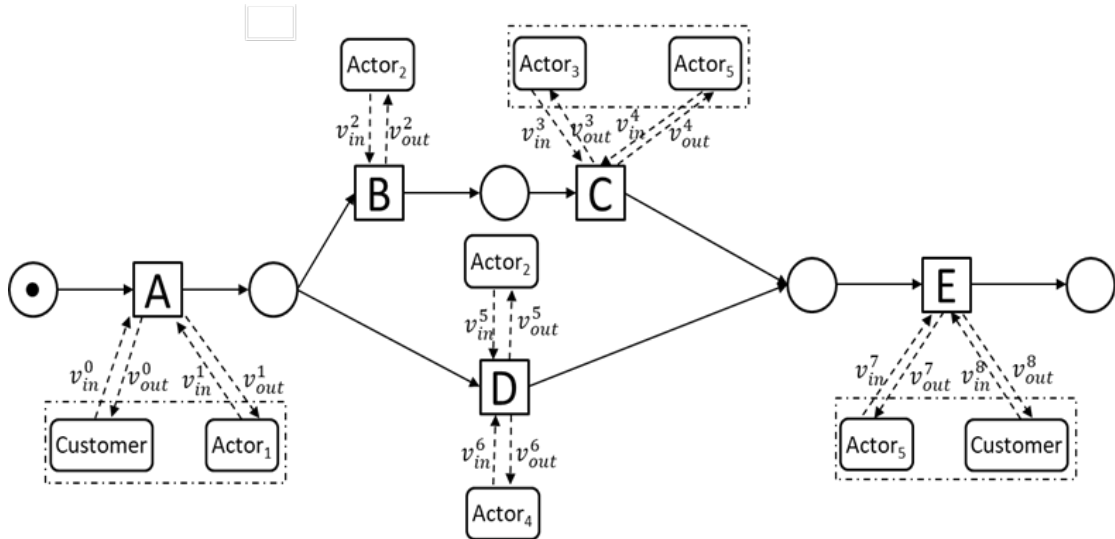


Figure 3.9 The general form of the service value model.

collaboration together. Activity D can be performed by *Actor₂* or *Actor₄*, which is not cooperative, but alternative or competitive. Finally, the service needs to be delivered to the customer, so activity *E* needs to be completed by *Actor₅* and the *Customer* together. Since the customer is the receiver of the service, we put the *Customer* after *Actor₅*. The service process starts from the customer's service demand and ends at the service delivery to the customer. Every activity in the service process is involved in value creation.

3.6 Conclusion

In this chapter, we first describe the process, activity, and entities involved in the service, introduce the concept of service value, and define it in terms of dimensions and granularity, so as to clarify the value of the activity and the value of the service process. Then, the service value indicators are defined, and these value indicators are classified from the perspectives of generality, domain-related and entity-related, and the mapping relationship between service event attributes and value indicators is given. Based on this, we describe a framework for constructing service value model based on process mining, which can use two different ways to generate service value model from service logs stored in information systems, and give a generic model of service value model based on Petri net.

The proposed framework also describes a method with a set of steps to follow to construct service process model. It provides added value to the state of the art in several points:

- It allows to identify and define service value indicators that can be mapped to event attributes.

- Some rules are defined so that various service functional elements are taking into account when building the service value model.
- Using the proposed approach described in this chapter, the relationships between activities, actors and value creation are considered in an integrated way in the service value model.

CHAPTER 4

Mining Service Value Model from Event Log

4.1 Introduction

The framework proposed in the previous chapter is conceptual and abstract. It does not give a particular process mining algorithm to use and how to build the service value model from the service event log. We did not use the traditional modeling method, but one based on the event log of service performance in the information system. The main reason why we introduced process mining techniques into the construction of the service value model is that process mining can discover the process from the actual event log in the service system. As mentioned in reference (Banerjee et al. 2011), “the main benefit of process mining techniques is that information is objectively compiled”. In the process of service execution, the corresponding event log will be recorded in the information system. With the accumulation of time, a large number of service event logs will be saved in the information system, so that all paths of process execution can be covered. As we know, there may be differences between the actual implementation of the process and the ideal situation. Therefore, research on the actual service process is more meaningful, and at the same time, avoids the error of manual construction of the service process. The research results of many scholars on process mining provide us with a solid research foundation. Using the existing process mining algorithm, we can build a process model faster. However, the model obtained by using the existing process mining algorithms is not the final model that we need. Since the service process is customer-oriented, value is driven and determined by customers, and value creation is domain related, we must improve the existing algorithms and tools to meet the needs of research, and experiment by combining the specific service domain knowledge.

Therefore, in this chapter, two different algorithms are presented, an improved inductive mining algorithm and a new value-oriented service process mining algorithm, which will be used to implement the specific construction process of the service value model.

4.2 Background

In this section, we present the formal definitions of concepts related to service event log. And the inductive miner (IM), which is the basis of the improved algorithm, is also briefly described in this section.

4.2.1 Service Event Log

Events are atomic units in the event log. Typically, the life cycle of an event includes the beginning and end. An event may also be Instantaneous, then its start and end can be combined into one state. A Trace records an actual service process instance that has been executed. An event log contains multitudes of traces. Event and Trace in the event log can be defined as follows:

Definition 4.1: An Event E is an atomic granule of a process instance and it can be denoted as $E_s/E_c = (eName, t, actor, attrVal)$, where:

- The subscript “s” and “c” represents the state of an event, E_s represents the start of its life cycle, and E_c represents the completion of its life cycle. If an event is instantaneous, it is possible to represent this event only by E_c , i.e. the event starts and ends at the same time.
- $eName$ is the name of Event E , E_s and E_c have the same $eName$. We usually use the abbreviation $E(eName)$ to represent an event E ;
- t is the timestamp of Event E . E_s and E_c each have a timestamp;
- $actor$ is the person, organization, or automated resource in charge of event E . Actor can be expressed as $actor = \{service\ provider, partners, customer, automated\ resource\}$, automation resources can be external entities such as sensors and software systems.
- $attrVal = \{(attr_1, val_1), \dots, (attr_n, val_n)\}$ is a set of the attributes and value of event E . $attr_i$ is the i th attribute of event E and val_i is the value of attribute $attr_i$.

Definition 4.2: A Trace T is composed of a series of events in chronological order and it can be denoted as $T(tName) = \langle E(1), E(2), \dots, E(m) \rangle$, where:

- $tName$ is the unique identifier of a Trace;
- $E(i)$ is the i th Event of the event sequence in the Trace.

Service process is composed of a limited number of activities according to specific dependency relation. At this level, service process and activity are abstract. Relatively,

trace and event are real and concrete. When an activity in a service process is executed, the information system records the corresponding event information, including its start and end status, participants, timestamp, etc. Correspondingly, each trace which consisting of a series of events in chronological order is an instance of a service process. When a service process executes once, a trace is recorded in the information system.

Therefore, the events in trace are arranged according to temporal relation. There are four types of dependencies between events (activities) , including sequential relation, parallel relation, exclusive relation and loop relation. Events have two life cycle states, start and complete, so there are three different temporal relations between two different events as shown in Figure 4.1, including sequential, inclusion, and coincidence temporal relation. The events with sequential temporal relation will be judged as sequential dependency relation; while the events with inclusion and coincidence relation will be judged as parallel relation, the specific merging and mapping methods are as follows.

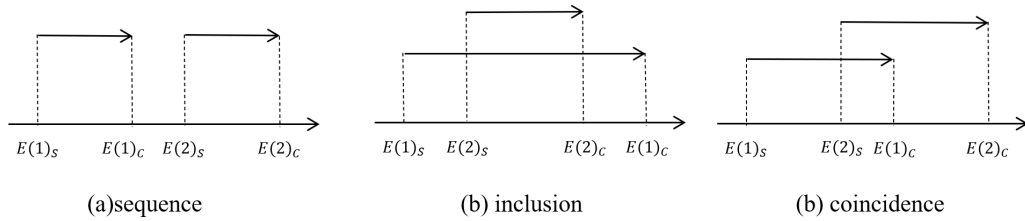


Figure 4.1 Temporal relations.

- Sequential relation, indicating that events happen in sequence. If exists $\langle E(1)_s, E(1)_c, E(2)_s, E(2)_c \rangle$ in a trace, then $E(i)_s$ and $E(i)_c$ will be combined and mapped into $E(i)$, because $E(i)_s$ and $E(i)_c$ have the same event name, indicating the beginning and end of the event, and event $E(1)$ and $E(2)$ are judged to be sequential relation. This part of trace will be transformed into $\langle E(1), E(2) \rangle$.
- Parallel relation, referring to the simultaneous occurrence of multiple events, including the inclusion relation as well as coincidence relation. If exists $\langle E(1)_s, E(2)_s, E(2)_c, E(1)_c \rangle$ in a trace, or $\langle E(1)_s, E(2)_s, E(1)_c, E(2)_c \rangle$, then $E(i)_{s/c}$ will be combined and mapped into $E(i)$, and activity $E(1)$ and $E(2)$ are judged to be parallel relation. This part of trace will be transformed into $+ [E(1), E(2)]$.

For example, in a trace record shaped as $\langle E(1)_s, E(1)_c, E(2)_s, E(3)_s, E(3)_c, E(2)_c \rangle$, the relation between events is judged sequentially: the first two events $E(1)_s$ and $E(1)_c$ will be merged and mapped as $E(1)$; the next event $E(2)_s$ is start state, but its next event is not the end state of it, so looking at the next three events sequentially, we can find that the temporal relation of the four events in this fragment belongs to the inclusion relation, so they are merged and mapped as parallel activity combination

$+ [E(2), E(3)]$. Therefore, this trace will be transformed into an initial activity chain shaped as $\langle E(1), + [E(2), E(3)] \rangle$.

- Exclusive relation, after completing an activity, one of the multiple activities following it can be selected to complete. In normal circumstances, exclusive relation exists when the service process model contains multiple service process paths. But the exclusive relation may exist in a separate trace when there is loop relationship, which is detailed in loop relation.
- Loop relation, indicating that events can be repeated in a service process. If exists $\langle E(1)_s, E(1)_c, \dots, E(2)_s, E(2)_c, E(1)'_s, E(1)'_c, \dots \rangle$ in a trace record, then $E(i)_s$ and $E(i)_c$ will be combined and mapped into $E(i)$, and there is a loop relation between $E(2)$ and $E(1)$. Actually, the loop relation belongs to a special form of exclusive relation, which represents after completing $E(2)$ there is an option to repeat $E(1)$. Thus, it will be transformed into $\times [E(2), E(1), \dots]$, which means $E(2)$ can be followed by any activity in this combination other than $E(2)$. Meanwhile, recurring activity may bring another form of exclusive relation in separate trace as well, like $\langle E(1), E(2), \dots, E(1)', E(3), \dots \rangle$. That is, the activities followed by repeated $E(1)$ are different, which leads to an exclusive relation of $E(1)$ and will be transform to $\times [E(1), E(2), E(3), \dots]$.

For example, in an initial event chain shaped like $\langle E(1), E(2), E(1), E(3) \rangle$, after completing the event $E(1)$ and $E(2)$, the event $E(1)$ is repeated, indicating a loop relation, so they will be converted to $\langle E(1), [E(2), E(1)], \dots \rangle$. After completing $E(1)$ again, a new event $E(3)$ is completed, which indicates the loop relation leading to an exclusive relation of $E(1)$, with the option to complete $E(2)$ or $E(3)$. This initial event chain will be converted into an event chain of the form $\langle [E(1), [E(2), E(1)], E(3)] \rangle$.

4.2.2 Inductive Miner

The core of process mining is process discovery, for which many scholars have proposed different algorithms. Van der Aalst's team first uses Petri nets to represent the process model and proposed the process discovery algorithm, α algorithm, which discover the process model according to the temporal relations (Maruster et al. 2002, 2006). Its main limitation is that it cannot guarantee the reliability and is only suitable for the noise-free log. Weijters, Aalst and Medeiros (2006) first applied Heuristic Miner to model discovery in process mining. It is a significant improvement, but it is also not guarantee that the correct process model will be obtained. Some new data-driven methods have been applied in the field of process mining, and the most effective algorithms are those based on computational intelligence, language-based region, and divide-and-conquer method. IM proposed by Leemans et al. (2013) is one of the best

algorithms based on divide-and-conquer method. The process tree and the model of block-structured workflow net can be mined from event logs, with guarantee of the robustness and adaptability (Leemans et al. 2013, 2018). And the results returned by IM can easily be converted to other notations, such as Petri net.

The main idea of the Inductive Miner is to decompose the problem of finding a process model of log L into the problem of finding n sub-process models of n sub-logs obtained by splitting log L . Leemans et al. (2013) defines an Inductive Miner direct-follows framework (IMD framework), which discovers process models using the idea of divide-and-conquer and recursion. To implement the splitting of Log L , IM algorithm defines four “cut” operators (\oplus), which are sequence (\rightarrow), exclusive-choice (\times), parallel (\wedge) and redo-loop (\odot), as follows.

- \rightarrow : sequence cut is a cut that there is outgoing edge from sub-process A to sub-process B , but no incoming edge, and only one side to the other in general.
- \times : exclusive-choice cut is a cut that there is no connection between sub-process A and sub-process B . The successor activity of an activity in sub-process A cannot be in sub-process B and the successor activity of an activity in sub-process B cannot be in sub-process A . They are not connected to each other.
- \wedge : parallel cut is a cut that sub-process A has both an outgoing edge to sub-process B and an incoming edge from sub-process B to sub-process A . The two cross each other and exist in parallel.
- \odot : redo-loop cut is a cut that an activity starts from sub-process A , arrives in another sub-process B , and then reappears from B back to A .

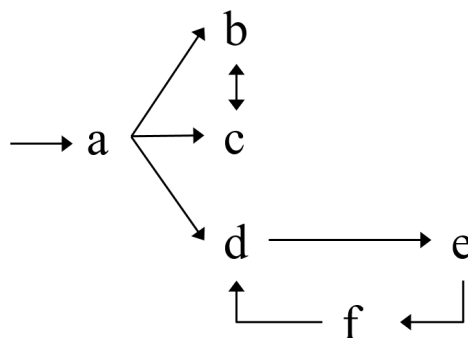


Figure 4.2 The directly-follows graph of log L .

The main steps of IM algorithm can be described as follows: First, for a given event log L , it is transformed into a directly-follows graph is $G(L)$. A directly-follows graph (DFG) is the simplest representation of the process models. In a DFG, each node represents an activity and the arcs describe the relationship between various

activities (van der Aalst 2019). According to $G(L)$, the IMD framework judges the relation among activities and divides the activity set into a subset of activities, then, based on the subset, L is cut into smaller sub-logs, which can be combined with \oplus to restore the log L . Then, the sub-process trees are recursively obtained in the sub-log, and the sub-process trees are combined into a complete process tree through \oplus . When L can no longer be split, the recursion ends. For example, for an event log $L = \{ \langle a, b, c \rangle^3, \langle a, c, b \rangle^2, \langle a, d, e \rangle, \langle a, d, e, f, d, e \rangle^3 \}$, a DFG is first generated as shown in Figure 4.2. The above DFG is then split using the four cut operators (\oplus), and the splitting process is shown in Figure 4.3, where (a), (b), (c), (d) are sequentially cut for sequence cut, exclusive-choice cut, parallel cut and redo-loop cut, which can be expressed as:

1. $\{ \rightarrow (L, (\{a\}, \{b, c, d, e, f\})) \} \Rightarrow (L_1 = \{ \langle a \rangle \}, L_2 = \{ \langle b, c \rangle, \langle c, b \rangle, \langle d, e \rangle, \langle d, e, f, d, e \rangle \})$;
2. $\{ \times (L_2, (\{b, c\}, \{d, e, f\})) \} = \times (L_3 = \{ \langle b, c \rangle, \langle c, b \rangle \}, L_4 = \{ \langle d, e \rangle, \langle d, e, f, d, e \rangle \})$;
3. $\{ \wedge (L_3, (\{b\}, \{c\})) \} = \wedge (L_5 = \{ \langle b \rangle \}, L_6 = \{ \langle c \rangle \})$;
4. $\{ \circlearrowleft (L_4, (\{d, e\}, \{f\})) \} = \circlearrowleft (L_7 = \{ \langle d, e \rangle \}, L_8 = \{ \langle f \rangle \})$.

Then according to the above procedure, the recursion ends when each L_i can no longer be cut. This means that each subset has only one activity in it. The result can be transformed into a process tree model $M \Rightarrow (a, \times(\wedge(b, c), \circlearrowleft(\rightarrow(d, e), f)))$, as shown in Figure 4.4.

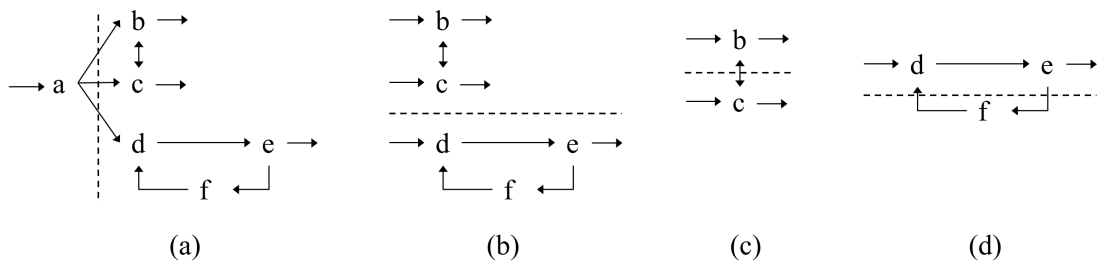


Figure 4.3 The cut operations on log L .

Since IM algorithm ensures that the block model obtained at each step is structured throughout the computation process, the final process model is also structured. The IM is one of the most effective algorithms in the field of process mining, with the advantage of being able to mine process models of high quality and low computational time complexity. However, it focuses on the business process construction, and does not consider extracting service stakeholders and their relationships from the service event log, nor does it consider extracting service value information from the log.

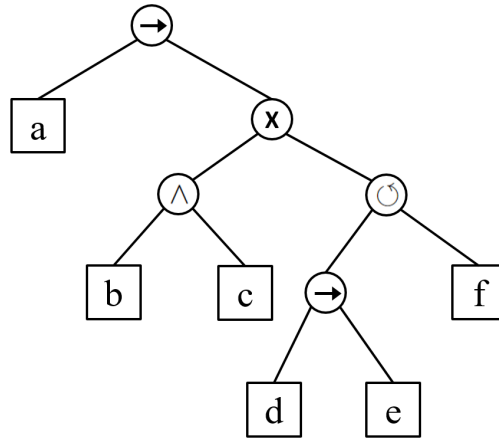


Figure 4.4 The process tree model of log L .

4.3 Improved Service Production-oriented Inductive Miner

Different from the existing algorithms for mining business processes, the improved inductive miner pays more attention to the service process, and can effectively mine the actors, actor relationships and value flow in the service process. Meanwhile, it can extract value from the service process to establish the service value model.

4.3.1 Service Process and Value

Compared with the traditional business process, in the product service system, the service process has the following two characteristics: (1) Block structure, in the service process, a service can be split into smaller primitive services, and primitive services can be combined into a composite service, so the service process has a certain block structure; (2) Interaction and value, in addition to the process sequence of service activities, the service process also pays attention to the interaction of all stakeholders in the service process and the flow of value among stakeholders.

IM algorithm due to its recursive mining characteristics, the generated process tree has a hierarchical structure, which can be transformed into a workflow network with a block structure, and directly generate a block-structured process model. Therefore, this section chooses to optimize and improve the service-oriented process mining based on the IM. However, the IM algorithm cannot be directly used to mine how stakeholders participate in activities and value flow among stakeholders in the service process. Moreover, it does not solve the problem of identifying activities with the same name in the process, that is, two different activities with the same name in the log, which will cause the generated process model to fail to accurately describe the actual process. Therefore, this section optimizes and improves the IM algorithm and uses the service value chain model proposed in the previous chapter. The model is a derivation of the

workflow network with the addition of active participants and participant value flow, and is represented using Petri net.

4.3.2 Idea of Improving Inductive Miner

The idea of improving the inductive miner is shown in Figure 4.5. First, the original event log is filtered to obtain a valid event log. Then, on the one hand, a directly-follows graph with actors $G_A(L)$ is generated based on the valid event log, and its node form is “activity with actor”; next, a process tree with actors is obtained by mining the $G_A(L)$ using the improved IMD framework; we then convert the process tree into a block-structured workflow network with actors; by identifying the relationships between actors and merging the same activities in the workflow network, we obtain a service process network with actors. On the other hand, the activity and actor information is extracted from the valid event log, and the value information can be extracted on this basis, and then the value arc between the activity and the actor can be established. Finally, a service value model is constructed by separating the activities from the actors in the transition nodes in the service process network and adding the corresponding value arcs to the service process network.

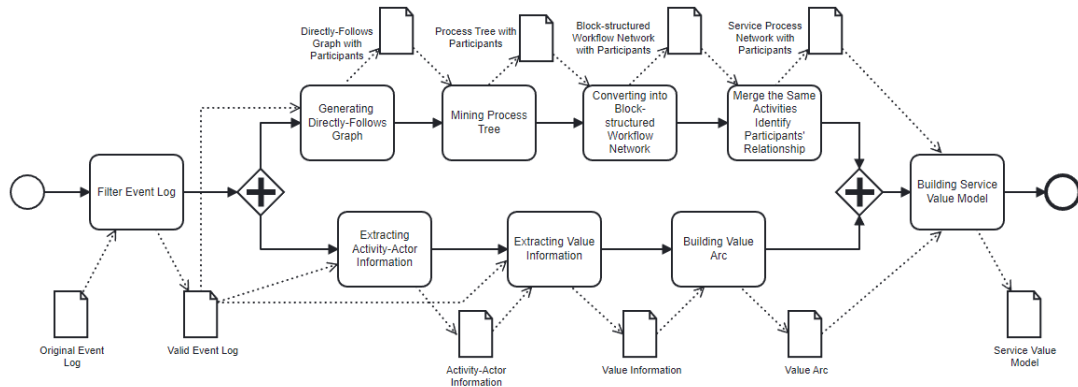


Figure 4.5 Idea of improving the inductive miner.

4.3.2.1 Construct a Directly-follows Graph with Actors

In order to introduce the mining of actors in the subsequent service process mining, and to facilitate the solution that the IM algorithm cannot mine activities with the same name, this thesis considers the actor attributes of Event in the event log, and changes the node of log’s directly-follows graph to the form of “activity with actor”, which is like: $n_i = (activity_i, actor_i)$. The actors of an Event are usually represented using the event attribute with the key “org:resource”, which describes the participant providing the service from the point of view of the resource, or “org:role”, which is generally used for the demander of the service. The same activity of different actors is treated

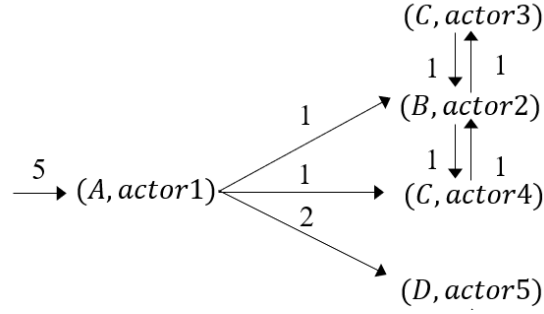


Figure 4.6 An example of a directly-follows graph with actors

as two different nodes. Similarly, different activities of the same actor are also two different nodes in the graph. The directly-follows graph with actors $G_A(L)$ shown in Figure 4.6 has 5 nodes, namely $(A, actor1)$, $(B, actor2)$, $(C, actor3)$, $(C, actor4)$ and $(D, actor5)$. Each node contains one activity and one actor, for example $(A, actor1)$ means activity A is participated by $actor1$. Activity C is divided into node $(C, actor3)$ and node $(C, actor4)$ in the graph due to the participation of different actors $actor3$ and $actor4$. Arrows with numbers indicate the times of directly-follows-ups between activities. For example, the arrow between $(A, actor1)$ and $(B, actor2)$ indicates that $(B, actor2)$ appears directly after $(A, actor1)$ once.

We build the directly-follows graph with actors in much the same way as the original IMD framework, but with the addition that when an active node is discovered, the actor attribute in the corresponding Event is also extracted. On the basis of the directly-follows graph with actors, the improved inductive miner is used to identify splitting and recursive construction. The obtained process tree leaf nodes will also be in the form of "activity with actor", and the actors are included in the process tree's leaf node.

4.3.2.2 Framework of Hierarchical Identification Service Process

In order to enable the improved algorithm to recognize the cut operators in the directly-follows graph with actors, the recognition and splitting steps are redefined in this thesis. Since the actor in the node $(activity_i, actor_i)$ are only associated with the activity in the same node, and have no relationship with the activities of other nodes, we regard the node $(activity_i, actor_i)$ as the original activity in IM, so we use the operations $\oplus \in \{\rightarrow, \times, \wedge, \circ\}$ to cut it. According to this idea, we update the cut operation rules in Section 4.2.2, and replace the corresponding sub-process with the sub-graph of directly-follows graph with actors $G_A(L)$ and the activity with the node in $G_A(L)$. Then we can obtain the process tree with actors. As shown in Figure 4.7, it is an example of process tree. The sub-tree composed of leaf nodes $(C, actor3)$, $(C, actor4)$ and their parent node operator (\times) means that one of the two leaf nodes is selected for execution; and this sub-tree, leaf node $(B, actor2)$ and their parent node operator (\wedge) represent

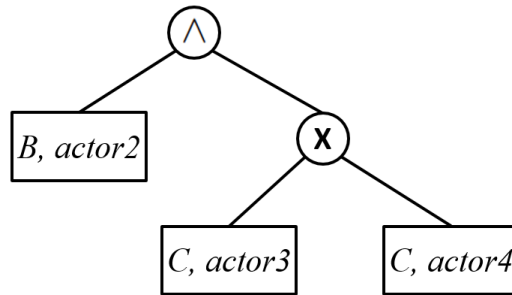


Figure 4.7 Process tree with actors

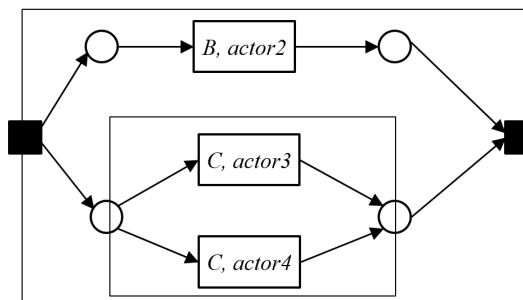


Figure 4.8 An example of a block structure workflow network with actors

that the sub-tree part is executed in parallel with $(B, actor2)$..

Transforming the process tree into a block-structured workflow network can realize the hierarchical display of service process, and identify primitive services as well as composite services. The activity nodes in the workflow network are primitive services, and the process blocks are composite services; At the same time, it is convenient to establish a service value model defined in the form of Petri nets. Therefore, it is necessary to convert the process tree with actors into a block-structured workflow network with actors. The process blocks are divided by the sub-nodes of each operator in the process tree, and each box represents an operator's object. Figure 4.8 is the workflow network obtained after the transformation of Figure 4.7. The exclusive choice of $(C, actor3)$ and $(C, actor4)$ is divided into a process block, and parallel execution of this process block and $(B, actor2)$ forms a larger process block.

4.3.2.3 Building a Service Process Network

The steps to build a service process network are as follows.

(a) Identify duplicate name activity and the same activities. The “duplicate name activity” refers to activities that have the same name in the event log, but in multiple different process positions in the actual service process. For example, there will be a pair of duplicate name activities all called “test repair” in a process of repair, but in reality they are respectively the test before and after repair and correspond to different

positions in the process model. The “same activity” refers to the activities which have same name and same location in the process model, in fact they are the identical activity. In the workflow network, the activities with the same name can be identified according to whether the nodes before and after the nodes $(activity, actor)$ are consistent. Transition nodes with identical before and after node sets are the same activities and can be merged; transition nodes with different before and after node sets are duplicate name activities and cannot be merged.

(b) Identify the relationship between actors in the same activity. After merging the nodes, it is necessary to determine the collaboration relationship between the different actors of the merged activity. There are two kinds of relationships for different actors in the same activity. According to the following rules, it is possible to identify whether the relationships between the different actors involved in the same activity in the workflow network are done independently or collaboratively.

- If multiple $(activity, actor)$ nodes of the same activity must not be triggered at the same time in an event trace, then the correspondence of these participants is completed independently, using $A \simeq (actor_i, actor_j)$ as identification.
- If multiple $(activity, actor)$ nodes of the same activity is triggered at the same time in an event trace, the corresponding relationship of these actors is cooperation completion, using $A \approx (actor_i, actor_j)$ as identification.

For example, in Figure 3.9, activity D is done independently by actor $Actor_2$ or $Actor_4$, and the two actors are in an independent or competitive relationship, and node $(D, Actor_2)$ and node $(D, Actor_4)$ can only appear in different Traces; activity C is done cooperatively by actor $Actor_3$ or $Actor_5$, and the two actors are in a cooperative relationship, i.e. node $(C, Actor_3)$ and node $(C, Actor_5)$ both appear in the same Trace.

By identifying the same activities and duplicate name activity in the block-structured workflow network with actors, we can merge the same activities. And by determining the collaborative relationships between different actors in the same activity and marking them on the workflow network, the workflow network can be converted into a service process network in the form of a Petri net. Figure 4.9 shows the service process network obtained by simplifying the workflow network in Figure 4.8. In Figure 4.8, the activities corresponding to nodes $(C, actor3)$ and $(C, actor4)$ are all activity C , which actually has the same activity in the same position in the process model. At the same time, two nodes must not be triggered at the same time in an event trace, which means that the relationship between the actors $actor3$ and $actor4$ is independently. So in Figure 4.9, the two nodes are merged into one node, and the relationship between the two actors is marked as independent completion with $C \simeq (actor3, actor4)$.

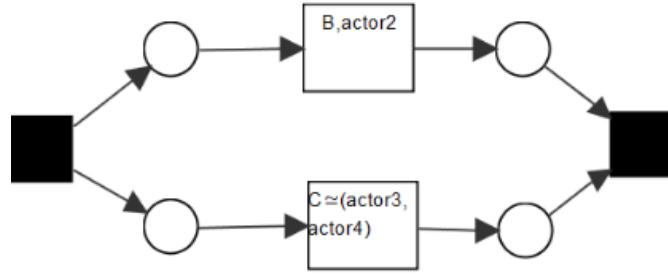


Figure 4.9 An example of service process network

4.3.2.4 Mining Value Flow in Service Process

The steps of mining value flow in service process are as follows.

(a) Value information extraction. In the actual operation of the product service system, in addition to the sequence of events, a lot of extended information is also involved. Extracting value information from it can provide great help for the analysis and optimization of the service process. The XES format event log used in this thesis has great scalability. In addition to basic information, it can also achieve standard recording of most extended information. This thesis explores the value flow in the service process based on the definition of service value in section 3.3. The service value is divided into three dimensions, namely the time-space dimension, profit dimension and experience dimension as $V = (v_{ts}, v_p, v_e)$. Based on this, this section considers the value attributes of these three dimensions in the event log in XES format, and uses ts, benefit, and expr as the extension prefixes for the time and space, benefits, and experience dimensions, respectively. The extended prefix can be used as the prefix of the value attribute of the corresponding dimension, indicating that the value attribute belongs to the dimension. For example, the value attribute productState that represents the product state, after adding the prefix ts, is ts:productState, indicating that it belongs to the time and space dimension.

We first extract all activities and their corresponding actor from the event log and use them as keys to extract value information from the event log. For each “activity-actor” key, the value attribute of the three dimensions is identified by the attribute prefix in the event log, and the attribute value is extracted as the value data. Figure 4.10 shows an event in the event log, and its corresponding “activity-actor” key is “Repair-Staff1”. The attribute keys of the time and space dimension values contained in this event are “time: timestamp” and “ts: productState”. The former indicates that the occurrence time of the event is “2020-12-01T09:00:06.000+01:00”, and the latter indicates that the state of the product is “false”. The attribute with the key “benefit: knowledgeShare” is the profit dimension value, which indicates that the benefit received by Staff1 from sharing the repair knowledge is 4; The keys “expr:serviceType”, “expr:complexity” and

```

<event>
  <string key="org:role" value="Customer" />
  <string key="org:resource" value="Staff1" />
  <string key="expr:serviceType" value="Replacement" />
  <int key="expr:complexity" value="2" />
  <string key="expr:replace" value="component1" />
  <string key="benefit:knowledgeShare" value="4" />
  <date key="time:timestamp" value="2020-11-29T15:00:00.000+01:00" />
  <string key="concept:name" value="Repair" />
  <boolean key="ts:productState" value="false" />
  <string key="lifecycle:transition" value="start" />
</event>

```

Figure 4.10 An example of event log

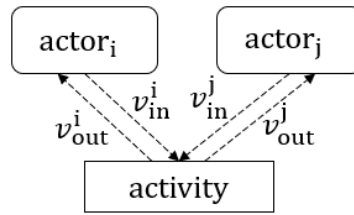


Figure 4.11 A value arc model

“expr:replace” are attributes of the experience dimension value, which indicates the experience that can be gained by Staff1 through the repair activity including the repair type of “Replacement”, the repair complexity of 2, and the component to be replaced of “component1”, respectively.

(b) Building the value arc. The goal of each actor in the service process participating in the service is to create and obtain value. Each actor creates value in the service process and meets their own value expectations. Different service actors have different value expectations. When an actor participates in an activity in the service process, there will be a value arc of the corresponding actor flowing into the activity and a value arc flowing out of the activity. When different actors act on the same activity, each actor has its corresponding inflow and outflow value arc as shown in Figure 4.11. Based on this, we define the value arc as follow:

Definition 4.3 value arc v is a directed arc, $v = \{activity, actor, v_{ts}, v_p, v_e\}$, where activity represents the activity in the event log, and actor represents the actor in the event log, Direction represents the direction of value flow (inflow or outflow activity), v_{ts} , v_p and v_e correspond to the three dimensions of value information. There is a value arc between activity and actor, if and only if $actor \in A, activity \in T : (activity, actor) \in SN$, where SN is the service process network mined in section 4.3.2.3, and A is the set of actors in SN , T is the transition set in SN .

For some value indicators that cannot be mapped directly from attributes, they can be obtained through relevant calculations, as described in section 3.4.5. For example, in

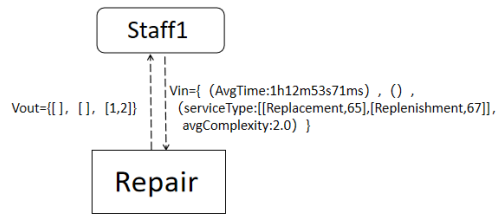


Figure 4.12 An example of value arc

Figure 4.10, in the time and space dimension, based on the values for all attributes with the key “time:timestamp” corresponding to the “Repair-Staff1” key, the average repair time of Staff1 can be calculated by performing statistical analysis on the extracted value data. Not all value indicator calculations involve an arithmetic analysis of attribute value data; some may require a simple count of the number of occurrences of an attribute value. For example, for the repair type indicator in the experience dimension value, it is only necessary to count the number of occurrences of the different values of the attribute with the key “expr:serviceType”, e.g. the number of times “Replacement”, so that it will tell us how many times the repair service with the service type of “Replacement” has been performed by Staff1 in the log.

After obtaining the value information of three dimensions, we combine it with the “activity-actor” key to build a value arc. Figure 4.12 is an example of a value arc for the activity Repair and the actor Staff1. The value input by the actor Staff1 in the activity Repair includes the average repair time *AvgTime* in the time and space dimension, the service type statistics and the average repair complexity in the experience dimension. There is no value in the profit dimension. Among them, the value of the *serviceType* in experience dimension is [[Replacement,65], [Replenishment,67]], which means that Staff1 has performed 65 replacement parts services and 67 supplementary services in the time period recorded in the log. The value of Repair output Staff1 is only the number of repairs in the experience dimension, including the 1 and 2 repairs.

4.3.2.5 Building a Service Value Model

By Separating the transition node of the service process network in 4.3.2.3 into two nodes of activity and actor, we use the “activity-actor” as the key to find the corresponding value arc in the value arc of 4.3.2.4, and add the value arc to the service process network to build the service value model. As shown in Figure 4.13, the activities and actors of the service process network in Figure 4.9 are separated into two nodes, and the value arcs corresponding to the activities and actors are added. The original node ($B, actor2$) is separated into activity node B and actor node $actor2$, and a corresponding value arc is added. This value arc includes activity B and actor $actor2$, as well as the value of $Vin1$ flowing from actor $actor2$ to activity B and $Vout1$ flowing

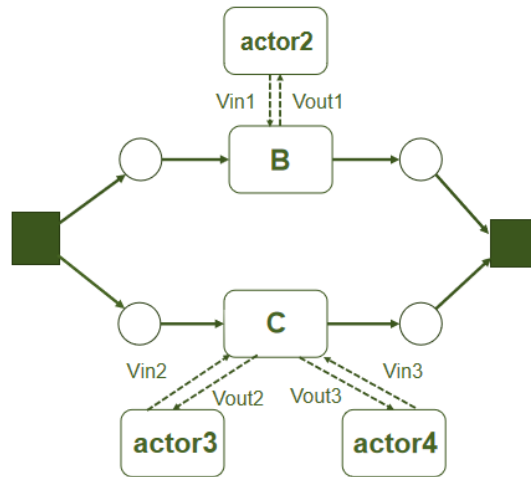


Figure 4.13 An example of service value model

from activity B to actor $actor2$; node $C \simeq (actor3, actor4)$ is separated into activity node C and actor nodes $actor3, actor4$, and the corresponding value arcs are added.

4.3.3 Specific Steps of the Algorithm

According to the previous description, the specific steps of the improved algorithm given in this section are shown in Table 4.1.

4.3.4 Comparison of the Algorithms

Using the event log from the case study as data (see Chapter 6), the α algorithm, IM, and the improved algorithm were compared. The comparison of the running results of the three algorithms is shown in Table 4.2. All three algorithms form a completed service process model that identifies the four basic process structures (sequential execution, parallel execution, loop, and exclusive choice). However, the α algorithm and the original IM algorithm cannot be used to mine actors, actor relationships and value flows in the service process.

The comparison of the time taken by the three algorithms to mine event logs of different sizes is shown in Figure 4.14, from which it can be seen that the mining speed of the IM algorithm and the improved IM algorithm is faster than that of the α algorithm. Especially when the log reaches 10,000 traces, the gap is significant. The mining speed of the improved algorithm is slightly lower than that of the IM algorithm. The main reason is that the value information extraction step increases the time complexity, but the gap is not obvious when processing large data.

Table 4.1 Steps of the improved algorithm

Input: log file in XES format <i>log</i>
Output: Service Value Model <i>SVM</i>

Step 1: Data preprocessing, input a log file in XES format, filter the log, remove incomplete processes in the log, and obtain a valid service process event *log*;

Step 2: Extract the directly-follows graph with actors $G_A(L)$ from the event log *log* and node set N ;

Step 3: Use an improved inductive miner to mine $G_A(L)$, and obtain the process *Tree* with the leaf node as the $\langle activity - actor \rangle$ node;

Step 4: Convert the process *Tree* into a block-structured workflow network, and obtain the primary workflow network of the $\langle activity - actor \rangle$ node WF_1 ;

Step 5: Identify the relationship between different actors in the activity of the same name in WF_1 , merge the transition nodes of different actors of the same activity into $\langle Activity, ActorRelationship \langle Actor_1, \dots, Actor_n \rangle \rangle$, split the actor transition nodes of different activities with the same name are $\langle activity, actor relationship \langle actor_1, \dots, actor_i \rangle \rangle$ and $\langle activity, actor relationship \langle actor_j, \dots, actor_n \rangle \rangle$, generate an accurate and concise service process network WF_2 ;

Step 6: Extract the "activity-actor" information from the log, and identify the attribute tags corresponding to the value indicators, perform statistics and analysis, mine the value information, and build the value arc set VA ;

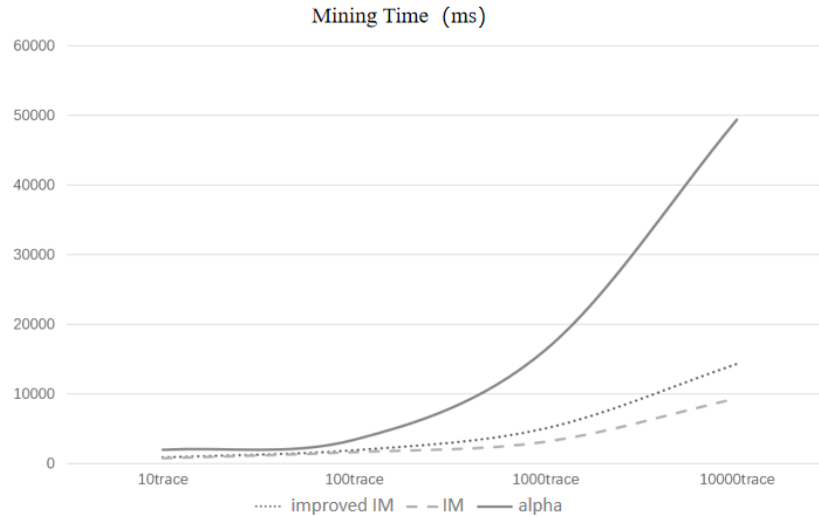
Step 7: Separate activities and actors from the transitions of WF_2 , regard $\langle Activity \rangle$ and $\langle Actor \rangle$ as two different types of nodes, and add the corresponding value arc in VA between $\langle Activity \rangle$ and $\langle Actor \rangle$, construct the *SVM*.

4.4 Value-oriented Service Process Mining Algorithm

Unlike the improved IM algorithm, this section proposes a new service value model mining algorithm and the results of mining are described using BPMN. The reason of using BPMN includes: (1) BPMN is a specification that defines business process modelling notation and its representation in XML. XES also is described in XML. (2) BPMN provides a more comprehensive set of elements that go far beyond the mere definition of a place/transition flow and also provides more elements to express popular behaviours. (3) In terms of representing complex models, BPMN is simpler and more intuitive and easier for users to understand. It is also possible to transform the Petri net model into a BPMN model, but the algorithm incurs additional overhead and the more complex the model, the longer it consumes. The new algorithm is simpler in terms of ideas and more efficient.

Table 4.2 Comparison of alpha, IM and improved IM

Algorithm	alpha	IM	improved IM
four basic structures	X	X	X
duplicate name activity			X
actor			X
relationship of actor			X
value information			X
low time-complexity		X	X

**Figure 4.14** Compare with IM and alpha algorithm.

4.4.1 Concept for Service Process Mining Algorithm

As mentioned previously, service process is a series of activities completed by people, organizations, or automated resources to provide specific services to the target customer. Activity is the basic unit of the service process, which completes the specific task in the service. A SPM may contain multiple service process variants. For example, the SPM in Figure 4.15 contains three service processes variants. Service process variant 1 indicates that activity *A* and *B* are completed first, and activity *E* is completed after completing activity *C* and *D* in parallel; service process variant 2 indicates that after completing activity *A* and *F*, activity *G* can be repeatedly executed and activity *H* is completed last; service process variant 3 indicates that activity *A*, *I*, *J* can be completed sequentially. Each service process variant represents an execution path in the model, and merging these variants yields the complete SPM.

The relationship between activities, service process variant and service process model can be defined as follows:

Definition 4.4: Activity combination *C* is the relationship between a group of activities and it can be denoted as $C = \#[a(1), \dots, a(k)]$, where:

- $a(i)$ is an activity *a*;

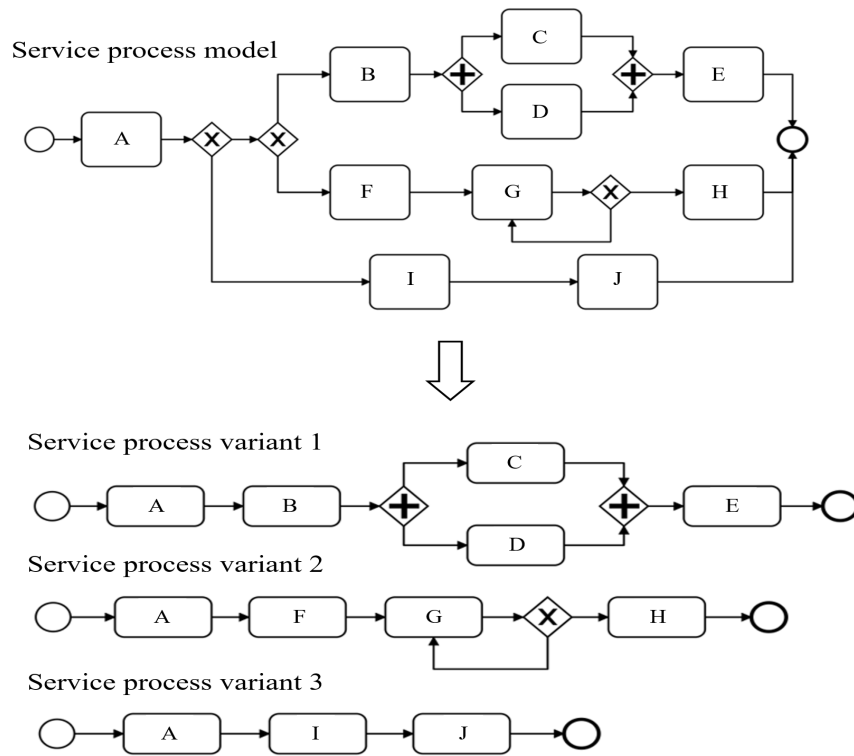


Figure 4.15 Service process model and process variants.

- # is an operator which represents the dependency of activities in C , such as operator \times means the exclusive relation and operator $+$ means parallel relation.

Definition 4.5: Service process variant var is a service process path to perform the service, and it can be denoted as $var = (vName, VI, freq)$, where:

- $vName$ is the name of variant, We usually use the abbreviation $var(vName)$ to represent a variant;
- VI is a chain of activities or activity combinations including the dependency relation between activities. VI can be expressed as $VI = \langle I_1, \dots, I_p \rangle$, where I_i is an activity a or activity combination C .
- $freq$ is the ratio of the execution frequency of service process path var to the total number of times over a period of time. Suppose that the service process is executed 10 times in one minute, and var is executed 3 times, then the $freq$ of var is 30%.

Definition 4.6: A service process model SPM is a BPMN model, and it can be denoted as $SPM = (A, Edge, GXOR, GAND, start, end)$, where:

- A is a set of activities;

- $Edge = \{(head, tail)\}$ is the set of edges, where: $(head, tail)$ represents an edge from $head$ to $tail$, and $head \in \{A, GXOR, GAND, start\}$, $tail \in \{A, GXOR, GAND, end\}$;
- $GXOR$ and $GAND$ are the exclusive and parallel gateways;
- $start$ and end respectively represent the start and end nodes of the service process.

Service value model is a description of service process from the perspective of value, considering the relationship between actors and their value co-creation mechanism in the service process. Value is the goal pursued by all the actors in the PSS. In order to define the service value model, we use the value arc to describe the value input and value output in the process of completing activities.

Definition 4.7: A value arc is the value flow between an activity and an actor. When an activity is performed by an actor, there is a value arc between them, expressed as $va = (a, ar, v_{in}, v_{out})$, where:

- a is an activity;
- ar is the actor in performing a ;
- v_{in} is the input value or cost of ar completing the activity a ;
- v_{out} is the output value gained by ar in completing the activity a .

Here, service value includes both tangible value and intangible value. Time, status, money, knowledge, experience and so on all belong to the scope of service value. When these values are extracted, they will be mapped to the three dimensions in Figure 3.3.

Definition 4.8: A service value model is a value-oriented service process model, which is defined as $SVM = (A, Actor, VA, Edge, GXOR, GAND, start, end)$, where:

- $A, Edge, GXOR, GAND, start, end$ are the same as in the service process SPM ;
- $Actor$ is a set of actors in the service process;
- VA is a set of value arcs between A and $Actor$.

4.4.2 Idea of Value-Oriented Service Process Mining Algorithm

This section proposes a Value-oriented Service Process Mining (VSPM) algorithm, which is based on the idea of industrial value matrix (Wang et al. 2008), process variant merging method based on petri nets (Wang et al. 2021) and process mining using BPMN (Kalenkova et al. 2015). Its idea is shown in Figure 4.16. Firstly, service event

logs from information systems are filtered to remove incomplete traces and obtain a valid event log. Then the service process model and value arcs are mined in parallel from the valid event logs. Finally, the value arcs are annotated to the service process model according to the mapping relationship between activities, actors and values, to construct complete service value model.

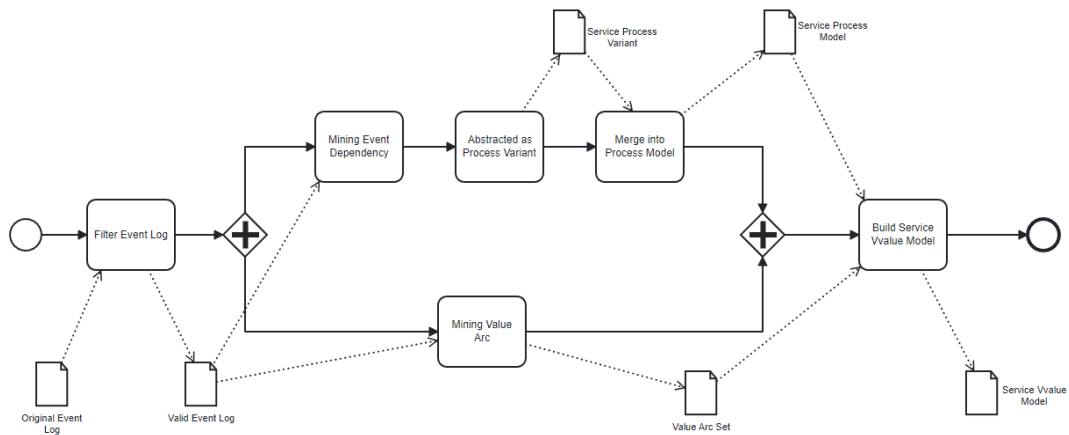


Figure 4.16 Idea of the mining algorithm.

4.4.2.1 Filter Event Log

The purpose of this phase is to filter out the noise and incomplete traces in the original service event log to obtain the valid event log. The event log used in this thesis has lifecycle states, each event must contain both start and end states. If a trace contains events which only have one state, this record is incomplete and should be filtered.

Besides, there are some abnormal behaviors in the logs that cause noise interference. These abnormal behaviors are usually low-frequency, and the corresponding low-frequency traces are filtered out in the subsequent steps. Filtering can debase the influence of the noise and the disturb.

4.4.2.2 Mining Service Process

The focus of service process mining algorithm should be the service process, which is a complete process triggered by the customer and finally delivered to the customer to satisfies their needs. Therefore, the algorithm needs to discover all the real service processes from a holistic perspective and analyze the characteristics of them in order to better meet the needs of customers. This thesis defines service process variant to represent service process. First mine a set of service process variants from the event log, then merge these variants into the service process model.

a) Abstract traces as variants

The events in trace are arranged according to temporal relation, while process variant implies the dependency relation between activities. In order to obtain abstract service process variants from a large number of concrete process instances, each process instance needs to be abstracted by mapping the events in it to activities and mining the three dependencies of the activities based on temporal relationships, including sequential, parallel and loop relationships. Firstly we map events into corresponding activities with the same name. After the mapping, an initial activity chain can be obtained, in which the elements can be activities or parallel activity combinations, all arranged sequentially. Next is to discover loop relation from initial activity chain. By scanning the repetitive activities in the initial activity chain, we can discover the loop relation in it.

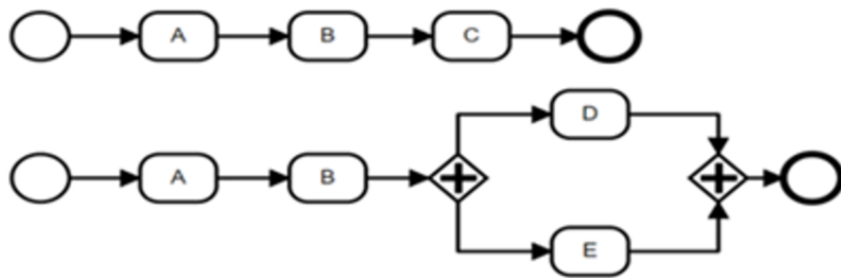
After mapping all the traces in the event log into activity chains, the same activity chain are abstracted into a service process variant *var*, and each trace is an instance belonging to this variant. The number of traces corresponding to *VI* is counted, and its percentage of all process variants in the log is calculated as the *freq* of service process variant.

b) Merge variants to service process model

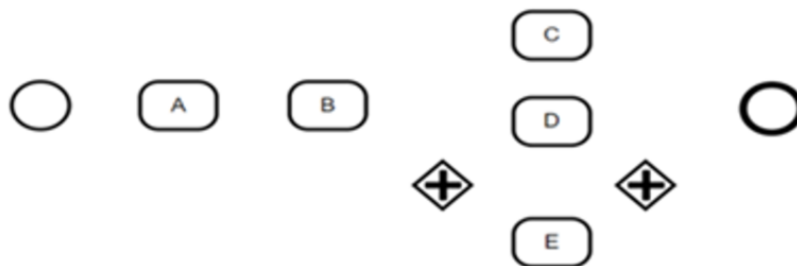
Service process variants with lower frequency are often caused by system failures or logging errors, and are very disruptive for process mining. In order to avoid the interference of noise, variants whose *freq* is lower than the preset threshold are filtered out (Wang and Wang 2019). In addition, the service process variants will be filtered out from a service perspective, i.e., the service process variant should satisfy the service integrity: the first activity is triggered by the customer and the last activity is delivered to the customer. Therefore, if the first or last activity of a variant does not involve the customer, the variant should be filtered.

After filtering low-frequency and problematic variants, the reserved variants will be merged into service process model *SPM* by comparing the *VI* in the set of *var*. Integrating and retaining the same parts of *VI* in the two *var*, while the different parts exist in the form of exclusive relations (Wang et al. 2021). For example two activity chains VI_1 and VI_2 of two variants shaped as $\langle A(1), A(2), A(3) \rangle$ and $\langle A(1), A(2), A(4) \rangle$ respectively, with the same part $A(1)$ and $A(2)$, the different parts $A(3)$ and $A(4)$, the two *VI* will be combined as $\langle A(1), A(2), [A(3), A(4)] \rangle$. The *I* of *VI* is an activity or combination, and combination consists of activity with $\#$. Either way, *VI* is made up of *A* and $\#$. Therefore, the activity *A* of *VI* will be transformed into the *A* in *SPM*, and the $\#$ representing the relation between activities will be transformed as follows: the exclusive relation will be represented by *G XOR*; the parallel relation will be represented by *G AND*; the sequential relation will be represented by *Edge* using its directivity.

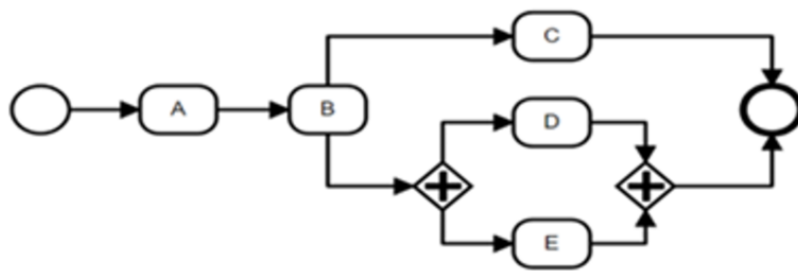
The process of merging two variants into a service process model can be described



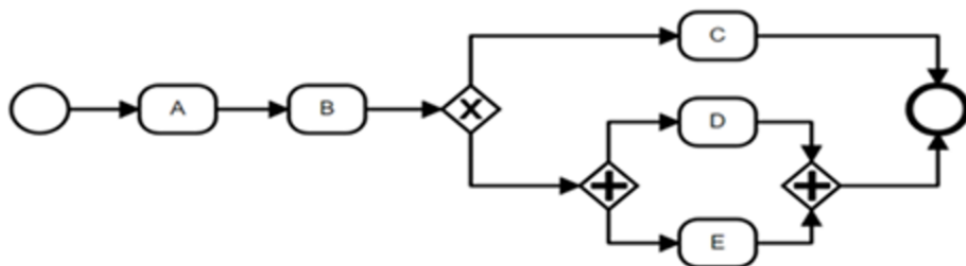
(a) var_1 and var_2



(b) extract activities and gateways



(c) add edge



(d) add exclusive gateway

Figure 4.17 An example of merging variants to service process.

as follow. First all non-repeating activities and gateways in the original variants are extracted, and gateways are identified according to their connected elements. Then, each edge $(head, tail)$ in the variants is traversed and added to the new model without repetition. Due to the existence of different parts between variants, there may be cases in the new model where a non-gateway element has more than one outgoing edge, and a exclusive gateway needs to be added for that element: replace $head$ with the exclusive gateway for all outgoing edges of that element, and delete all outgoing edges of that element, and finally add an edge that points to the exclusive gateway from that element. As shown in the Figure 4.17, it is an example of merging two variants into a service process model with the form of BPMN.

4.4.2.3 Mining Value Arc

In the meanwhile, the core of the service value model is the value co-creation with customers. Therefore, service process mining also needs to mine the value information about stakeholders. In this thesis, based on the idea of establishing service value model proposed before, we extract value information attached to events from log and construct value arcs according to domain knowledge, then annotate the value arcs to the activities of the service process model and build the service value model.

In the actual service event log of PSS, in addition to the dependency relation of events, it also records the value information created by actors as $AttrVal$ in the events. If the actor ar_j participants in the activity a_i , then build a value arc va_{ij} for between them. a_i, ar_j will be used as a key to extract the value information from the corresponding end state of event in the log, and the value information should be divided into v_{in} and v_{out} of va according to the domain knowledge. An example of value arc between activity and actor(s) is shown in Figure 4.18. There are two actors $actor_i$ and $actor_j$ participating in the $activity$, each actor forming a value arc with the activity as shown in Figure 4.18, and we use BPMN to represent it as shown in Figure 4.19.

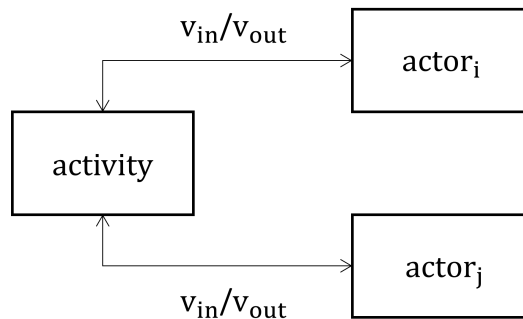


Figure 4.18 Value arc between activity and actor(s).

For example, there are two events named “Interaction” in two different traces, their end states are $E1_c = (Interaction, t1, actor(Customer, A1), attrVal(CusInValue :$

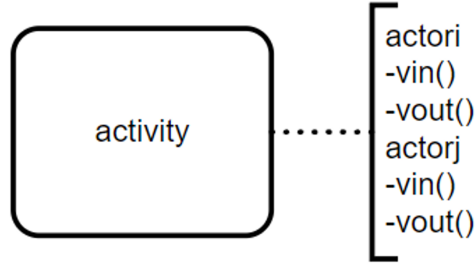


Figure 4.19 Value arc in BPMN.

$value1; ActorOutValue : value2)$ and $E2_c = (Interaction, t2, actor(Customer, A2), attrVal(CusInValue : value3; ActorOutValue : value3))$. $E1_c$ and $E2_c$ can be mapped to activity $A(Interaction)$, and it has 3 participants, including actor $Customer$, $A1$ and $A2$. Then there is a value arc between activity $A(Interaction)$ and each of the actors. The actor $Customer$ has the input value $value1$ in $E1_c$ and the input value $value3$ in $E2_c$, so the value arc between it and activity $A(Interaction)$ is $(Interaction, Customer, v_{in}(value1, value3), v_{out}())$. The value arc between activity $A(Interaction)$ and actor $A1$ or $A2$ can be obtained similarly. All the value arcs between activity and actors are shown in Figure 4.20.

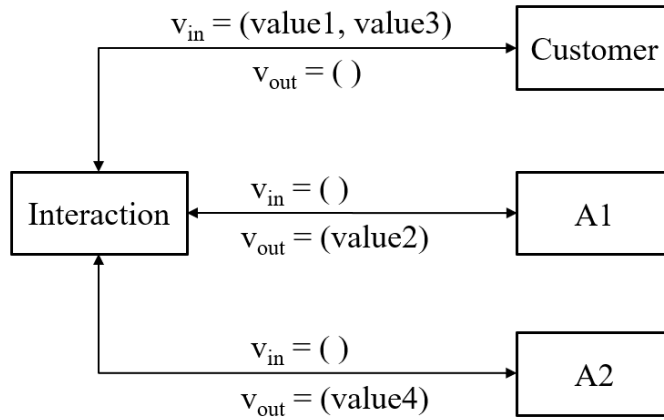


Figure 4.20 Example of value arc.

4.4.2.4 Construct Service Value Model

The service value model is constructed based on the service process SPM and the set of value arcs $\{va_{ij}\}$ obtained in previous section. Since SPM consists of all service activities arranged according to dependency relation and the value arc set $\{va_{ij}\}$ is built for all activities with actors. Accordingly, the mapping relationship of activity-actor-value can be determined. If a in va and $a \in A$ in SPM are the same, then integrate va into a of SPM . Performing this process on all elements in $\{va_{ij}\}$, the service value

model *SVM* can be constructed by integrating the value arcs into the service process.

4.4.3 Specific Steps of the Algorithm

According to the previous idea description, the specific steps of the proposed algorithm are shown in Table 4.3.

Table 4.3 Steps of the algorithm

Input: service event log
Output: service value model SVM
Step 1: Data filtering. Open the service event log in XES format, traverse the log, remove noise and incomplete traces, and obtain a valid log;
Step 2: Mining dependency relation of events E in the valid log, abstract traces T to variants var ;
Step 3: Filter low-frequency and problematic variants from var set;
Step 4: Merge remaining variants in var set to service process model SPM ;
Step 5: Determine the value arc set $\{va_{ij}\}$ of activities and actors;
Step 6: According to the mapping relationship of activity-actor-value, integrate $\{va_{ij}\}$ into service process SPM , build the service value model SVM .

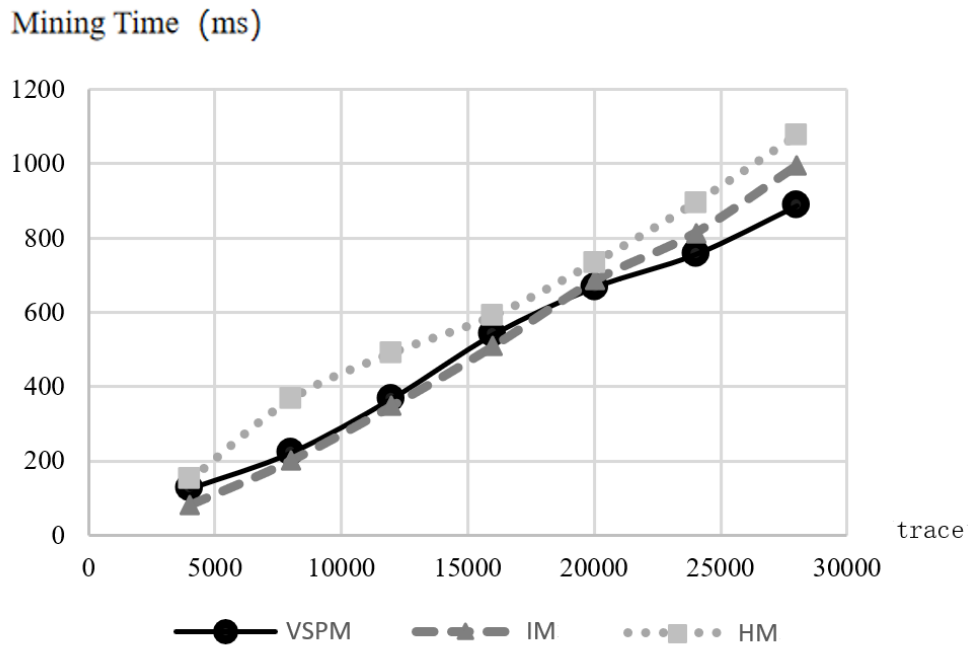


Figure 4.21 Compare with IM and HM.

4.4.4 Compare with Other Algorithms

For the VSPM algorithm, we compare it with IM and HM algorithms. In order to verify whether the mining results are consistent, we do not extract the value, but only

consider the construction of the process model. Using the event log from the case study as data (see Chapter 6), we have obtained different forms of models, but the model structure is the same, including activities and their dependencies. In terms of mining efficiency, VSPM, IM and HM algorithm are used to mine event logs of different sizes. The mining time taken by the three algorithms is shown in Figure 4.21, from which it can be seen that the mining speed of HM is lower than that of the other two algorithms. When the number of traces in the log is small, the mining speed of IM is slightly faster than that of VSPM; However, as the number of tracks in the log becomes larger, the VSPM algorithm gradually becomes faster in mining time and progressively less time consuming than the IM algorithm.

4.5 Conclusion

In this chapter, two algorithms for constructing service value models are presented. The first algorithm is an improved IM-based algorithm that introduces a hierarchical identification of service process framework and value arcs to present the results of mining in the form of an extended Petri net. The second one is a value-oriented service process mining algorithm, which constructs a service value model described by BPMN based on service process variants and value arcs. Although there are differences in the presentation of the obtained model, there is no difference in essence. In terms of the ease of understanding the model and the scalability of the functionality, BPMN is more advantageous.

The two mining algorithms are developed to take into account the specific characteristics of customer-oriented service process and meet the requirements in constructing its value-oriented service model. They allow to generate a better reliable model by taking into account the specific service domain knowledge and particular customer's needs. The process model obtained is closer to the expected one and can in most of the cases implemented with limited or no adaptations. Consequently, the proposed algorithms contribute to go a step forward towards an automation of constructing customer-oriented service value model from event log. Through this approach, a new research direction is initiated to develop mining algorithms adapted to build customer-oriented service process model focusing on values, customer's needs and satisfaction.

CHAPTER 5

Resource Allocation Method for Product-service Process

5.1 Introduction

As the increasing complexity and personalization of customer needs, service providers cannot meet the requirements of customers with the services and resources they have alone. At the same time, service providers need to provide customers with a transparent and complete service, reduce customer participation and improve customer satisfaction. Hereby, the actors and resources in the value chain need to be integrated to meet the massive individualized needs (Xu et al. 2018). Cloud computing provides the access mode of service resources, while big service provides the construction method of complex services (Xu, Sheng, Zhang, Fan and Dustdar 2015). However, the resource allocation of service-oriented process and activity level is still lack of in-depth research combined with the actual scenarios and data of PSS.

For this gap, in the context of cloud computing and big service, this thesis proposes a new resource allocation method for PSS that adopts Bilateral Resource Integration Service (BIRIS) mode and considers the service process life cycle. Based on the process mining techniques, this method extracts knowledge from the execution event log of the service process stored in the enterprise's information systems, constructs the resource allocation problem model, and gives the corresponding solution algorithm. Through the mining and analysis of real data, the construction and solution results of the model can be more in line with the actual situation of the enterprise, and the weakness of difference between theoretical analysis and practical application can be avoided. Moreover, the method proposed in this chapter can improve the computability of resource allocation in PSS, especially in terms of work efficiency and service time.

5.2 Background

The classic project scheduling problem usually takes the construction period and cost as the scheduling goal, and the resources have single capability (Ma et al. 2019). Later, resources were further subdivided into renewable resources, non-renewable resources, doubly-constrained resources, and partially-renewable resources (Kolisch and Padman

2001). In the follow-up modeling research, most scholars focus on renewable resources, but ignore the flexibility of resources. Yu et al. (2010) studied the project scheduling problem with flexible resource constraints, and they designed a two levels mapping network to mapping relationships among tasks, capabilities and resources.

With the rapid development of cloud computing and big data, the research on service resource allocation problem becomes more complicated (Xu et al. 2017). Wang and Xu (2009a) designed a BIRIS model, which introduced a third-party service platform for resource integration, it could integrate service resources to customers and customer resources to providers. Pawar and Wagh (2012) proposed a dynamic resource allocation mechanism for preemptable jobs in the cloud, and proposed a priority-based algorithm to meet the fast response in multi-client situations. Mezache et al. (2016) proposed an adaptive resource allocation algorithm for cloud systems, and used genetic algorithm to solve it. Zhuang et al. (2016) pointed out that there are some important business constraints between services and resources, and valuable service experience can be obtained through statistical analysis, data mining and other techniques. (Zhang et al. 2020) proposed a method based on PSS multilayer network to solve the problem of service activity selection as well as resource allocation. Wang et al. (2022) argued that in the context of big services, the provision of resources is often cross-industry, and the algorithm search space is huge, in this case, more efficient resource allocation can be achieved through the aggregation of services and resources in different fields. Kang et al. (2021) proposed an auction-based cloud configuration and sharing method for the logistics product service system to solve the problem of logistics resource allocation. Xu et al. (2020) analyzed relevant literature and pointed out that the relationship between capabilities and resources can be further studied.

In the new social and economic environment, traditional resource allocation methods are no longer suitable for proposing service-oriented solutions. In order to quickly match the supply and demand sides, various techniques can be used to complete the resource allocation in the current big service system.

5.3 Resource Allocation Problem Model for PSS

With the development of PSS, traditional resource allocation methods need to be improved to adapt to the new demands of the current service ecosystem. This section clarifies the research issues and proposes an analytical framework, then defines related concepts, and finally proposes a resource allocation mathematical model.

5.3.1 Description of Problem in Resource Allocation

As mentioned in the literature review section, BIRIS is a service integration model proposed due to the huge number of both supply and demand sides, which consists of three

parts: customers, providers and third-party platform (Wang and Xu 2009a). For customers, it is reflected in the rapid response to their needs, and can use the platform's services transparently without paying attention to details. For providers, it is reflected in improving the provider's business quality and efficiency. Considering the characteristics of the PSS, it extends the application scenario of BIRIS mode, which is described in Figure 5.1. On the one hand, the service system integrates the service needs from customers, on the other hand, it integrates the primitive services and service resources of service actors. The service system is operated by the service provider, and the actors in the service system could be service providers, its partners or customers. Compared with BIRIS, it emphasizes that all actors in the service value chain complete the service together for the target customers, and emphasizes the mutual collaboration of participants and value co-creation in the service process.

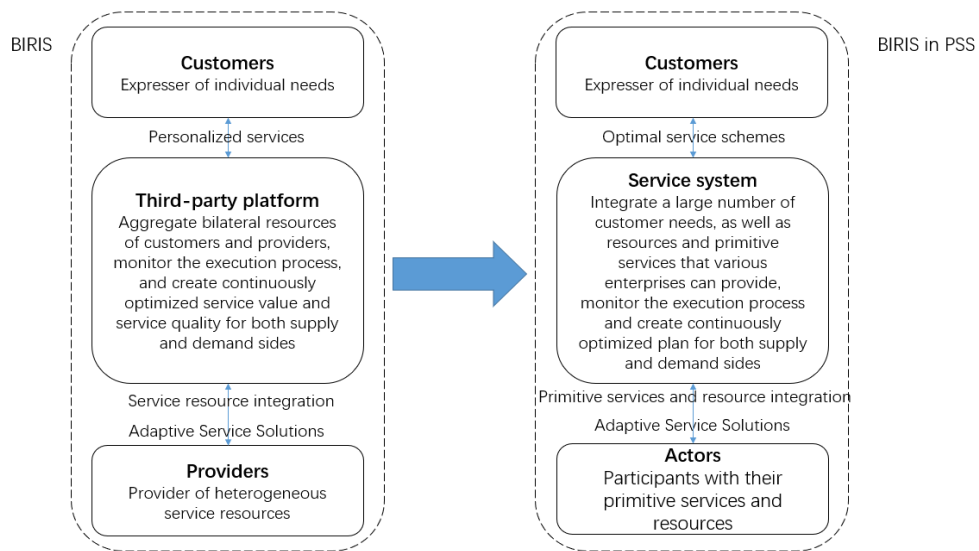


Figure 5.1 Extention of BIRIS in PSS

Combined with the new models and technologies emerging in the current PSS development, this thesis integrates the concept of BIRIS in PSS into the big service system (Xu, Sheng, Zhang, Fan and Dustdar 2015), and uses the idea of cloud computing to propose an analysis framework of PSS considering resources. As shown in Figure 5.2, the left and right sides are the aggregation of customer needs and actors respectively. The cloud in the middle is the service system that the service provider matches the supply and demand sides. Service models including service process information are stored in the service library. Atomic services and resources provided by different actors are stored in primitive service repository and virtual resource pool respectively. In this framework, service provider integrate various actors with their primitive services and resources to participate in the service according to the needs of customers. As mentioned above, some related small-granularity services can combine into a service pattern (Xu

et al. 2019). When the customer's service order arrives, the service provider finds the suitable service model and the appropriate atomic services or service patterns from the repositories. Then, it allocates resources to these services and finally executes the service tasks and collects the feedback for continuous optimization. Customers only need to use the services in the service system according to their needs, without knowing who will complete their service orders.

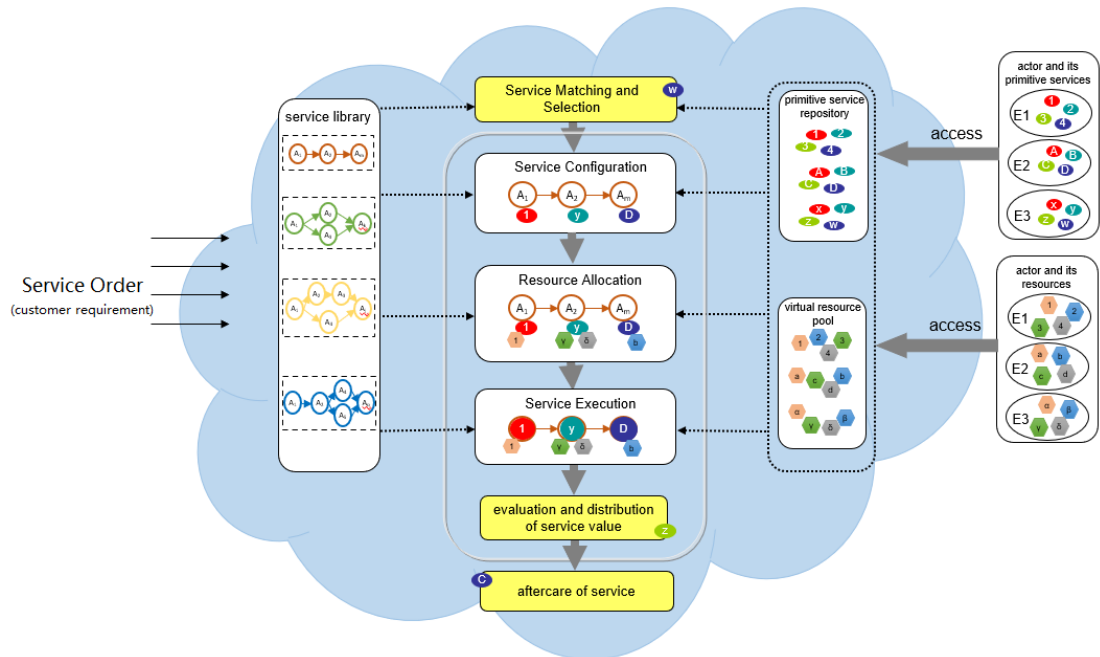


Figure 5.2 An analysis framework of PSS considering resources

This chapter mainly focuses on the resource allocation step in the proposed framework to achieve efficient execution of service process. For example, in the air conditioner repair service (see chapter 6), it requires engineer to carry repair tools and parts, drive to the agreed site to perform the task. But the engineer's schedule may already be filled with other tasks, or the parts may be out of stock. In these situations, it requires waiting for these resources to become available again, or select other resources to perform the task. When calling other resources, the execution efficiency of the task may change. Because the capabilities of different resources are often different, such as engineer *A* can complete the repair in half an hour, but engineer *B* may take two hours due to his or her unfamiliarity with this type of repair. Therefore, how to complete the order efficiently through reasonable resource allocation is the practical problem that this research intends to solve.

5.3.2 Concepts of Resource Allocation in PSS

The following defines the relevant concepts and establishes a mathematical model for the resource allocation step in the framework. The definition can be divided into two parts, the definition of resource and the definition of service. During a resource allocation process, a $(-)$ is used as the prefix to indicate the value of a variable before it is involved in the configuration. Variables without the prefix notation default to the general state, with no particular emphasis on the state of the resource and state changes.

Definition 5.1 The customer resource R_{demand} is stored in the form of service order, and the service order O is the entity corresponding to the customer's service request in the service system. The two can be expressed as:

$$R_{demand} = (cID, oID)$$

$$O = (oID, oLoc, oNeed, oTime)$$

where,

- R_{demand} is customer resource, which consists of a customer code cID and order code oID . cID is a unique number that identifies a customer, and oID is a unique number that identifies an order;
- $oLoc$ is the location of the order. The location of the order reflects where the customer wants to be served;
- $oNeed$ is the type of customer's need;
- $oTime$ is the generation time of the order.

Definition 5.2 The service resource R_{supply} refers to the resource that can be provided by actors, which are stored in the virtual resource pool. The service system will match the resources and the needs. The service resources can be expressed as:

$$R_{supply} = (sID, rID, rLoc, rType, rName, rCapability, rState, N_{remain})$$

where,

- sID represents the code of the actor providing the service, uniquely identifying an actor;
- rID is the code of the resource, which uniquely identifies a resource;
- $rLoc$ is the location of the resource. If the distance between $oLoc$ and $rLoc$ exceeds a certain threshold, the resource does not have the ability to serve the order;

- $rType$ is the type of resource, and the variable can be assigned according to different resource classification methods according to business needs;
- $rName$ is the name of the resource;
- $rCapability$ is the capability set of a resource, which reflects whether the resource is a flexible resource. If $rCapability$ contains only one element, the resource is a common resource, and if there is more than one capability, the resource is a flexible resource. This research represents the capability level of flexible resource by quantifying the specialization level of resources. For a specific service task, the capabilities of flexible resources can be expressed in the form of a set:

$$rCapability = \{(cName, avg(T_e))\}$$

where $cName$ is the name of the capability, T_e refers to the service execution time spent by the flexible resource to perform specific tasks to meet customer needs.

- $rState$ represents the state of the resource, if the resource is now available, then $rState=1$, otherwise, if the resource is unavailable during that time period, $rState=0$.
- N_{remain} indicates the remaining number of resources.

Definition 5.3 The allocated resource $R_{allocation}$ refers to the resources participating in the resource allocation process, and is combined with the service to form a service solution. The configured resource contains the type and quantity of the resource and can be expressed as:

$$R_{allocation} = (R_{supply}, N_{allocation})$$

where,

- R_{supply} is the same as it of Definition 5.2;
- $N_{allocation}$ is the number of resources configured.

Definition 5.4 Atomic service, also named primitive service, is the smallest granularity of services that can no longer be segmented. It is stored in the service repository, and it can be defined as:

$$S = (sID, sName, sNeed, sCapability)$$

where,

- sID is the code of the atomic service;
- $sName$ is the name of the atomic service;
- $sNeed$ represents the set of requirements that the atomic service can be used to satisfy;
- $sCapability$ is the set of capabilities required by the atomic service.

Definition 5.5 Service pattern, also known as Business-Oriented Service Complex, is a series of primitive service that can fit customer's need efficiently (Wang et al. 2013). It is related to a priori business, which can realize the mapping of service requirements to specific service combinations. It can be represented by a multi-dimensional vector (Zhuang et al. 2016) as:

$$SP = (pInfo, pService, pResource, pConstraint, pNeed)$$

where,

- $pInfo$ is the basic information set of the service pattern, including the service pattern code $spID$ and the applicable service processes;
- $pService$ stores the atomic services included in the service pattern and the logical relationship between them;
- $pResource$ is a collection of resources required by the service pattern;
- $pConstraint$ is a set of constraints of service modes, mainly including logical constraints and association constraints between atomic services;
- $pNeed$ is the set of requirements that the service model can be used to satisfy.

Definition 5.6 Service scheme is a service execution plan for the process, which include atomic services, service patterns, and logical relationships between them, which can be defined as:

$$\mathbb{S} = (C(S), C(R_{allocation}))$$

where,

- $C(S)$ represents a collection of services, which store atomic services, service patterns, or a combination of the two required by the service solution;
- $C(R_{allocation})$ represents a collection of allocated resources.

5.3.3 Resource Allocation Model for PSS

In PSS, the service system provides knowledge support for the whole life cycle of the service process through knowledge extraction by process mining, specifically in three areas: clarifying the process, mining service association rules and mining resource behaviors.

The service process can be obtained through process mining algorithm, as well as the key activities related to resource allocation can be obtained through value analysis. The association between services is defined as $Cor < s_i, s_j > \Leftrightarrow p(s_i, s_j) \geq P$ (Xu et al. 2017). If the collaboration probability $p(s_i, s_j)$ between two services is greater than a certain threshold P , then these two services are the set of associated services. In the heuristic mining algorithm, the collaboration probability and order relationship between services can be measured by $a \Rightarrow_W b = \left(\frac{|a>_W b| - |b>_W a|}{|a>_W b| + |b>_W a| + 1} \right)$. $a \Rightarrow_W b$ takes a value between $[-1, 1]$, and the more the value tends to 1 or -1 indicates a stronger sequential relationship and dependence between the two (Weijters, Aalst and Medeiros 2006). In this research, we define that if the dependency between two activities is greater than 0.9, then they are positively sequential and have a strong association. The historical behavior information of resources can be obtained by mining service value.

According to the framework of Figure 5.2 and concept definition, a model for resource allocation process is established as follows:

$$\min T = \min (T_p (rState, oLoc, rLoc) + T_e (\mathbb{S})) \quad (5.1)$$

s.t.

$$cp (\mathbb{S}) \geq oNeed \quad (5.2)$$

$$|oLoc - rLoc| \leq d, \forall r \in R_{allocation} \quad (5.3)$$

$$rState = 1, \forall r \in (-)R_{allocation} \quad (5.4)$$

$$N_{allocation} > 0, \forall r \in R_{allocation} \quad (5.5)$$

$$N_{remain} - N_{allocation} \geq 0, \forall r \in (-)R_{allocation} \quad (5.6)$$

$$|rCapability| \geq 1, \forall r \in R_{supply} \quad (5.7)$$

$$p(s_i, s_j) \geq P_{correlation}, \forall s_i, s_j \in pService \quad (5.8)$$

$$ST_{s_j} \geq FT_{s_i}, \forall s_i, s_j \in C(S), \forall i < j \quad (5.9)$$

$$FT_{s_i} - ST_{s_i} > 0, \forall s_i \in C(S) \quad (5.10)$$

Equation (5.1) is the objective function of the model, that is, to meet the customer's

service needs in the shortest time. According to the service process life cycle, it can be decomposed into solving the problem of minimizing the sum of service preparation time $T_p(rState, oLoc, rLoc)$ and service execution time $T_e(\mathbb{S})$. This model is to rapidly integrate and match the orders, services and resources of both supply and demand sides to provide customers with efficient and complete big services. According to the actual situation of service-oriented manufacturing industry, this research mainly considers the time-consumption of service preparation phase and service execution phase of the service process life cycle.

Equation (5.2)-(5.10) are constraints of the model. The constraints of the model can be divided into two parts, one part is the constraints arising from the matching between the integration requirements and the integration services and resources. The other part is the constraints formed within the service process. Equation (5.2)-(5.7) are the constraints generated by the matching process. Different demands of orders, different types of services, and different states and efficiencies of resources will all have an impact on resource allocation.

In equation (5.2), $cp(\mathbb{S})$ represents the service capability value of \mathbb{S} , which needs to be greater than the user's requirement $oNeed$ (Wang et al. 2022); Equation (5.3) indicates that for all configured resources, the location $oLoc$ of the customer should be within the distance d that the actors and their partners can provide the service. Equation (5.4) states that the resource can only participate in the task if state of it is 1; Equation (5.5) means that for all the resources $R_{allocation}$ involved in the allocation, the number of configurations $N_{allocation}$ needs to be non-zero; Equation (5.6) indicates that for all resources $R_{allocation}$ involved in the configuration, it is necessary to determine whether the number of configurations $N_{allocation}$ exceeds the remaining number N_{remain} before configuration, if it exceeds N_{remain} , the constraint is not met and cannot participate in the allocation; in Equation (5.7), for all R_{supply} , the number of capabilities $|rCapability|$ needs to be greater than or equal to 1, otherwise the resource does not have the prerequisite to create value.

Equation (5.8)-(5.10) are the constraints formed within the service process. This thesis measures indivisibility by the correlation properties of services. The correlation relationship between services is defined as $Cor < s_i, s_j > \Leftrightarrow p(s_i, s_j) \geq P$ (Xu et al. 2017). Referring to this definition, the measurement based on service pattern is proposed as Equation (5.8). As it is mentioned above, a service pattern is a collection of business-related services which is related to the prior tasks (Wang et al. 2013). This thesis uses Equation (5.8) to verify whether there is a correlation between service tasks, that is, if any s_i and s_j belong to the same service pattern, then the collaboration probability $p(s_i, s_j)$ between them should be higher than a certain threshold $P_{correlation}$. The s_i and s_j are any two primitive services or service patterns in the $C(S)$ that have

a sequential logical relationship. Equation (5.9) indicates that if s_i is executed before s_j , then the start time ST_{s_j} should be later than the end time FT_{s_i} . Equation (5.10) indicates that the execution time of the service task should be greater than 0.

5.4 Solution for the Resource Allocation Model

Based on the defined framework, concepts and models, this section proposes the following solution considering the service process lifecycle.

5.4.1 Idea of the Solution

The operation of a service system is a continuous cycle, in which a new log is generated in one operation, which in turn can be used as the data for the next cycle. A professional division of labour for resources can improve the efficiency of the service, and how to use professional resources to deal with domain problems is an important issue to be considered in process optimisation (Zhao and Liu 2014). This section presents a process mining-based solution for optimizing the analysis of resource allocation.



Figure 5.3 The solving process of resource allocation problem

The idea of solving the resource allocation problem is shown in Figure 5.3. The outer loop represents the operation of the service system, and the inner loop represents

the continuous update of the resource state. The details of the solution process of resource allocation problem are as follows.

5.4.1.1 Process Mining

In the database of information system, there are a large number of event logs that record historical information. The actual process, resource type and efficiency information can be obtained through process mining techniques. It can provide basis for Equation (5.8) and following service aggregation.

5.4.1.2 Integration of Needs

Integrate and categorize needs of customers. The customer's need may reach the service provider in various ways, or the service provider may actively generate service requirements before the customer finds the problem. These requirements are passed into the service system in the form of O .

5.4.1.3 Service Configuration

Under the constraints of SLA, build service process and select services that match orders. The service model is matched to S and SP according to the correlation between the customer's needs and the services obtained through process mining.

5.4.1.4 Resource Allocation

Atomic service and service patterns configured in the service process require various resources. Multiple resources of various actors conforming to Equation (5.7) are stored in the virtual resource pool in different $rState$. They have different efficiency of the service for different tasks due to their specialised properties difference. This step requires considering the constraints of the model to find the optimal solution under the resource constraints.

First, the service system integrates the bilateral resources. For the customer side, the service system needs to extract the demand category $oNeed$ and location $oLoc$ from the order arriving at the system. For the actors providing the service, the service system combines all the \mathbb{S} that can satisfy the demand and are relatively efficient into the candidate service solution set \mathbb{CS} according to Equation (5.2). Then it judges in the \mathbb{CS} whether the $C(R_{allocation})$ in \mathbb{S} meets the constraint of Equation (5.3), and if the distance is beyond the scope, then \mathbb{S} is removed from \mathbb{CS} . And the service solutions in \mathbb{CS} are arranged in ascending order according to the service execution time T_e . Then it scans each \mathbb{S} in \mathbb{CS} sequentially, if all the resources required in \mathbb{S} satisfy Equation (5.4)-(5.6), these services and resources can form a complete large service to meet the needs of

the customer. And Equation (5.8)-(5.10) are considered to obtain the optimal resource constraint under logical restrictions. The resources are then configured and $rState$ of them are updated. If some of the resources required by \mathbb{S} are in an unavailable state, then scan the next \mathbb{S} . If all \mathbb{S} have some or all of their resources in an unavailable state, a wait or reorganisation operation needs to be performed as appropriate.

The waiting operation is to wait for the occupied resources to become available again ($rState$ changes from 0 to 1). The execution of services usually requires the participation of multiple resources, and the waiting time t_w is determined by the resource with the longest waiting time. Calculate the sum of the service preparation time and the service execution time, and select the shortest one, then record it as T_{temp_1} .

The reorganization operation is to configure alternative resources for service tasks based on historical data obtained by process mining. Executing a service task requires a simple resource or a subsystem (a collection of simple resources or other subsystems), and when some of them are unavailable, alternative resources can be used to execute the service task (d'Ambrogio and Zacharewicz 2016). In order to improve the response speed to customers, this thesis defines the concept of service reorganization. Service reorganization is to reorganize the resources required within a certain range. However, not all resources that have historically implemented this kind of service can participate in reorganization. Only historically sub-optimal but acceptable ones can be allocated. Thus, if these resources are used to execute the service tasks, the finish time may be earlier than the time to wait for efficient resources to complete the same tasks. The combination of these resources and tasks is defined as the sub-optimal service plan. When some of the resources are occupied, the solution with the shortest time-consuming T_{temp_2} is searched in the sub-optimal service plan. Then compared with the shortest waiting time T_{temp_1} , and choose the shorter to form an optimal solution.

5.4.1.5 Aftercare of Service

According to the above steps, the service execution plan can be obtained and executed. The service system will collect feedback information after the execution of the business, and dynamically adjust the use efficiency of resources according to the feedback to meet the needs of the next round of service orders.

5.4.2 Specific Steps of the Algorithm

According to the idea above, the allocation steps are shown in Table 5.1. Through these steps, the delivery of the order can be completed through a complex service. At the same time, the execution of the entire process only requires the service provider to allocate the right resources for the service task via the service system, thus reducing the involvement of the customer. In addition, PMRA is a dynamic resource alloca-

tion algorithm and collects feedback during subsequent operations in order to achieve continuous optimisation of the service system.

Table 5.1 Resource Allocation Algorithm based on Process Mining (PMRA)

Input: orders, event log
Output: service plan

Step 1: Using process mining algorithm to extract knowledge, including service processes, service actors, resources, etc.

Step 2: Combining related services into a service pattern;

Step 3: Extraction of $oNeed$ and $oLoc$ from order O for arriving systems;

Step 4: Service configuration of orders to form or update candidate service solutions \mathbb{CS} ;

Step 5: Sort \mathbb{CS} in ascending order by service execution time T_e ;

Step 6: Iterate through the \mathbb{CS} sequentially and if all resources in \mathbb{S} are available, form the optimal service plan for the order and skip to step 8;

Step 7: If the current resource is not available, wait or reorganise the operation, choosing the least time-consuming option;

Step 8: Complete the resource configuration for the order, update the resource status, execute the configuration plan, and collect feedback.

5.4.3 Method Comparison

The Randomised Resource Allocation Algorithm (RRA) is a simple and easy to implement base algorithm commonly used in a variety of systems. Genetic Algorithm (GA) is a heuristic algorithm that has also been applied to resource allocation in some research (Kim and Ko 2015, Mezache et al. 2016, Yao 2020). Here, we compare the PMRA algorithm with RRA and GA in terms of solution speed and solution quality. Since the consumption of parts is determined after the demand order is determined, this section makes an algorithm comparison under the assumption that the number of parts is sufficient. RRA refers to an algorithm that allocates resources based on the rules of random dispatch. Engineers with historical experience can accept orders. While waiting, the service system will give priority to the engineer who is about to complete the current task. GA is a widely used algorithm in resource allocation (Yao 2020). It refers to the idea of solving resource allocation problem through GA proposed by Mezache et al. (2016), using activities as chromosomes and engineers as genes, and measuring fitness through total service time T . Taking the air conditioner repair service data as a case (see chapter 6), we developed a program using java to verify the solution. Considering the geographical and regional relevance of air conditioner repair service, we compare the configuration efficiency and configuration results of the three when 10, 20, 30, 40, and 50 orders arrive at the service system under the same number of parts, the same order quantity and generation time, and the same order type. As shown in Figure 5.4

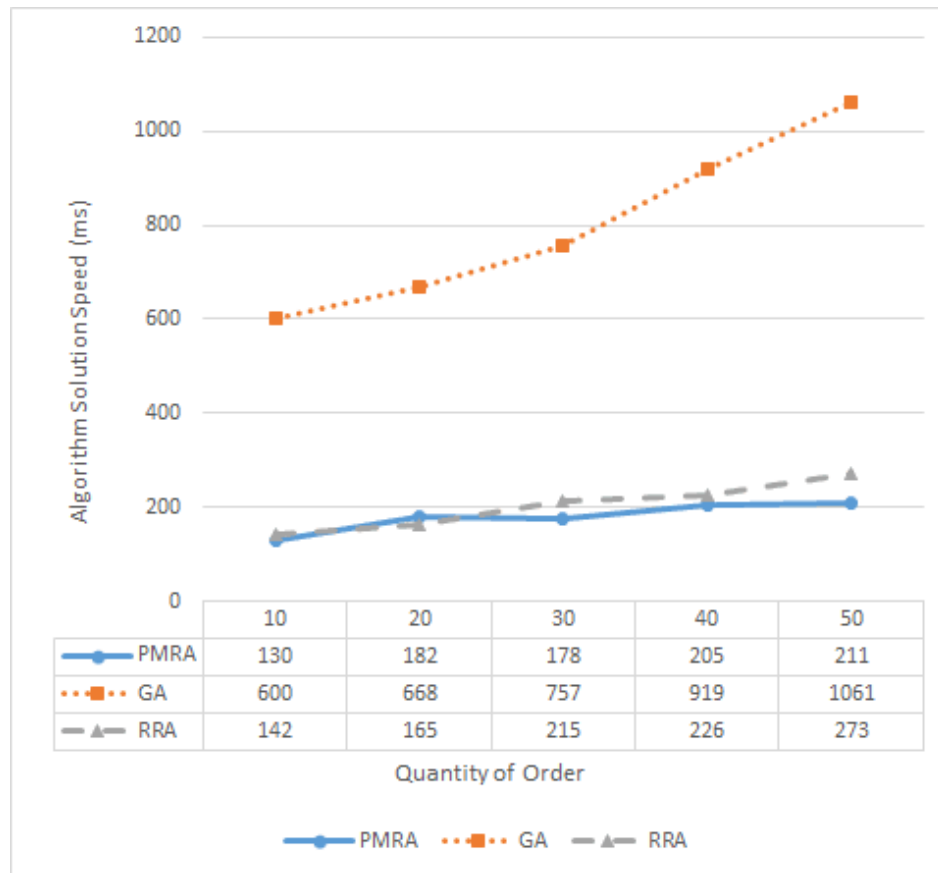


Figure 5.4 Algorithm speed comparison

and Figure 5.5, they demonstrate the speeds and results of the three algorithms when 10-50 orders arrive at the service system.

Figure 5.4 is a comparison of the speed of the three algorithms. With the increase in the number of orders, the solution speed of the three algorithms is increasing, but the solution speed of GA increases the fastest. With the same initial state of variables, GA has the longest running time, and PMRA and RRA have roughly the same running time. In addition to the defect that the GA algorithm itself is slow to solve, GA also ignores the characteristics of the process, which is also one of the reasons for the slow solution speed. For example, when generating the initial solution, GA does not consider resource behavior information, resulting in poor initial solution quality.

Figure 5.5 is a comparison of the solution quality of the three algorithms. PMRA takes about 5-20 hours less than GA, and about 5-30 hours less than RRA. Since PMRA is a dynamic allocation algorithm, resources can be allocated directly to the order when the order arrives at the system, while GA needs to wait for a period of time so that the order can form chromosomes before resource allocation. So GA takes longer than PMRA. Besides, RRA ignores resource behavior information when dispatching orders, and places too much emphasis on the response speed of a single order, resulting in

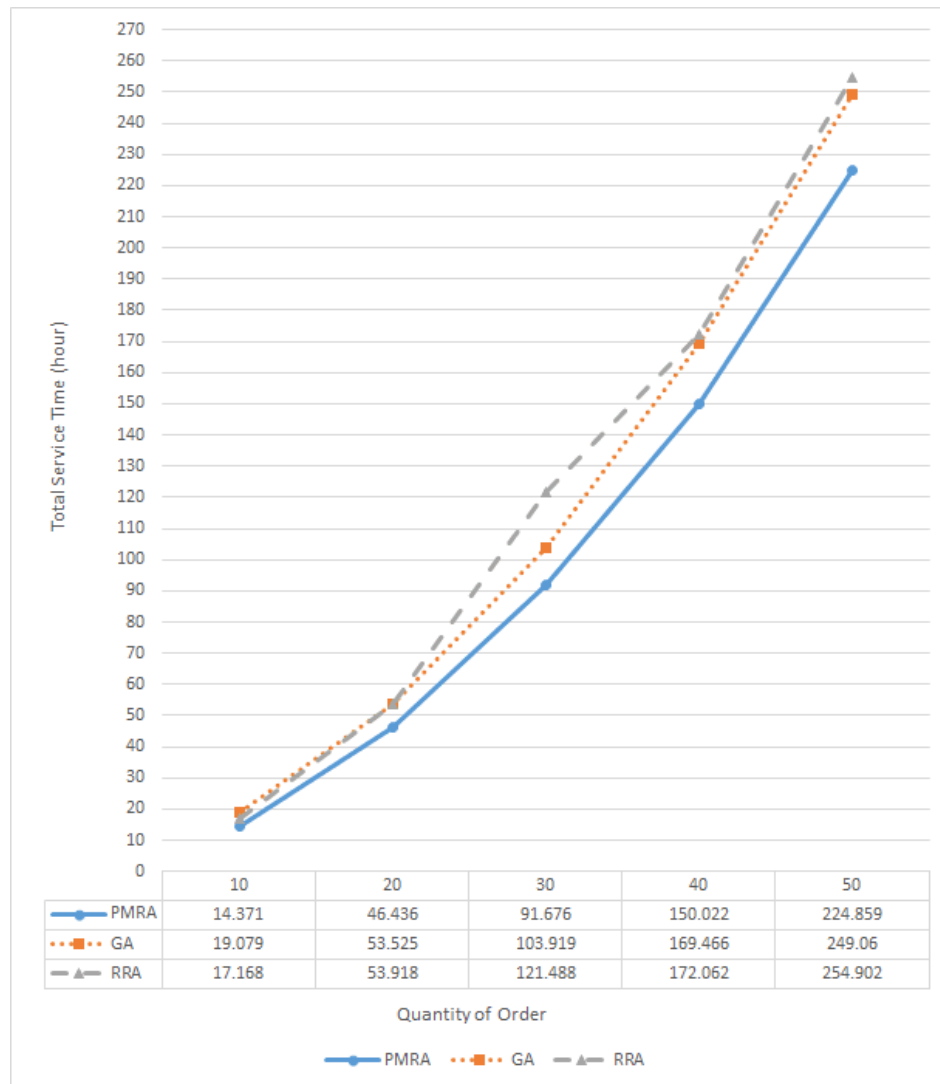


Figure 5.5 Algorithm solution quality comparison

an increase in the overall time-consuming. On the other hand, due to the existence of randomness in GA and RRA, the quality of the solution is very unstable, and it is highly dependent on the initial solution, and GA is also affected by parameter settings.

Although the service system is not limited by time and space when accepting service orders, the repair of air conditioner is limited by time and space, which is closely related to the characteristics of the product and service. Air conditioner is large home appliance and usually requires professional engineer to come to the house to repair it when a fault occurs. It is necessary to consider the location where the air conditioner is installed, the available time of customer, the engineer’s schedule, and the availability of the equipment and spare parts needed for the repair, all of which will have an impact on the service process. In practice, service points and maintenance engineers will be divided into different regions. Considering the service cost, cross regional repair services is not feasible. From the perspective of the whole service system, the number of service

orders is very large. However, the air conditioner repair will be determined according to the location of the air conditioner and completed by the service resources in the region. At the same time, considering customer satisfaction, the order should be fulfilled in the shortest possible time. In addition, according to our survey of H company, more than 90% of the work of air conditioner repair service is spare parts replacement, rather than on-site repair of defective parts. This practice can save a lot of time on site repairs and solves problems faster. And the replaced parts can be returned to the partner companies where they were manufactured for further processing. This is the service scenario for which our proposed algorithm is oriented, so it may not be applicable in other scenarios. Therefore, our algorithm has certain limitations in application scenarios, or we can extend the algorithm to apply to more service scenarios. In addition, this service scenario can be limited in its characteristics for heuristic algorithms, such as GA, and is therefore less satisfactory in terms of performance and the results obtained. As described above for air conditioner repair service, this experiment is applicable to large household appliance service scenarios that require on-site service. Its result can be used as a reference, but it cannot be considered that the algorithm is universal enough.

5.5 Conclusion

In this chapter, we propose a resource allocation method of product-service process based on process mining techniques. On the basis of reviewing the literature of product service system, resource allocation and process mining, we introduce an analysis framework of PSS considering resources, which combines the ideas of BIRIS, cloud computing and big service. In this framework, we describe the resource allocation problem in PSS, define the concepts of service resource, service order, service pattern and so on, and establish the mathematical model of resource allocation. Aiming at this mathematical model, taking the event log of the service system as the starting point, this chapter gives the solution idea and specific implementation steps based on process mining. The results show that the resource allocation method we proposed can complete the entire service with a shorter time. The main difference from other resource allocation methods is that the resource allocation method proposed in this research considers the actual execution of the service process, which fills the gap of research literature in this field to a certain extent. At the same time, it is also a new attempt to introduce process mining techniques into the resource allocation of service system.

Last but not least, compared with traditional resource allocation method in product manufacturing process, the proposed resource allocation for customer oriented service process allows to allocate different adequate resource and actor to meet different customer needs. This specific characteristic of customer oriented process is particularly important. Using the proposed method, individualized customer requirements can be

mapped to historical allocation records and an optimized allocation be selected to maximize customer satisfaction.

CHAPTER 6

Air Conditioner Repair Service Case Study

6.1 Introduction

In the previous chapters, the service value model construction framework based on process mining has been proposed; and two algorithms for constructing service value model are introduced. Furthermore, a solution to the resource allocation problem in the product-service process is given. In this chapter, a case study of air conditioner repair service will be used to show how to use the framework, mining algorithms and resource allocation method to construct and optimize the service value model. The event log of air conditioner repair service used in this chapter is from H company, a Chinese household appliance manufacturer. Air conditioner is one of its main products. Repair service is one of the important work of product after-sales, and it is a typical scenario that reflects the company's ability to satisfy customer needs.

In this chapter, to support the case study, the following software and tools will be used.

- ProM framework. The improved inductive miner is implemented as a plug-in of ProM. The version of ProM framework is 6.9, which was released in 2019, and its revision is 41850.
- BPMN-JS. It is used as an interface to a web-based service value model mining tool to present the result of value-oriented service process mining algorithm in the form of a BPMN model.
- Eclipse and Tomcat. Eclipse as a Java source code development environment and Tomcat as a web server runtime environment.
- Camunda and Camunda-modeler. Camunda v7.17.0 and Camunda-modeler v5.5.0 are used as process engines for the process simulation in resource allocation.

In addition, the data used in this case study is simulation data based on real data. Since the real data involves the key business and customer privacy information of company H, which cannot be fully disclosed, this thesis desensitizes and simplifies the original data provided by company H, and stores it in XES format.

6.2 Air Conditioner Repair Service

6.2.1 Repair Service System

According to the investigation of H company and the interview with the relevant personnel of air conditioner repair service, the air conditioner repair service system of H company is shown in Figure 6.1. It is a complex service platform built on the cloud environment. The core part mainly includes Access System, Intelligent Omnimedia Interactive System, Service support platform and Service Analysis Platform, as well as other auxiliary systems, including user data system, interactive assistant system, self-service access system, remote assistant system, and Service training system. These systems are uniformly managed by the cloud platform. In fact, some of them are operated by different parts of the company and some are operated by different cooperative enterprises.

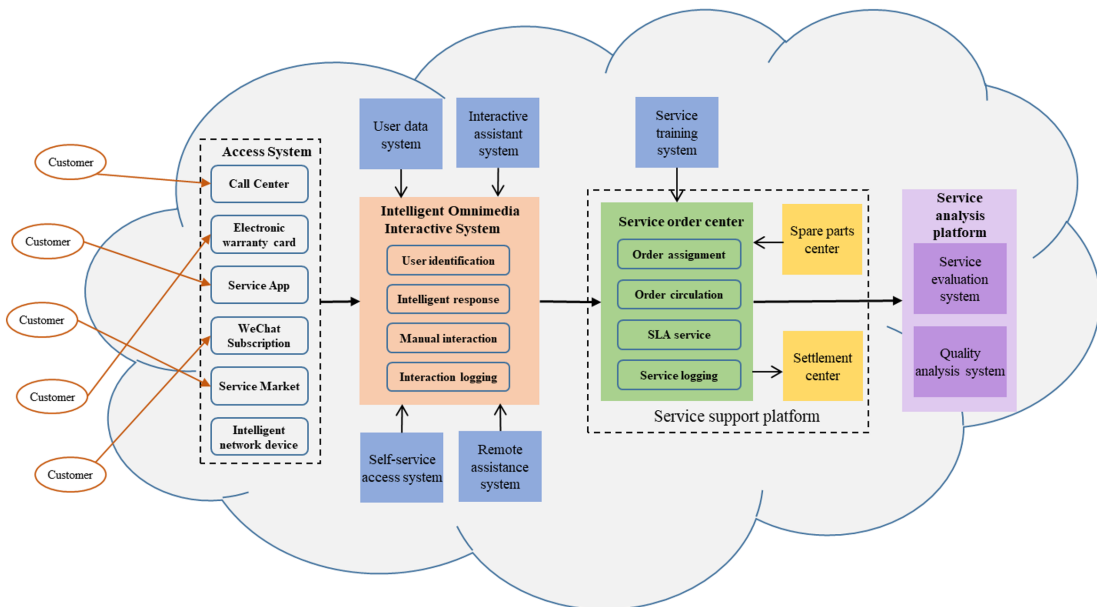


Figure 6.1 Air conditioner repair service system

In these systems, the Access System is the interface to obtain customer service requirements, and provides different access methods for customers. Access methods include call center, Electronic warranty card, Service App, WeChat Subscription, Service Market and Intelligent network device. The Intelligent network device access method is used by air conditioners installed with sensors and corresponding applications to automatically submit service requests via the network when the air conditioner breaks down, with prior authorization from the customer; all other methods are initiated by the customer personally through the use of phone, mobile apps, web, etc. The Intelligent Omnimedia Interactive System processes customer requests from different access

methods, including user identification, intelligent response, human interaction, and interaction logging. In general, firstly, with the assistance of User Data System, the user is identified through the service demand information submitted by the customer, identifying customer information, product information, etc. Then, with the support of the Intelligent assistant system, Self-service access system and Remote assistant system, the intelligent response system or the customer service personnel respond to the service needs in order to solve the customer's problem. The interaction process with the customer will be saved in the system by the interaction logging function. Service support platform includes three parts: service order center, spare parts center and settlement center. Service order center is responsible for order assignment, order circulation, SLA service and service logging; Spare parts center manages the spare parts needed for air conditioner repair services; Settlement center provides support for the settlement of each participating entity in the service process. The service training system provides training, information management, grade assessment and other functions for air conditioner maintenance engineers, and is used to assist in the distribution and completion of service orders. The service analysis platform is divided into two parts: the service evaluation system, which evaluates and analyzes repair services, and the quality analysis system, which analyzes the quality of services, products and parts.

In the case study of this thesis, the repair services triggered by the access method of the Intelligent network devices are not considered. In addition, in the actual service process, if the intelligent response system can solve the customer's problem, the customer service staff will be required to return and confirm the customer's visit subsequently.

6.2.2 Service Scenario

As a manufacturer of air conditioners with an annual output of over 20 million units, after-sales service is a very important part of the business, and repair service is the key to after-sales service, because the probability of failure is inevitable in so many air conditioners. Regardless of the situation that is automatically initiated by the intelligent network device, a typical air conditioner repair service process initiated by the customer is described below.

The service process starts from the customer's application for repair, in which the application for repair is manually applied by the customer through different channel, such as call center, Wechat subscription, service app, or service market, as shown in Figure 6.1. After receiving the application, the Intelligent Omnimedia Interactive System will identify the customers according to the customer information, and feedback automatically through the chat robot. If the robot cannot solve the customer's problem correctly, it will be transferred to the manual customer service staff, who will further try to solve the customer's problem. Some simple common problems can be solved at

this stage, such as the problem that the air conditioner cannot be turned on because the remote control has no power. For the problem that cannot be solved by the service staff, he or she will issue a service order through the service order center. The service store or maintenance engineer obtains the order through the service order center, and then the repair personnel go to the customer's place for repair at the appointed time. When the repair is completed, it needs to test whether the fault has been fixed. If the fault has not been eliminated, it needs to be repaired again. If the fault is eliminated, the repair service is delivered successfully. It is usually impossible to repair the air conditioner for an unlimited number of times. When the air conditioner cannot be fixed in 3 times, it will be given up and provide customer with replacement service. After the completion of the service, customers can evaluate the service, and finally the system needs to archive the information of the whole repair service. Since the data in the log involves the business operation information of the enterprise and cannot be completely disclosed, we have processed the data.

6.2.3 Service Event Log

The service event log is a collection of records of air conditioner repair services. Each Trace in the log is a specific service instance. As shown in Figure 6.2, it is a trace of a service process instance of air conditioner repair in the service log of H company after processing. The name of the trace is Repair7, and there are 11 events in it, including Apply Repair, User Identification, Intelligent Response, Manual Interaction, Release Order, Order Assignment, Repair, Test Repair, Success, Service Evaluation and Archive. In each event, the "time:timestamp" attribute indicates when the event occurs, and the "lifecycle:transition" attribute indicates the state in which the event is located. For events that can be completed instantaneously, the start state and the end state can be considered as occurring at the same time, and the value of the attribute is only "complete", i.e., only E_c in Definition 4.1 exists, while for events that require a certain time span to complete, the values of the attributes are "start" and "complete", i.e., E_s and E_c in Definition 4.1 both exist. The "org:resource" attribute indicates the service resources involved in the completion of the event, which can be various software systems, customer service personnel, engineers, etc., while the "org:role" attribute is the external entity, usually the customer.

In the Apply Repair event, the customer applied for repair through the service APP application, and submitted the product type and error code of the product as "PT003" and "E007" respectively. In the User Identification event, the user system confirmed that the product warranty period is "in" and the customer feature is "ES7" through customer information and product information. Subsequently, the interaction between the ChatRobot and the customer was an Intelligent Response event. Since the cus-

```

<trace>
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  <string key="description" value="Repair Service Process Instance"/>
  <event>
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    <string key="product.errorCode" value="E007"/>
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    <string key="lifecycle.transition" value="complete"/>
  </event>
  <event>
    <string key="org.resource" value="User System"/>
    <string key="product.warranty" value="in"/>
    <date key="time.timestamp" value="2020-07-25T12:02:00.000+08:00"/>
    <string key="concept.name" value="User Identification"/>
    <string key="lifecycle.transition" value="complete"/>
    <string key="customerFeature" value="ES7"/>
  </event>
  <event>
    <string key="org.role" value="Customer"/>
    <string key="org.resource" value="ChatRobot"/>
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  </event>
  <event>
    <string key="org.role" value="Customer"/>
    <string key="org.resource" value="ChatRobot"/>
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    <string key="concept.name" value="Intelligent Response"/>
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  </event>
  <event>
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  </event>
  <event>
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    <string key="org.resource" value="Staff3"/>
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    <date key="time.timestamp" value="2020-07-25T13:00:00.000+08:00"/>
    <string key="concept.name" value="Manual Interaction"/>
    <string key="lifecycle.transition" value="complete"/>
  </event>
  <event>
    <string key="org.resource" value="Staff3"/>
    <date key="time.timestamp" value="2020-07-25T13:16:03.000+08:00"/>
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    <string key="customerFeature" value="ES7"/>
    <string key="lifecycle.transition" value="complete"/>
  </event>
  <event>
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    <date key="time.timestamp" value="2020-07-25T13:41:31.000+08:00"/>
    <string key="concept.name" value="Order Assignment"/>
    <string key="serviceType" value="Repairment"/>
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    <string key="lifecycle.transition" value="complete"/>
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  <event>
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    <date key="time.timestamp" value="2020-07-25T16:00:00.000+08:00"/>
    <string key="concept.name" value="Repair"/>
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  </event>
  <event>
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    <string key="concept.name" value="Repair"/>
    <string key="repairDetail" value="Repair_PT003E007"/>
    <string key="lifecycle.transition" value="complete"/>
  </event>
  <event>
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    <string key="repairDetail" value="Repair_PT003E007"/>
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  </event>
  <event>
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    <date key="time.timestamp" value="2020-07-25T17:00:00.000+08:00"/>
    <string key="concept.name" value="Test Repair"/>
    <string key="repairDetail" value="Repair_PT003E007"/>
    <string key="product.status" value="fixed"/>
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  <event>
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    <string key="org.resource" value="Engineer5"/>
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    <string key="concept.name" value="Success"/>
    <string key="lifecycle.transition" value="complete"/>
  </event>
  <event>
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      <int key="evaluation:serviceAttitude" value="3"/>
      <int key="evaluation:satisfaction" value="3"/>
      <int key="evaluation:usability" value="5"/>
    </list>
    <string key="lifecycle.transition" value="complete"/>
  </event>
  <event>
    <string key="numberRepairs" value="1"/>
    <string key="org.resource" value="System"/>
    <date key="time.timestamp" value="2020-07-26T10:18:27.000+08:00"/>
    <string key="product.status" value="Fixed"/>
    <string key="concept.name" value="Archive"/>
    <string key="lifecycle.transition" value="complete"/>
  </event>
</trace>

```

Figure 6.2 An example of repair service Trace in XES log

customer's problem was not solved, the customer service agent "staff3" entered into the "Manual Interaction" with the customer. As the product is under warranty, the price type of the repair is "0", and the customer's address "address2" and the appointment time for door-to-door service "2020-07-25T16:00:00.000+08:00" are obtained. Then "staff3" recruited repair engineers for this service through "Release Order". The "Order Assignment" event indicated that the engineer responsible for completing the order is "Engineer5", the "netPoint" (branch) number is "4", the specific repair service type is "Repairment", and the corresponding repair manual (handbook) is shared. Engineer5 arrived at the customer's address at the agreed time for the "Repair", which began at 16:00:00 and ended at 16:41:43. The "Repair" event recorded the details of the repair, the model of part used, and the inventory information of the part. After the repair, Engineer5 conducted a "Repair Test" between 16:46:39 and 17:00:00. The result of the test is that the "product: status" is "fixed" and the number of repairs is 1. This led to the "Success" event. The engineer and the customer made a handover, and since the product was under warranty, the customer's "payment" for this repair was 0. In the "Service Evaluation" event, customers evaluated the service in terms of timeliness, service attitude, satisfaction and usability. Finally, the system archived the service, recording the number of repairs as 1 and the status of the product as fixed.

The processing of raw data from service logs is difficult because of the need to shield some sensitive data related to the company's critical business and private information of customers. In addition, the data set provided by the enterprise is relatively small, which may bring some minor deficiencies. We pre-processed the available data in conjunction with interviews with engineers and domain experts from the company. In this case the process model obtained from the event log used in process mining will be weakened and the actual business of the enterprise will be more complex. In addition, the sample of service event log contains service instances Trace triggered by the smart network device access method, but their pre-processing is handled automatically by the system and may only require human intervention after a service order has been released, so the service instances associated with them are not considered in this thesis for the time being.

6.3 Service Value Model of Air Conditioner Repair Service

In this section, the two algorithms proposed in Chapter 4 are used to mine the air conditioner repair service log, and the service value model obtained is represented by Petri net and BPMN respectively.

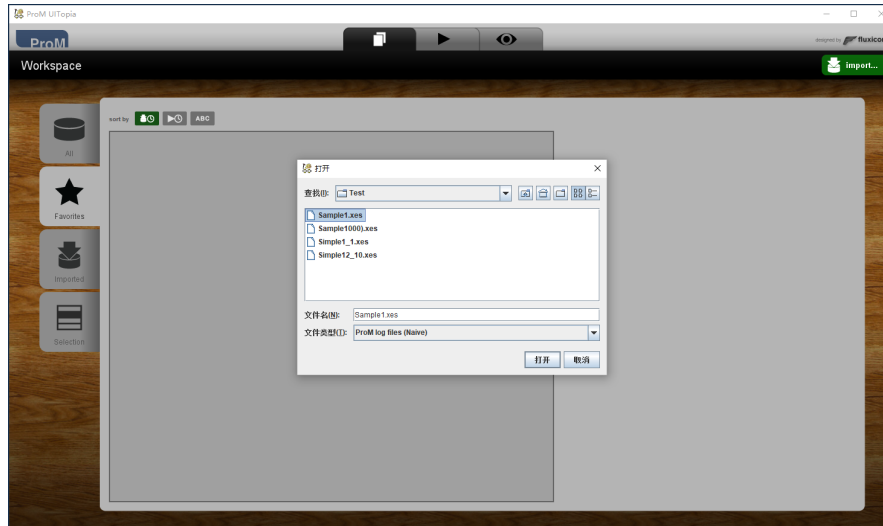


Figure 6.3 Import the service log sample

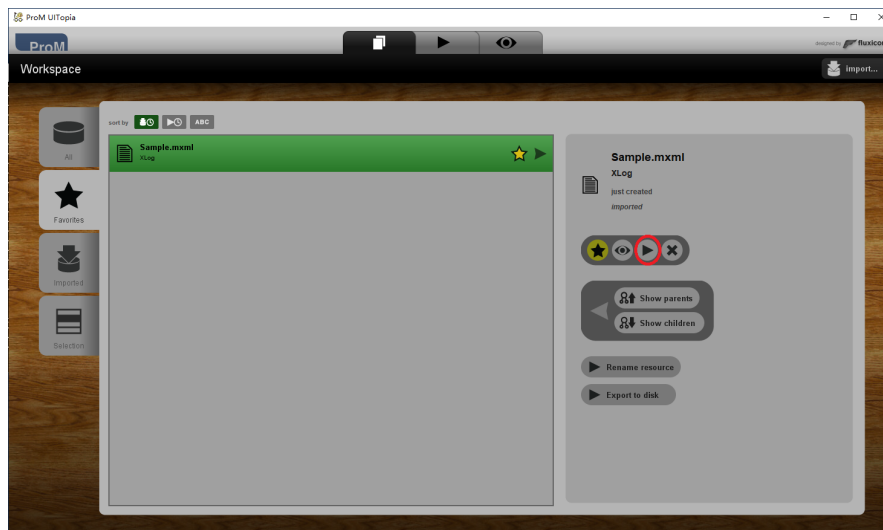


Figure 6.4 Workspace of ProM

6.3.1 Model Construction using Improved IM Algorithm

Since the improved inductive miner has been implemented as a plug-in to ProM framework, ProM is used here to demonstrate the process of constructing the service value model. First, we run ProM and enter the main interface, and select the service log sample file through the “import...” function, as shown in Figure 6.3. The ProM import plug-in will process the file to generate resources in MXML format. Then we access the resource operation interface through the “Use resources” function in the red circle in Figure 6.4. As shown in Figure 6.5, all plug-ins in the ProM framework will be displayed in alphabetical order in the window. In order to display the plug-in developed in this thesis at the top, it is named “OHIT Service Value Chain Miner”. Select this plug-in and click the “start” button to launch it for service value model building.

Since the service log sample has been processed, according to the idea of the im-

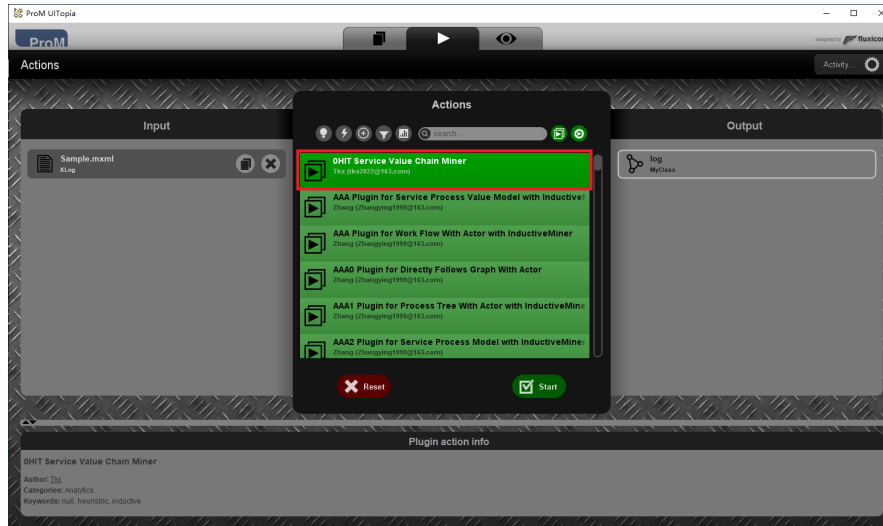


Figure 6.5 Select the plug-in in Actions window

proved IM algorithm, first generate the DFG with actors from the service log resource. The full figure of DFG with actors is too large and can be found in Appendix A. Figure 6.6 is a part of the DFG with actors starting from node (Intelligent Response, ChatRobot, Customer). This node has 3 edges, an edge with weight 6 pointing to node (Manual Interaction, staff3, Customer), an edge with weight 5 pointing to node (Manual Interaction, staff2, Customer), and an edge with weight 4 pointing to node (Manual Interaction, staff1, Customer). Additionally, node (Manual Interaction, staff3, Customer) has an edge with weight 5 pointing to node (Release Order, Staff3), node (Manual Interaction, staff2, Customer) has an edge with weight 3 pointing to node (Release Order, Staff2), and node (Manual Interaction, staff1, Customer) has an edge with weight 2 pointing to node (Release Order, Staff1). Nodes (Manual Interaction, staff3, Customer), (Manual Interaction, staff2, Customer), (Manual Interaction, staff1, Customer) have an edge pointing to themselves with weights 6, 5, 4 respectively. The edge's weight of directly-follows graph indicates the number of times the arc head node directly follows the arc tail node. For example, the edge with weight 6 from node (Intelligent Response, ChatRobot, Customer) to node (Manual Interaction, staff3, Customer) indicates that node (Intelligent, ChatRobot, Customer) directly follows node (Manual Interaction, staff3, Customer) six times; the edge with weight 6 pointing to node (Manual Interaction, staff3, Customer) which from itself indicates that node (Manual Interaction, staff3, Customer) directly follow itself six times.

The improved algorithm is then used to generate the process tree with actors, and transform it into workflow network with actors. Due to the complexity of the actual log's service process, in order to avoid the SPN being too complex, this section omits the process block in the actual SPN modeling. The transition nodes of different actors of the same activity in the workflow network are merged, and the actor relationships are

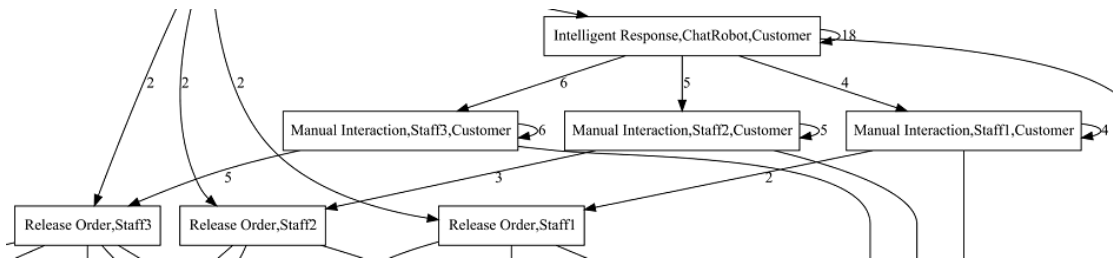


Figure 6.6 Part of the directly-follows graph with actors

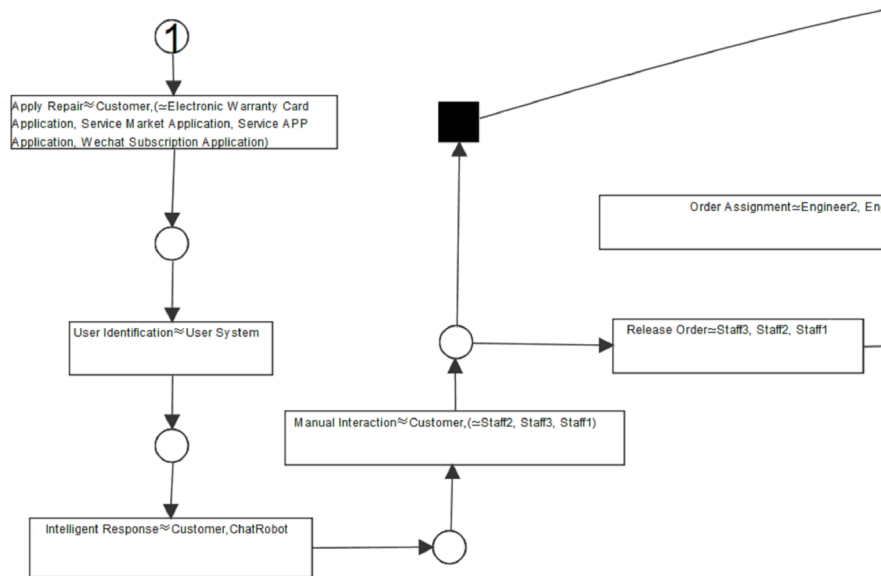


Figure 6.7 Part of the service process network with actors

identified and marked to obtain the SPN with actors. Figure 6.7 is a part of the SPN, the full figure of SPN with actors is too large and can be found in Appendix A. The process first starts with the activity Apply Repair, and the actor Customer is always appearing in every “Apply Repair” event in the log. In addition, only one of these actors, including Electronic Warranty Card Application, Service Market Application, Service APP Application and Wechat Subscription Application, can appear in each “Apply Repair” event, so the relationship among them is independent. The relationship between Customer and (Electronic Warranty Card Application, Service Market Application, Service APP Application, Wechat Subscription Application) is cooperation, and the node should be (activity name \approx Customer (\approx Electronic Warranty Card Application, Service Market Application, Service APP Application, Wechat Subscription Application)). In the same way, the node of the activity Release Order is (Release Order \approx (Staff3, Staff2, Staff1)), and the node of the activity Intelligent Response is (Intelligent Response \approx (Customer, ChatRobot)).

Then, the activities and actors in the SPN are separated and each activity and actor is treated as an independent node, and a value arc is constructed between the activity and the corresponding actor, and the value information is annotated on the value

arc. The value information annotated on the value arc is divided into three dimensions: time and space, profit and experience, and each dimension is separated by a semicolon. Figure 6.8 is a part of the service value model of the sample, and the activities in it are Release Order, Order Assignment and Repair from left to right. Activity Repair can be performed by each of the 7 participants independently, namely Engineer2, Engineer6, Engineer7, Engineer3, Engineer4, Engineer5, and Engineer1; The actors of activities Release Order and Order Assignment also can be found in the figure. There are two dashed arcs between each activity and the actors. The arc from the actor to the activity represents the value arc that flows into the activity, and the arc from the activity to the actor represents the value arc that flows out of the activity. For example, in the value arc between the activity Repair and the actor Engineer3, the value of Repair output to Engineer3 is the storage location of repaired parts [loc2,loc3,loc1,loc6,loc7,loc4,loc5,loc8,loc9] and the storage status of repaired parts [inStock]; the value of Engineer3 flowing into Repair includes the average repair time (AvgTime: 1h16m24s358ms), models of parts used to complete the repair [P005,P004,P007,P006,P001,P003,P002,P009,P008].

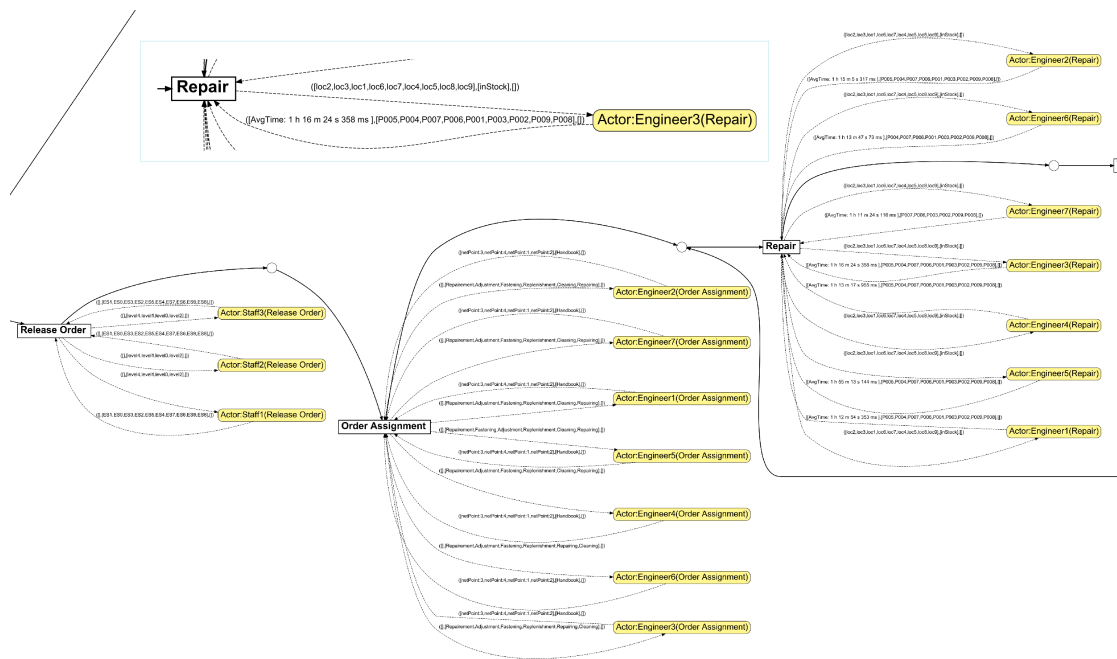


Figure 6.8 Part of the service value model

The improved IM algorithm forms a completed service process, which can identify four basic process structures (sequential execution, parallel execution, loop, and exclusive choice), and mine the actors, activity-actor relationships, and value flow in the service process, thus enabling the construction of a service value model.

6.3.2 Model Construction using VSPM Algorithm

We used a web-based development approach to implement the VSPM algorithm, using the Java programming language, to achieve the processing of service event log sample, the mining of process variants, the determination of service process model, the extraction of service value information and the construction of service value model. Since some of the figures in this section are too large, please see Appendix B for details.

Since the service log sample has been processed, according to the idea of the VSPM algorithm, Firstly, we select the XES file used to save the service event log sample and upload it to the web-based mining tool. Then we determine the set T of all Traces based on the dependencies of event E in each Trace. As shown in Figure 6.9, there are 5 different Trace records in the set T , indicating that there are 5 different types of service instances in the service log sample. Among them, the 1st type of Trace is the most typical air conditioner repair service scenario described in Figure 6.2, and the engineer fixed the air conditioner through 1 times repair; while the 2nd type of Trace is the worst repair service scenario, where the engineer repaired the air conditioner three times, but the fault had not been eliminated, and the air conditioner has to be "Renew". The 3rd type of Trace solved the problem of air conditioner failure during the interaction between customer service staff and customers. For example, the air conditioner could not be started due to the battery failure of the remote controller, and the battery was replaced under the guidance of the customer service staff. The Trace of type 4 and type 5 are cases where the engineer has eliminated the fault by two or three repairs respectively. We can count the number of times each Trace appears in the sample during processing, which is not shown in the figure.

1. Apply Repair --> User Identification --> Intelligent Response --> Manual Interaction --> Release Order --> Order Assignment --> Repair --> Test Repair --> Success --> Service Evaluation --> Archive
2. Apply Repair --> User Identification --> Intelligent Response --> Manual Interaction --> Release Order --> Order Assignment --> Repair --> Test Repair --> Restart Repair --> Repair --> Test Repair --> Restart Repair --> Repair --> Test Repair --> Renew --> Service Evaluation --> Archive
3. Apply Repair --> User Identification --> Intelligent Response --> Manual Interaction --> Service Evaluation --> Archive
4. Apply Repair --> User Identification --> Intelligent Response --> Manual Interaction --> Release Order --> Order Assignment --> Repair --> Test Repair --> Restart Repair --> Repair --> Test Repair --> Success --> Service Evaluation --> Archive
5. Apply Repair --> User Identification --> Intelligent Response --> Manual Interaction --> Release Order --> Order Assignment --> Repair --> Test Repair --> Restart Repair --> Repair --> Test Repair --> Restart Repair --> Repair --> Test Repair --> Success --> Service Evaluation --> Archive

Figure 6.9 Service process instances of the sample

Next, we can abstract and merge the individual types of Trace in the set T to obtain service process variants. As shown in Figure 6.10, these are 4 process variants obtained after abstraction. Of these, the first variant corresponds to the first type of Trace, and there is only a sequential relationship throughout the service process; the second variant corresponds to the second type of Trace, due to the existence of a chain of Events $\langle E(Repair), E(TestRepair), [E(RestartRepair), E(Repair), E(TestRepair)], E(Renew) \rangle$ in the Trace, where there is a loop in the corresponding variant; the third variant is con-

sistent with the third type of Trace; The fourth variant includes the fourth type and the fifth type of Trace. The only difference between the two Traces is that the number of cycles is 2 and 3 respectively, so they can be combined into one variant. Although the first process variant can be considered as the case that the fourth process variant is executed once in a loop, when analyzing Trace, the first variant does not have an activity chain with a loop structure, so it is an independent variant at this stage.

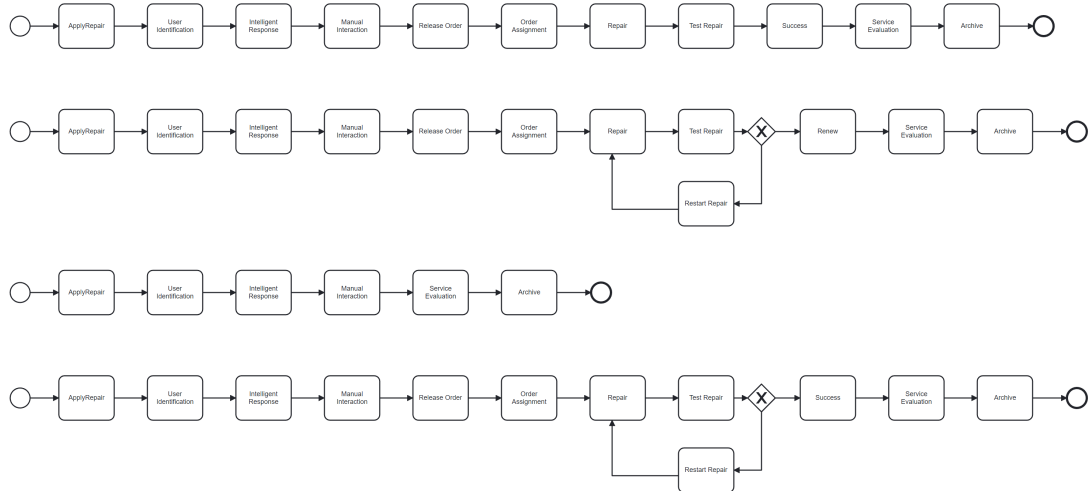


Figure 6.10 Service variants of the sample

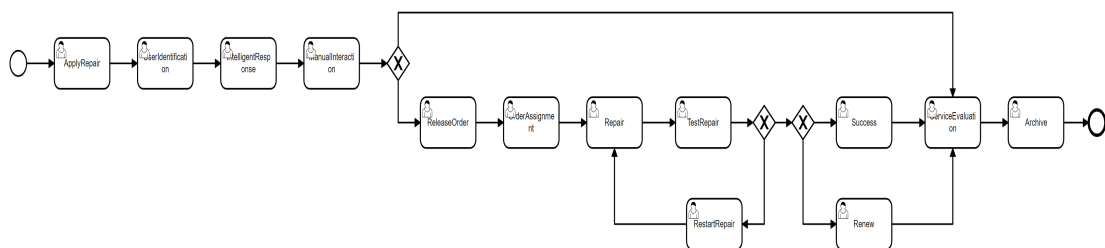


Figure 6.11 Service process model of the sample

According to the idea of merging variants into service process models in VSPM algorithm, we combined the four variants obtained in the previous step to obtain the service process model as shown in Figure 6.11. In all variants, the activity chain $\langle A(\text{ApplyRepair}), A(\text{User Identification}), A(\text{Intelligent Response}), A(\text{Manual Interaction}) \rangle$ is the first four activities, so they are merged into one. After the $A(\text{Manual Interaction})$, there is an exclusive relation, that is, there are two optional activities $A(\text{ReleaseOrder})$ and $A(\text{ServiceEvaluation})$. Therefore, there should be an exclusive gateway connecting to $A(\text{ReleaseOrder})$ and $A(\text{ServiceEvaluation})$ respectively. As mentioned in the previous paragraph, Variant 1 can be merged into Variant 4. For activity $A(\text{TestRepair})$, in addition to the loop, there are two exclusive

activities $A(Success)$ and $A(Renew)$ after it ends. Based on the above process, the service process model is built.

While building the service process model, actor information and value information can be extracted from the log sample for each activity. In fact, the process of constructing the value arc can be divided into two stages, firstly identifying the actors of each activity from the log based on the idea of “participation matrix” in section 2.4.2, and then extracting the input and output values of each actor for completing the activity, and connecting the activity and actor with value flow according to the definition of a value arc. As shown in Figure 6.12, it is a part of the value arc set of the log sample. In the figure, the left side shows the value arcs formed by activity $A(Order Assignment)$, its actors and the value flows between them; and the right side shows the value arcs formed by activity $A(Repair)$, its actors and the value flows between them. Other value arcs in the set are not shown in the figure; the complete set of value arcs can be found in the Appendix B.

Finally, we annotate the set of value arcs to the service process model, thus enabling the construction of a service value model. This is done by matching the activities in the value arcs with those in the service process model and merging the activities in the value arcs with the same activities in the service process, so that the value arcs are connected to activities in the service process and form a service value model. As shown in Figure 6.13, it is the service value model of the log sample represented by BPMN.

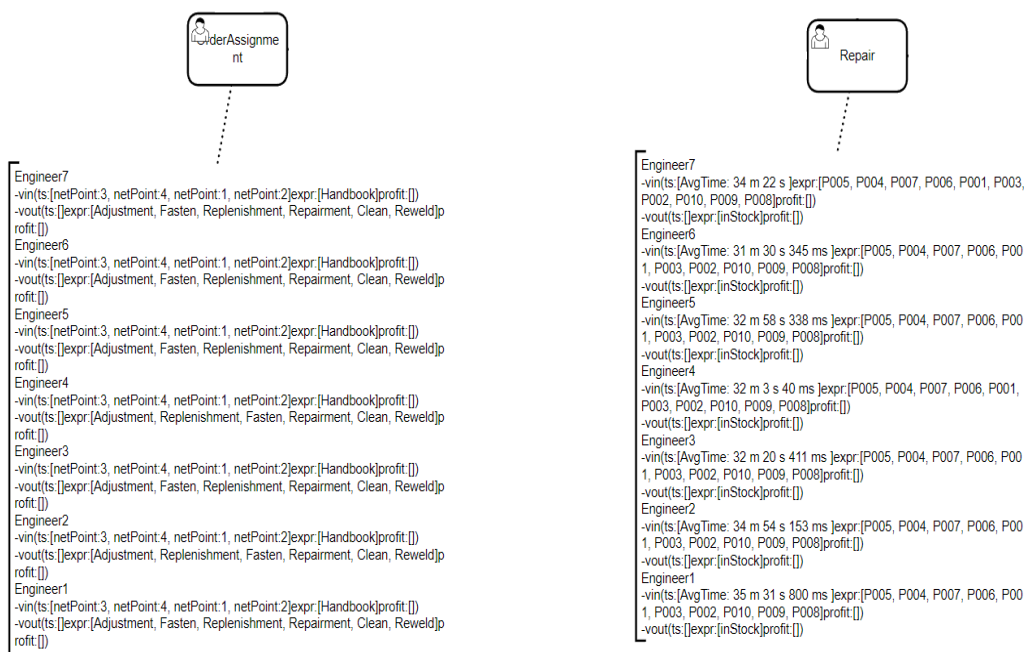


Figure 6.12 Part of the value arc set of the sample

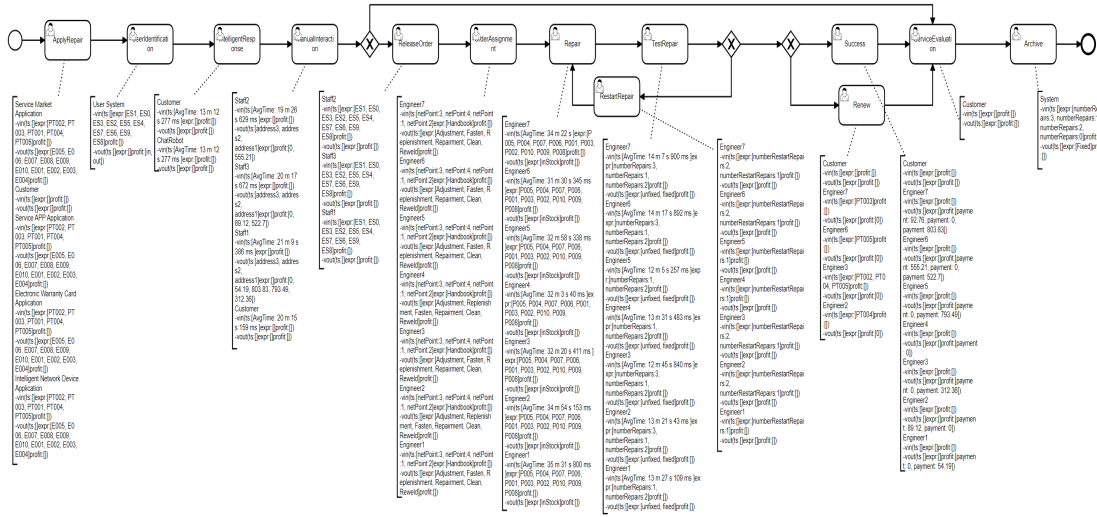


Figure 6.13 Service value model in BPMN

6.4 Resource Allocation in Air Conditioner Repair Service

The case in this thesis is based on the principle of FIFO, which prioritizes the allocation process to the orders that arrive earlier.

6.4.1 Knowledge Extraction

The service value model of the service event log samples is obtained using the two algorithms in the previous section. The “Repair” activities in the service value model are extracted in the form of BPMN as shown in Figure 6.14. It can be seen that the name of the service, actors and value information are all extracted. However, the “AvgTime” extracted from the service event log is the average time of all kinds of “Repair” activities by a certain actor. In addition, the types of parts in the service value model are also the total set of parts required for certain actor in all types of repairs. Therefore, in this chapter, the mining algorithm is improved to mine more accurate information of service time and part requirements. Then to mine the efficiency of engineers, which can be used as a basis for measuring T_e . The efficiency information of engineers is stored in a Hash Map structure, where the key is the specific error type, such as “PT001E002” is error 2 of product 1. The value is stored in LinkedHashMap, where the key is rID (engineer number). The value is the average repair time of this engineer in seconds, which is composed together with the “repairDetail” to form $rCapability$ of the engineer. The efficiency information in LinkedHashMap is sorted by the ascending order of $avg(T_e)$.

Figure 6.15 shows the results of mining the historical event logs. In Repair_PT004E005, there is a significant difference in capability between different engineers, Engineer7 has the lowest efficiency, requiring three times more time than Engineer5 to complete the repair. However, Engineer7 has the highest repair efficiency in Repair_PT004E004, so

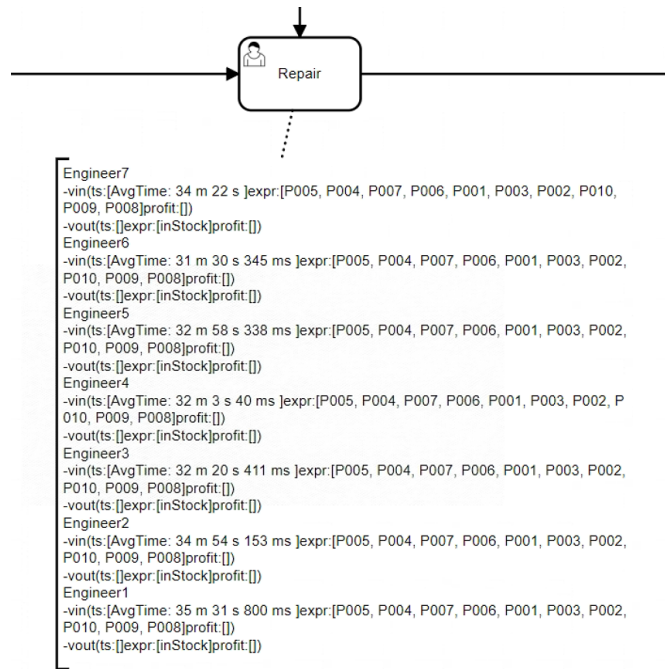


Figure 6.14 Repair activity in service value model

Engineer7 is better at repairing Repair_PT004E004 comparing to Repair_PT004E005. Since the repair efficiency of Engineer7 for Repair_PT004E005 task is too low to efficiently meet the customer's needs and the composed service solution cannot provide a quality solution for the customer, the service system will not involve Engineer7 in this kind of task configuration or reorganization when allocating resources.

```

Repair_PT004E005: {Engineer5=1439.5, Engineer2=2144.0, Engineer6=3258.333, Engineer4=3792.5,
Engineer7=4488.0}
Repair_PT004E004: {Engineer7=1589.0, Engineer6=2160.5, Engineer1=2683.333, Engineer3=2872.0,
Engineer2=3106.285, Engineer4=3218.5}

```

Figure 6.15 Partial efficiency information

By mining the historical logs, the demand for parts for various error types of different products can be obtained. Considering interviews with H company, we get that there are three states of parts. If the inventory is sufficient, the waiting time is 0. if the store inventory is insufficient and the parts need to be obtained from the warehouse, the customer needs to wait for 1 day. If there are no parts in the warehouse, the customer needs to wait for 3 days.

In this section, the focus of using process mining is to clarify the enterprise service process and obtain the relationship between activities and resource efficiency information. Hereby, some other valuable information about the process may be ignored. For example, the efficiency mining in this section is based on the start of repair and the complete of test repair by the engineer, but it does not consider whether the repair is successful or not, that is, it does not consider the situation of restart repair. Because

this information may also have some impact on the time-consuming of the engineer and customer satisfaction, this is a limitation.

6.4.2 Demand Integration and Service Matching

Customers can initiate the demand as well as the service provider can proactively identify the customer's needs. The service process can be obtained by process mining, if it is customer-initiated demand, it needs to go through the intelligent response first, if the problem is not solved, manual interaction is needed. If the problem still not be solved, the service order is formed according to the user description, enter the service system and wait for the service configuration and resource allocation. If the demand is generated through the identification of intelligent network device, it will be confirmed with the customer and then generate a service order to access the service system.

The speed of order generation is related to various factors, for example, during the peak season for the using of air conditioner, more orders may arrive at the service system within a certain time. This case assumes that 10-50 orders arrive at the system within half an hour in a given month. The subsequent example of 50 orders dynamically generated between 8:00 and 8:30 is used to illustrate the solving process of the PMRA algorithm. The differences in results and efficiency of PMRA algorithm, Genetic Algorithm and the Random Resource Allocation Algorithm are compared using 10, 20, 30, 40 and 50 orders respectively.

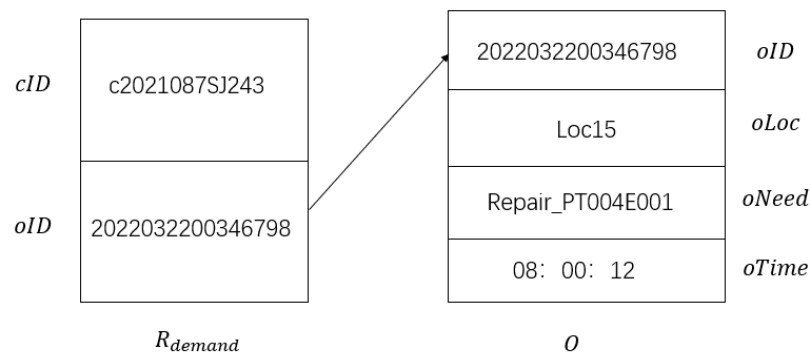


Figure 6.16 Customer order

As shown in Figure 6.16, *O* for PT004E001 is generated at 08:00:12, which is located at “Loc15”. Due to the characteristics of the repair service, the location where the order is generated is consistent with the location where the customer wants to be serviced. Considering the realities of the repair process, engineers usually have all the parts and tools they need for all of today's orders ready before departure, rather than completing one order and returning to the company to prepare the resources needed for the next. In the actual PSS lifecycle, however, the state of the service system is often elastic, especially for human-related activities, and there are often errors in the actual

execution (Man et al. 2019). Therefore, this thesis uses variable *errorTime* to measure the uncertainty of an engineer travelling to the next location. When the engineer travels to the next location, the *errorTime* is used to measure t_d to better suit the needs of this research’s scenario.

The analysis of the service value chain reveals that “Repair” and “Test Repair” are the key activities related to resource allocation because resources are used for “Repair” activity in the air conditioner repair service, and the “Test Repair” determines whether to do “Repair” again. In this case, the heuristic process mining algorithm was used to mine the causality matrix of the process, and the dependency relationship between “Repair” and “Test Repair” was found to be 0.9989, which is a strongly correlated sequential relationship (Weijters, Aalst and Medeiros 2006). The relationship was further mined by the “Event Name and Resource” classifier of the heuristic algorithm, and it was found that the actors of the “Repair” and “Test Repair” were the same engineer. Therefore, these two activities satisfy the constraints of Equation (5.8). Due to their inseparability, these two activities and their logical relationship and required resources can be combined to form a service pattern. Under the constraints of Equations (5.9) and (5.10), the logical sequence relationship in the service pattern is repair (start), repair (complete), test repair (start), and test repair (complete).

6.4.3 Resource Allocation

The resources considered in this section in the key activities are mainly divided into two categories, engineers and parts.

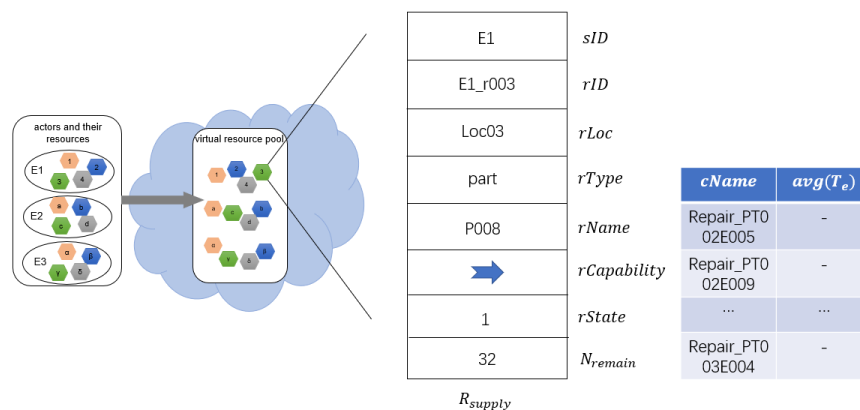


Figure 6.17 P008 storage structure

As shown in Figure 6.17, resources provided by different actors are allocated and managed uniformly by accessing the virtual resource pool. The storage structure of P008 is shown on the right. The engineers of different outlets are also stored in the virtual resource pool, waiting for the scheduling of service tasks.

This case assumes that the working hours of the engineer are from 8:00 to 18:00. For the arriving orders, the supply and demand sides are matched according to Equation (5.2). For a certain requirement, engineers whose $avg(T_e)$ is less than 30 minutes directly participate in the service task, and engineers whose $avg(T_e)$ is within 30-50 minutes are sub-optimal resources and participate in the reorganization. Engineers whose $avg(T_e)$ is more than 50 minutes cannot participate in this type of task. They should be configured in more suitable tasks, or they can participate in network training before performing this type of service.

After the resources and services are matched to form \mathbb{CS} , the resource and service combinations that are not within the service distance are deleted according to Equation (5.3), and \mathbb{CS} is updated. Then arrange the \mathbb{S} in \mathbb{CS} in ascending order of $avg(T_e)$, scan the service schemes in turn, and judge whether all the resources in the service scheme are available according to Equation (5.4)-(5.7). If all the resources are available, configure the resources and update $rState$. If all the \mathbb{S} in the \mathbb{CS} cannot provide services at the current time, perform wait or reorganization operations. If the wait operation is selected, the system will optimize the shortest time that the order needs to wait for scheduling or join the waiting sequence. After the current time is consistent with the waiting time, the waiting time will be passed into the function to configure the resource and update $rState$. If the reorganization operation is selected, the sub-optimal resources are allocated according to the schedule and $rState$. Finally the resource allocation plan of the order is obtained.

```

-----Repair_PT004E003-----
Success!
Order generation time: 1day 8:28
Engineer:Engineer3
Part:P004
Part remains:4
Service start time:1day 15:27
Service end time:1day 15:56
Tp:6.998h
Te:0.478h
T:7.476h

```

Figure 6.18 Repair_PT004E003 configuration results

As shown in Figure 6.18, take Repair_PT004E003 as an example to illustrate the resource configuration result output by the console. The order is generated and arrives at the system at 8:28. The service system configures Engineer 3 and P004 for the order. After the configuration is complete, the P004 remaining quantity N_{remain} is 4. The start time of the service task is 15:27, the end time is 15:56, the service preparation time T_p is 6.998 hours, the service execution time T_e is 0.478 hours, and the total service time T is 7.476 hours.

Table 6.1 shows the time arrangement and resource allocation results of some orders during the dynamic arrival of 50 orders to the system. The last order Repair_PT001E008 needs to wait for more than one day. This is because the stock of P002 is insufficient in the store. It needs to contact the warehouse to replenish the inventory. At this time, the warehouse has stock, so it needs to wait one day until P002 arrives before the repair service can be carried out.

Table 6.1 Part of the service plan

Order	Engineer	Part	Start Time	End Time	T_p (h)	T_e (h)	T (h)
Repair_PT004E001	Engineer6	P002	1day 8:30	1day 9:06	0.500	0.611	1.111
Repair_PT004E003	Engineer3	P004	1day 8:30	1day 8:58	0.500	0.478	0.978
...
Repair_PT001E007	Engineer1	P003	1day 13:41	1day 14:20	5.338	0.640	5.978
Repair_PT002E003	Engineer3	P010	1day 14:13	1day 14:57	5.850	0.746	6.596
Repair_PT002E003	Engineer1	P010	1day 14:50	1day 15:27	6.466	0.621	7.087
...
Repair_PT001E008	Engineer6	P002	2day 8:30	2day 9:12	24.09	0.713	24.80

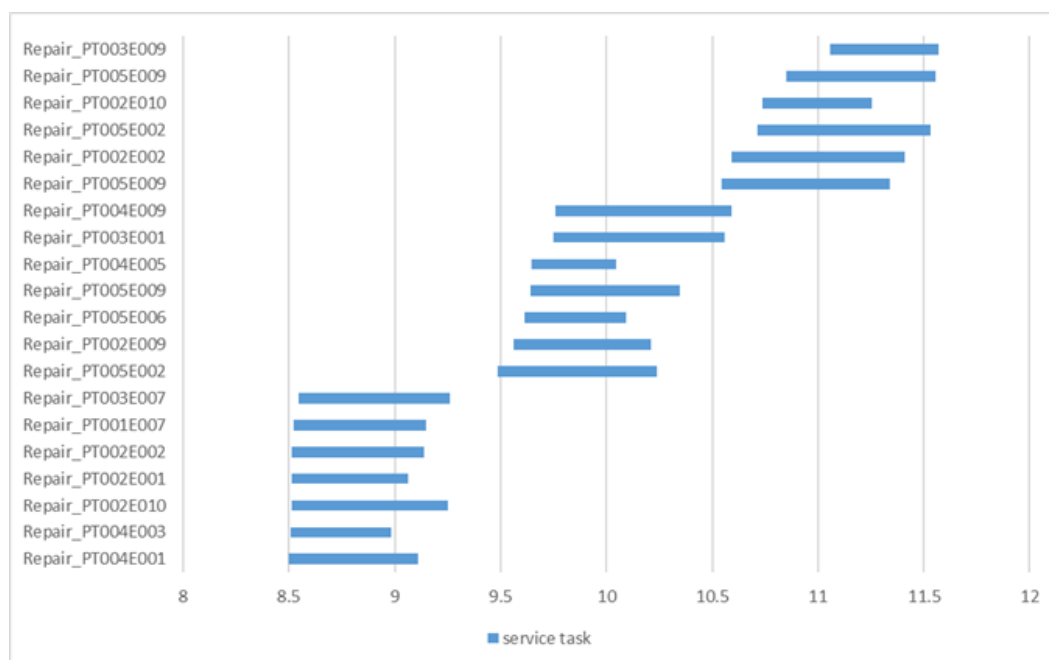


Figure 6.19 Service plan diagram

Figure 6.19 is a graphical display of the service execution scheme obtained according to Table 6.1. The horizontal axis is the time, the vertical axis is the order type, the blue bar is the service task, the time corresponding to the left endpoint is the start time of the service task, and the time corresponding to the right endpoint is the end time of the service task.

The implementation plan can be used in the resource allocation process of H com-

pany, and feedback is continuously collected to update the resource efficiency information to achieve the effect of continuous optimization.

6.4.4 Process Simulation of Resource Allocation

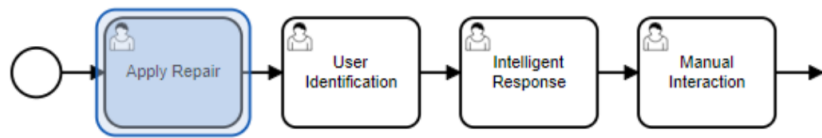
The environment for simulation of resource allocation is to integrate Spring Boot, Camunda v7.17.0 and Camunda-modeler v5.5.0. After getting the service plan, we use the Repair_PT002E010 service requirement as an example to show the simulation process and result. We do not take into account situations where companies actively identify needs in process simulation. Figure 6.13 shows the service process of H company. From “Apply Repair” to “Archive”, the service system integrates requirements and resources before assigning orders, and allocates resources according to the resource behavior information obtained by process mining. According to the obtained resource configuration results, the following simulation process can be performed.

As shown in Figure 6.20, it is the simulation process. The blue box represents where the activity goes, as shown in Figure 6.20(a), it means the process starts at “Apply Repair” activity. In the “Release Order” activity shown in Figure 6.20(b), the service system allocates resources to the order. In Figure 6.20(c) and Figure 6.20(d), and the “Repair” activity involves the transfer of various variables. The variables named “solve” and “repairDetail” are generated in the “Manual Interaction” activity, and their values represent whether the manual reply solves the customer’s needs and the type of repair respectively. Besides, “engineer” and “part” store the specific resource allocation plan. In this “Repair” activity, engineer *Engineer7* and part *P010* are involved.

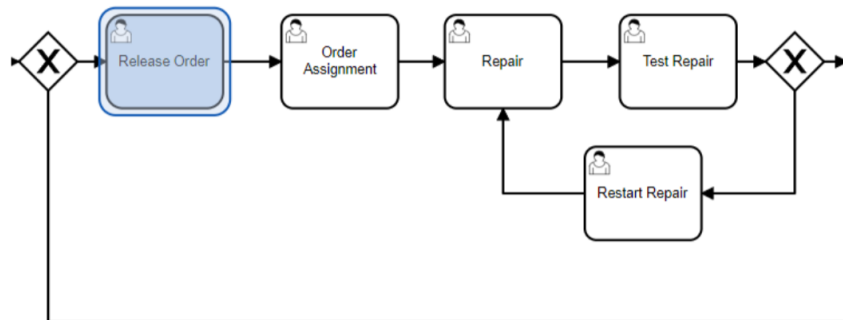
Table 6.2 Simulation results of activity nodes

Activity Node	Start		End	
	Day	Time	Day	Time
Apply Repair	1	7:00	1	7:00
User Identification	1	7:03	1	7:03
Intelligent Response	1	7:05	1	7:12
Manual Interaction	1	7:12	1	7:25
Release Order	1	7:31	1	7:31
Order Assignment	1	7:40	1	7:40
Repair	1	8:30	1	9:02
Test Repair	1	9:02	1	9:14
Success	1	9:15	1	9:15
Service Evaluation	1	11:37	1	11:37
Archive	1	11:41	1	11:41

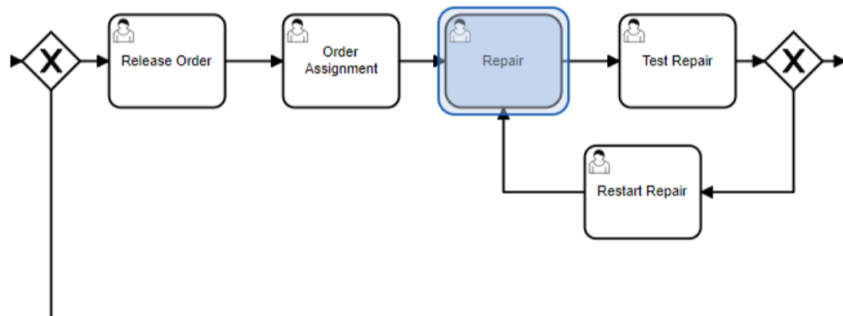
The start time and end time information of each activity node in the simulation is shown in the Table 6.2. If the start time is the same as the end time, it means that the duration of the activity is very short, which is consistent with the event which the



(a) Apply Repair



(b) Release Order



(c) Resource Allocation for Repair

Name	Type	Value
solve	Boolean	<input type="checkbox"/>
part	String	P010
repairDetail	String	Repair_PT002E010
engineer	String	Engineer7

Complete

(d) Part of the Process Simulation Diagram

Figure 6.20 Part of the process simulation

“lifecycle:transition” key only has the value “complete”.

Since process simulation is not the focus of this thesis, the content of this part is relatively simple. However, simulation is a good way to validate the algorithm, and simulation in a visual way can help manufacturing enterprise better understand the allocation of resources in the product-service process. We have now developed some basic simulation tools, and can subsequently conduct some more in-depth research in service process simulation.

6.5 Conclusion

In this chapter, taking the air conditioner repair service of company H as an example, the improved IM algorithm and the VSPM algorithm are used to mine the air conditioner repair service event log sample, and the service value models represented by Petri net and BPMN are successfully constructed to verify the effectiveness of the algorithms, respectively. On this basis, the knowledge obtained in the process of constructing the service value model is applied to the resource allocation problem of air conditioning repair service, and the configuration optimization of the arriving service orders considering resource constraints is realized to achieve the improvement of service efficiency and meet the needs of customers.

Although the case study has been simplified to a reasonable size, it does allow to illustrate how to use the proposed approach to build a customer oriented service process model using improved process mining techniques. The concepts, methods and models developed in this thesis are in line with the problems and research challenges given in the problem statement. The application in a real company shows the practical applicability of the proposal in industry.

General Conclusion

The research work presented in this thesis is supported by Topic 3 “Key Technologies for Service Value Chain Collaboration and Optimisation” (2018YFB1702603) of the “Product Service Lifecycle Integration Platform Research and Development” (2018YFB1702600) project of the National Key Research and Development Program of China.

Our motivation is based on the fact that service has become the main driving force for social and economic development. More and more manufacturing enterprises are undergoing service-oriented transformation. They are no longer limited to the sales of products, but provide product and service as a whole to increase the added value, improve corporate profits, and gain a competitive advantage in the market. Accordingly, a product service system oriented to customer needs is formed, with products as the carrier and services as the core, creating value together in the service process. Taking customer needs and customer value as the starting point, this thesis proposes a service value model construction method for product-oriented service systems, aiming to help relevant service actors to understand the collaborative relationship between participants in the service process and the value creation mechanism, so that they can optimise the service process and improve customer satisfaction.

The main results of research presented in each chapter are briefly summarized as follows:

In Chapter 1, the main objective, research problems and outline of the thesis are briefly introduced. Chapter 2 gives the state of the art including service system, process mining and industrial value chain. The concept and formalization of service, service value and service process are explained in the service system. The traditional process modeling method, service event log and typical process mining algorithm are explained in process mining. In the industrial value chain, the notions of value chain, industrial value chain system and modeling methods are explained. In the service system, the execution of services is continuously recorded in the enterprises’ information system, forming a large number of service event logs. Based on interviews with customers and domain experts, combined with the domain knowledge, chapter 3 defines the value creation entities of service, value dimension, activity value and service value, and determines the mapping relationship between event attributes and service value indicators, so as to build a service value indicator system. Then, the construction framework of the service value model is proposed and the model prototype is given. Chapter 4 describes two mining algorithms for automatically constructing service value model from the event log under the proposed construction framework. One is an improved algorithm

of inductive mining algorithm, and the other is a new value-oriented service process mining algorithm. Chapter 5 addresses the allocation of resources in the service value chain, considers the resource constraints and the historical experience obtained from mining, determines the resource allocation model, and gives the solution. In chapter 6, an air conditioner repair service is used as a case study to validate the proposals presented in the previous chapters and discuss the corresponding results.

The main contributions of this thesis are as follows:

- **The first contribution** is concerned with the development of a new method of constructing service value model based on process mining. The construction framework presented in chapter 3 describes the process, activity, and entities involved in the service, defines the concept of service value, service value indicators and the mapping relationship between service event attributes and value indicators, clarifies the relationship between activities, actors and value creation in the service process, and provides the steps to build a service value model based on process mining. Different from the traditional modeling methods, using the idea proposed in this thesis can build the service value model faster and more accurately. Due to the existence of a large number of event logs in the information system, it is possible to cover all paths of the service process. Hereby, based on the data reflecting the actual implementation of the process, an observed and running model is studied. Combined with the domain characteristics, the value information is extracted from the actual data and event log to make the model more reliable.
- **The second contribution** is that the two new algorithms proposed in this thesis can realize the automatic construction of the service event log to the service value model, and extend the application of the process mining algorithm to the service field. The two algorithms are considered from two aspects: one is to improve the inductive miner algorithm so that it can be applied to service scenarios; another is to propose a new value-oriented service process mining algorithm based on the characteristics of services. The two mining algorithms are developed to take into account the specific characteristics of customer-oriented service process and meet the requirements in constructing its value-oriented service model. They allow to generate a better reliable model by taking into account the specific service domain knowledge and particular customer's needs. Consequently, the proposed algorithms contribute to go a step forward towards an automation of constructing customer-oriented service value model from event log.
- **The third contribution** is that we propose a resource allocation method of product-service process based on process mining techniques. In this method, we introduce

an analysis framework of PSS considering resources combining with the ideas of BIRIS, cloud computing and big service, establishes the mathematical model of resource allocation and presents a novel resource allocation algorithm. Based on the historical usage of resources in the service system, using process mining algorithms, the resource allocation in the service process is optimized to better meet customer needs. Compared with traditional resource allocation method in product manufacturing process, the proposed resource allocation for customer oriented service process allows to allocate different adequate resource and actor to meet different customer needs. This specific characteristic of customer oriented process is particular important.

- **The fourth contribution** is that we developed a new ProM plug-in and a web-based service value model building tool, which are used in the air conditioner repair service, realize the construction and optimization of the service value model. Based on the need for validation of the theory presented in this thesis and the requirements of the project (2018YFB1702600), we first developed a plug-in for the open source framework ProM to implement and validate the methods described in the previous chapters. Subsequently, due to the need to integrate with existing web systems in practical application enterprises, we developed a web-based service value model building tool, which has essentially the same functionality as the plug-in. ProM is a good open source framework, but it is a desktop version, large and not easy to migrate. Businesses prefer to use web-based systems that are deployed once and used anywhere, lightweight and easy to integrate.

The proposal presented in this thesis is an overall approach with several components logically related from the conceptual framework structuring relevant concepts, issues and considerations down to supporting tools for elaboration of models through mining techniques and resource allocation method. It adds value to the state of the art by extending traditional mining based process model construction to the customer-oriented service process modelling domain with new mining algorithms and dynamic resource allocation. The case study carried out using real company data shows the applicability of the approach in industrial context.

The results achieved in this research have received some academic recognition and corporate application:

- The construction method of the service value model proposed in this thesis is one of the main results of the project of the National Key Research and Development Program of China (2018YFB1702603), which has been positively evaluated by experts in the field.

- Based on the results of this thesis, we applied to the China Intellectual Property Office for a patent “A service value chain construction method based on event log”, which was accepted.
- This work has already been published in two journals (Frontiers in Manufacturing Technology, Applied Sciences – impact factor: 2.83) and two international conferences (IEEE ICSS 2020, IEEE WET-ICE 2021).
- The web-based service value chain construction tool developed in this thesis has been integrated into the project (2018YFB1702600) outcome “Product Service Lifecycle Integration Platform”.
- Along with the deployment and use of the “Product Service Lifecycle Integration Platform” in companies in different industries, the results of this thesis are also being applied in the companies.
- The results of this thesis also have successfully applied in the 2021 Shandong Province technology-based SMEs innovation capability improvement project “Research and development of intelligent emergency management platform for chemical industry parks based on big data”.

However, this thesis still has some limitations:

- The method proposed in this thesis is mainly applicable to large household appliance manufacturing enterprises with more special domain characteristics, such as door-to-door service, on-site repair, and multiple activities completed by the same actor. Although it has also been applied in other large manufacturing equipment enterprises, it is not covered in this thesis.
- The framework for constructing a service value model proposed in this thesis is still rather crude to a certain extent, although the nesting of service processes is mentioned, it is necessary to be studied in depth.
- Although process mining techniques are the main tool used in this thesis, more applications and testing are needed. There is a need to delve deeper into the mining algorithms to better improve and come up with new ideas.
- For the sake of description, the data set used in the case study is a small sample, and although the original data is from the real records of the company, there is some distortion in the sample data compared to the real data due to the desensitisation process.

- Although the results are applied to different manufacturing companies, it is difficult to access available data from different industries as the service value chain involves the core business processes and confidential information of the company.

Perspectives:

This thesis proposes a service value model construction method based on process mining. The model constructed in this thesis is able to reflect how service actors co-create value in the actual execution of service process, and can help optimizing the resource allocation of the service system to achieve its value goals. However, there are still several points to be improved in depth:

- This thesis emphasises the importance of customer value. The focus of this thesis is on customer value as derived from the needs of customers and customer satisfaction. However, a critical problem is how to define and measure customer value. The tangible value is relatively easy to determine, while the intangible value, such as satisfaction, is difficult to quantify. At the same time, the value created by the customer's participation in the service process should also be considered. Hence, in order to make the service objectives more clear, it is necessary to conduct in-depth research on the definition and measurement of customer value.
- The service event log is the data base of this research. The data used in this thesis comes from real enterprise information systems, but is used with manually pre-processing, relatively small amounts of data stored in XES format files. However, the data of the enterprise is stored in the database, which has a huge amount of data, and the content and format of the data are relatively complex. Hence, it is necessary to deeply discuss how to directly obtain valid event logs from this data.
- The mining algorithm is the key technique to construct service value model. This thesis introduces two new mining algorithms for service value model construction. However, the idea of the algorithms are relatively rough, especially the service value extraction in the event log is not deep enough. Therefore, it is necessary to improve the mapping of service value indicators and event attributes, and explore the extraction process of service value in depth.
- Resource allocation is an important aspect of service optimisation. The resource allocation method proposed in this research considers the actual execution of the service process and attempts to introduce process mining techniques into the resource allocation. However, limited by the service scenario of air conditioner repair, this method involves relatively few types and quantities of resources, and has poor applicability in other service scenarios. Therefore, it is necessary to

expand service scenarios, resource types and quantities to improve resource allocation method.

- The mining tools are developed as a validation of the methodology presented in this thesis. We have developed a ProM plugin and a web-based mining tool. However, both tools share a common flaw in that they both have domain limitations, i.e. they are primarily oriented towards air conditioner repair services. Hence, the mining tools need to be further improved and optimised.

REFERENCES

Aalst, W. v. d., Adriansyah, A., Medeiros, A. K. A. d., Arcieri, F., Baier, T., Blickle, T., Bose, J. C., Brand, P. v. d., Brandtjen, R., Buijs, J. et al. (2011), Process mining manifesto, *in* 'International conference on business process management', Springer, pp. 169–194.

Agrawal, R., Gunopulos, D. and Leymann, F. (1998), 'Mining Process Models from Workflow Logs', pp. 467–483.

Akaka, M. A., Vargo, S. L. and Wieland, H. (2017), Extending the context of innovation: The co-creation and institutionalization of technology and markets, *in* 'Innovating in Practice', Springer, pp. 43–57.

Alexander, C. et al. (1979), *The timeless way of building*, Vol. 1, New york: Oxford university press.

Allee, V. (2008), 'Value network analysis and value conversion of tangible and intangible assets', *Journal of intellectual capital* .

Alter, S. (2008), 'Service system fundamentals: Work system, value chain, and life cycle', *IBM Systems Journal* **47**(1), 71–85.

Anderson, J. C., Jain, D. C. and Chintagunta, P. K. (1992), 'Customer value assessment in business markets: A state-of-practice study', *Journal of Business-to-Business Marketing* **1**(1), 3–29.

Antosz, K. and Stadnicka, D. (2018), Possibilities of maintenance service process analyses and improvement through six sigma, lean and industry 4.0 implementation, *in* 'Product Lifecycle Management to Support Industry 4.0', Springer International Publishing, Cham, pp. 465–475.

Antràs, P. and Chor, D. (2013), 'Organizing the global value chain', *Econometrica* **81**(6), 2127–2204.

Augusto, A., Conforti, R., Dumas, M. and La Rosa, M. (2017), Split miner: Discovering accurate and simple business process models from event logs, *in* '2017 IEEE International Conference on Data Mining (ICDM)', IEEE, pp. 1–10.

- Baines, T. S., Lightfoot, H. W., Benedettini, O. and Kay, J. M. (2009), 'The servitization of manufacturing: A review of literature and reflection on future challenges', *Journal of manufacturing technology management* .
- Banerjee, P., Friedrich, R., Bash, C., Goldsack, P., Huberman, B., Manley, J., Patel, C., Ranganathan, P. and Veitch, A. (2011), 'Everything as a service: Powering the new information economy', *Computer* **44**(3), 36–43.
- Barnett, N., Parry, G., Saad, M., Newnes, L. and Goh, Y. (2013), 'Servitization: Is a paradigm shift in the business model and service enterprise required', *Strategic Change, Special issue on New Entrepreneurial Models* **22**(3-4), 145–156.
- Basole, R. C. and Rouse, W. B. (2008), 'Complexity of service value networks: Conceptualization and empirical investigation', *IBM Systems Journal* **47**(1), 53–70.
- Bergenthum, R., Desel, J., Lorenz, R. and Mauser, S. (2007), Process mining based on regions of languages, in 'International Conference on Business Process Management', Springer, pp. 375–383.
- Berti, A., Van Zelst, S. J. and van der Aalst, W. (2019), 'Process mining for python (pm4py): bridging the gap between process- and data science', *arXiv preprint arXiv:1905.06169* .
- Bitner, M. J., Ostrom, A. L. and Morgan, F. N. (2008), 'Service blueprinting: A practical technique for service innovation', *California management review* **50**(3), 66–94.
- Bolt, A., de Leoni, M. and van der Aalst, W. M. (2016), 'Scientific workflows for process mining: Building blocks, scenarios, and implementation', *International Journal on Software Tools for Technology Transfer* **18**(6), 607–628.
- Brzozowski, J., Jirásková, G. and Zou, C. (2010), Quotient complexity of closed languages, in 'International Computer Science Symposium in Russia', Springer, pp. 84–95.
- Buijs, J. C., van Dongen, B. F. and van Der Aalst, W. M. (2012a), On the role of fitness, precision, generalization and simplicity in process discovery, in 'OTM Confederated International Conferences" On the Move to Meaningful Internet Systems"', Springer, pp. 305–322.
- Buijs, J., van Dongen, B. and van der Aalst, W. (2012b), A genetic algorithm for discovering process trees, in '2012 IEEE Congress on Evolutionary Computation', pp. 1–8.
- Büyüközkan, G., Feyzioğlu, O. and Nebol, E. (2008), 'Selection of the strategic alliance partner in logistics value chain', *International Journal of Production Economics* **113**(1), 148–158.

- Camacho-Miñano, M.-d.-M., Moyano-Fuentes, J. and Sacristán-Díaz, M. (2013), 'What can we learn from the evolution of research on lean management assessment?', *International Journal of Production Research* **51**(4), 1098–1116.
- Chandler, J. D. and Vargo, S. L. (2011), 'Contextualization and value-in-context: How context frames exchange', *Marketing theory* **11**(1), 35–49.
- Costa, N., Patrício, L., Morelli, N. and Magee, C. L. (2018), 'Bringing service design to manufacturing companies: Integrating PSS and service design approaches', *Design Studies* **55**, 112–145.
- CW Günther and Verbeek, H. (2014), 'XES - standard definition'.
- Dakic, D., Sladojevic, S., Lolic, T. and Stefanovic, D. (2019), Process mining possibilities and challenges: a case study, in '2019 IEEE 17th International Symposium on Intelligent Systems and Informatics (SISY)', IEEE, pp. 000161–000166.
- d'Ambrogio, A. and Zacharewicz, G. (2016), Resource-based Modeling and Simulation of Business Processes, in '2016 Summer Computer Simulation Conference (SCSC 2016)', Society for Modeling and Simulation International (SCS), Montreal, Quebec, CA.
- de Leoni, M., van der Aalst, W. M. P. and Dees, M. (2016), 'A general process mining framework for correlating, predicting and clustering dynamic behavior based on event logs', *Information Systems* **56**, 235–257.
- de Medeiros, A. K. A., Weijters, A. J. M. M. and van der Aalst, W. M. P. (2007), 'Genetic process mining: An experimental evaluation', *Data Mining and Knowledge Discovery* **14**(2), 245–304.
- Donelan, J. G. and Kaplan, E. A. (1998), 'Value chain analysis: A strategic approach to cost management', *Journal of Cost Management* **12**(2), 7–15.
- Du, Y. and Li, S. (2004), 'Industrial value chain: the innovative format of value strategy', *Studies in Science of Science* **22**(5), 552–556.
- Fan, W., Dong, X., Wei, H., Weng, B., Liang, L., Xu, Z., Wang, X., Wu, F., Chen, Z., Jin, Y. and Song, C. (2018), 'Is it true that the longer the extended industrial chain, the better the circular agriculture? A case study of circular agriculture industry company in Fuqing, Fujian', *Journal of Cleaner Production* **189**, 718–728.
- Frank, A. G., Mendes, G., Ayala, N. F. and Ghezzi, A. (2019), 'Servitization and Industry 4.0 convergence in the digital transformation of product firms: A business model innovation perspective', *Technological Forecasting and Social Change* **141**, 341–351.

- Gaiardelli, P., Pezzotta, G., Rondini, A., Romero, D., Jarrahi, F., Bertoni, M., Wiesner, S., Wuest, T., Larsson, T., Zaki, M., Jussen, P., Boucher, X., Bigdeli, A. Z. and Cavalieri, S. (2021), 'Product-service systems evolution in the era of Industry 4.0', *Service Business* **15**(1), 177–207.
- Gereffi, G., Humphrey, J. and Sturgeon, T. (2005), 'The governance of global value chains', *Review of international political economy* **12**(1), 78–104.
- Goedkoop, M. J., Halen, C. J. G. V., Riele, H. R. M. T. and Rommens, P. J. M. (1999), 'Product service systems, ecological and economic basics', *Economic Affairs* **36**.
- Gomes, A. F. D., de Lacerda, A. C. W. G. and da Silva Fialho, J. R. (2022), Comparative Analysis of Process Mining Algorithms in Process Discover, in 'New Trends in Disruptive Technologies, Tech Ethics and Artificial Intelligence', Vol. 1410, Springer International Publishing, Cham, pp. 258–270.
- Günther, C. W. and Rozinat, A. (2012), 'Disco: Discover your processes.', *BPM (Demos)* **940**(1), 40–44.
- Günther, C. W. and van der Aalst, W. M. P. (2007), Fuzzy Mining – Adaptive Process Simplification Based on Multi-perspective Metrics, in 'Business Process Management', Vol. 4714, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 328–343.
- Gupta, E. P. (2014), 'Process mining a comparative study', *International Journal of Advanced Research in Computer and Communications Engineering* **3**(11), 5.
- Gzik, T. (2020), 'Business Process as a Service—A Systematic Literature Review', *Towards Industry 4.0 — Current Challenges in Information Systems* pp. 163–181.
- Haksever, C., Chaganti, R. and Cook, R. G. (2004), 'A Model of Value Creation: Strategic View', *Journal of Business Ethics* **49**(3), 295–307.
- Herbst, J. and Karagiannis, D. (2004), 'Workflow mining with InWoLvE', *Computers in Industry* **53**(3), 245–264.
- Huang, X., Wang, L., Zhao, W., Zhang, S. and Yuan, C. (2006), 'A Workflow Process Mining Algorithm Based on Synchro-Net', *Journal of computer Science and Technology* **21**(1), 6.
- Huang, Z., Huai, J., Liu, X. and Zhu, J. (2010), Business process decomposition based on service relevance mining, in '2010 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology', Vol. 1, IEEE, pp. 573–580.

- Kalenkova, A. A., · W M P Van Der Aalst, Lomazova, I. A. and Rubin, V. A. (2015), 'Process Mining Using BPMN: Relating Event Logs and Process Models', *Software and Systems Modeling* **16**(4).
- Kang, K., Zhong, R. Y., Xu, S. X., Tan, B. Q., Wang, L. and Peng, T. (2021), 'Auction-based cloud service allocation and sharing for logistics product service system', *Journal of Cleaner Production* **278**, 123881.
- Kim, M. and Ko, I.-Y. (2015), An Efficient Resource Allocation Approach Based on a Genetic Algorithm for Composite Services in IoT Environments, in '2015 IEEE International Conference on Web Services', pp. 543–550.
- Kolisch, R. and Padman, R. (2001), 'An integrated survey of deterministic project scheduling', *Omega* **29**(3), 249–272.
- Leemans, S. J., Fahland, D. and Van Der Aalst, W. M. (2013), Discovering block-structured process models from event logs containing infrequent behaviour, in 'International Conference on Business Process Management', Springer, pp. 66–78.
- Leemans, S. J., Fahland, D. and Van der Aalst, W. M. (2018), 'Scalable process discovery and conformance checking', *Software and Systems Modeling* **17**(2), 599–631.
- Li, J., Liu, D. and Yang, B. (2007), 'Process mining: An extended alpha-algorithm to discovery duplicate tasks', *CHINESE JOURNAL OF COMPUTERS-CHINESE EDITION-* **30**(8), 1436.
- Li, J., Ma, D., Mei, X., Sun, H. and Zheng, Z. (2011), Adaptive qos-aware service process reconfiguration, in '2011 IEEE International Conference on Services Computing', IEEE, pp. 282–289.
- Liang, L., Ge, C., Liu, H. and Xie, J. (2015), 'Customer perceived value measurement of rental product service system', *Modern Management Science* **12**, 27–29.
- Lu, F., Zeng, Q., Duan, H., Cheng, J. and Bao, Y. (2015), 'Parallelized heuristic process mining algorithm', *Chinese Journal of Software* **26**(3), 533–549.
- Lusch, R. F., Vargo, S. L. and Tanniru, M. (2010), 'Service, value networks and learning', *Journal of the Academy of Marketing Science* **38**(1), 19–31.
- Lynn, T., O'carroll, N., Mooney, J., Helfert, M., Corcoran, D., Hunt, G., Van Der Werff, L., Morrison, J. and Healy, P. (2014), Towards a framework for defining and categorising business process-as-A-service (BPaaS), in 'Proceedings of the 21st International Product Development Management Conference', p. 65.

- Ma, Y., He, Z. and Wang, N. (2019), Proactive Project Scheduling Optimization Based on Flexible Resource Constraint, *in* '2019 International Conference on Industrial Engineering and Systems Management (IESM)', IEEE, pp. 1–5.
- Maglio, P. P., Srinivasan, S., Kreulen, J. T. and Spohrer, J. (2006), 'Service systems, service scientists, SSME, and innovation', *Communications of the ACM* **49**(7), 81–85.
- Man, H. Y., Rizvi, M. and Chew, E. (2019), Managing Value Co-Creation: An Integrated Design Framework for Service-Centric Product-Service Systems, *in* 'PICMET '19: Technology Management in the World of Intelligent Systems'.
- Manzini, E. and Vezzoli, C. (2003), 'A strategic design approach to develop sustainable product service systems: Examples taken from the 'environmentally friendly innovation' Italian prize', *Journal of cleaner production* **11**(8), 851–857.
- Maruster, L., Weijters, A. J. M. M. T., van der Aalst, W. M. P. W. and van den Bosch, A. (2002), Process Mining: Discovering Direct Successors in Process Logs, *in* 'Discovery Science', Lecture Notes in Computer Science, Springer, Berlin, Heidelberg, pp. 364–373.
- Maruster, L., Weijters, A. J. M. M., van der Aalst, W. M. P. and van den Bosch, A. (2006), 'A Rule-Based Approach for Process Discovery: Dealing with Noise and Imbalance in Process Logs', *Data Mining and Knowledge Discovery*.
- Matschewsky, J., Lindahl, M. and Sakao, T. (2020), 'Capturing and enhancing provider value in product-service systems throughout the lifecycle: A systematic approach', *CIRP Journal of Manufacturing Science and Technology* **29**, 191–204.
- Mezache, C., Kazar, O. and Bourekkache, S. (2016), A genetic algorithm for resource allocation with energy constraint in cloud computing, *in* 'Proceedings of 2016 International Conference on Image Processing, Production and Computer Science (ICIPCS'2016) London (UK)', pp. 62–69.
- Miao, Z. (2021), 'Digital economy value chain: concept, model structure, and mechanism', *Applied Economics* **53**(37), 4342–4357.
- Nan, Z., Qiu, X.-s. and Meng, L.-m. (2006), A sla-based service process management approach for soa, *in* '2006 First International Conference on Communications and Networking in China', IEEE, pp. 1–6.
- Netto, M. A., Bubendorfer, K. and Buyya, R. (2007), SLA-based advance reservations with flexible and adaptive time QoS parameters, *in* 'International Conference on Service-Oriented Computing', Springer, pp. 119–131.

- Pan, T. (2012), 'Value Chain Analysis Method of Smart Logistics Using Fuzzy Theory', *Information Technology Journal* **11**(4), 441–445.
- Pawar, C. S. and Wagh, R. (2012), 'A review of resource allocation policies in cloud computing', *World Journal of Science and Technology* **2**(3), 165–167.
- Piboonrungrroj, P., Williams, S. and Simatupang, T. (2017), 'The emergence of value chain thinking', *International Journal of Value Chain Management* **8**, 40.
- Porter, M. E. (1985), *Competitive Advantage*, The Free Press.
- Prado-Prado, J. C., García-Arca, J., Fernández-González, A. J. and Mosteiro-Añón, M. (2020), 'Increasing Competitiveness through the Implementation of Lean Management in Healthcare', *International Journal of Environmental Research and Public Health* **17**(14), 4981.
- Schimm, G. (2004), 'Mining exact models of concurrent workflows', *Computers in Industry* **53**(3), 265–281.
- Shamah, R. A. (2012), 'Innovation within green service supply chains for a value creation', *Journal of Modelling in Management* .
- Shou, W., Wang, J., Wu, P., Wang, X. and Chong, H.-Y. (2017), 'A cross-sector review on the use of value stream mapping', *International Journal of Production Research* **55**(13), 3906–3928.
- Siddike, M. A. K. and Hidaka, K. (2017), Toward a Value Metrics—A Service-Dominant Logic View, in 'Advances in The Human Side of Service Engineering', Vol. 494, Springer International Publishing, Cham, pp. 187–197.
- Sinha, N. and Matharu, M. (2019), 'A comprehensive insight into Lean management: Literature review and trends', *Journal of Industrial Engineering and Management* **12**(2), 302–317.
- Spohrer, J., Maglio, P. P., Bailey, J. and Gruhl, D. (2007), 'Steps Toward a Science of Service Systems', *Computer* **40**, 71–77.
- Stabell, C. B. and Fjeldstad, Ø. D. (1998), 'Configuring value for competitive advantage: On chains, shops, and networks', *Strategic Management Journal* **19**(5), 413–437.
- Strunk, A. (2010), Qos-aware service composition: A survey, in '2010 Eighth IEEE European Conference on Web Services', IEEE, pp. 67–74.
- Takahashi, H., Nishino, N., Takeshi, T. and Ishikawa, R. (2020), 'Interpreting value creation model by case-based decision theory', *Procedia CIRP* **88**, 584–588.

- Tukker, A. (2004), 'Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet', *Business Strategy and the Environment* **13**(4), 246–260.
- Van der Aalst, W. (2013), 'Service Mining: Using Process Mining to Discover, Check, and Improve Service Behavior', *IEEE Transactions on Services Computing* **6**(4), 525–535.
- Van Der Aalst, W. (2016), *Process mining: data science in action*, Vol. 2, Springer.
- van der Aalst, W. M. (2019), 'A practitioner's guide to process mining: Limitations of the directly-follows graph', *Procedia Computer Science* **164**, 321–328.
- Van der Aalst, W. M. P. (2011), *Process Mining: Discovery, Conformance and Enhancement of Business Processes*, Springer Berlin Heidelberg, Berlin, Heidelberg.
- Van der Aalst, W., Schonenberg, M. and Song, M. (2011), 'Time prediction based on process mining', *Information Systems* **36**(2), 450–475.
- Van der Aalst, W., Weijters, T. and Maruster, L. (2004), 'Workflow mining: Discovering process models from event logs', *IEEE Transactions on Knowledge and Data Engineering* **16**(9), 1128–1142.
- Van der Werf, J. M. E. M., van Dongen, B. F., Hurkens, C. a. J. and Serebrenik, A. (2009), 'Process Discovery using Integer Linear Programming', *Fundamenta Informaticae* **94**(3-4), 387–412.
- Van Dongen, B. F., de Medeiros, A. K. A., Verbeek, H., Weijters, A. and van Der Aalst, W. M. (2005), The prom framework: A new era in process mining tool support, in 'International conference on application and theory of petri nets', Springer, pp. 444–454.
- van Heck, E. and Vervest, P. (2009), 'Smart business networks: Concepts and empirical evidence', *Decision Support Systems* **47**(4), 275.
- Van Zelst, S. J., van Dongen, B. F., van der Aalst, W. M. P. and Verbeek, H. M. W. (2018), 'Discovering workflow nets using integer linear programming', *Computing* **100**(5), 529–556.
- Vandermerwe, S. and Rada, J. (1988), 'Servitization of business: Adding value by adding services', *European management journal* **6**(4), 314–324.
- Vargo, S. L. and Lusch, R. F. (2004), 'The four service marketing myths: Remnants of a goods-based, manufacturing model', *Journal of service research* **6**(4), 324–335.

- Vargo, S. L. and Lusch, R. F. (2016), ‘Institutions and axioms: An extension and update of service-dominant logic’, *Journal of the Academy of marketing Science* **44**(1), 5–23.
- Vázquez-Barreiros, B., Mucientes, M. and Lama, M. (2015), ‘Prodigen: Mining complete, precise and minimal structure process models with a genetic algorithm’, *Information Sciences* **294**, 315–333.
- Verbeek, H., van der Aalst, W. M. and Munoz-Gama, J. (2017), ‘Divide and conquer: A tool framework for supporting decomposed discovery in process mining’, *The Computer Journal* **60**(11), 1649–1674.
- Wang, P. P., Ming, X. G. and Zheng, M. K. (2016), A Framework of Value Creation for Industrial Product-Service, in ‘Product Lifecycle Management in the Era of Internet of Things’, Springer, Cham, pp. 311–320.
- Wang, Q. and Wang, L. (2019), ‘The online shopping process mining based on behavioral profile of Petri net’, *Journal of Yanbian University(Natural Science Edition)* .
- Wang, W., Huan, X. and Zheng, X. (2021), ‘A process variant merging method based on petri nets’, *Computer Science and Engineering* **43**(6), 1095–1103.
- Wang, X., Wang, Z. and Xu, X. (2013), ‘A Pattern-based Service Integration Methodology’, *Intelligent Computer and Applications* **3**, 1–5+9.
- Wang, X., Xu, H., Wang, Z., Tu, Z. and Xu, X. (2022), ‘Efficient method for constructing service solutions based on the supply-demand bilateral patterns’, *Computer Integrated Manufacturing Systems* **28**(3), 864–879.
- Wang, Y., Li, Y., Zheng, B. and Wang, C. (2008), Industrial value chain modeling based on industrial value matrix, in ‘2008 Chinese Control and Decision Conference’, IEEE, Yantai, Shandong, China, pp. 1100–1105.
- Wang, Z., Tang, Y. and Li, C. (2010), Industrial value chain modeling and technology elements analysis based on IDEF0, in ‘2010 IEEE 17Th International Conference on Industrial Engineering and Engineering Management’, IEEE, Xiamen, China, pp. 1675–1678.
- Wang, Z. and Xu, X. (2009a), ‘Bilateral resource integration service mode for value innovation’, *Computer Integrated Manufacturing Systems* **15**(11), 2216–2225.
- Wang, Z. and Xu, X. (2009b), ‘Multi-level graphical service value modeling method’, *Computer Integrated Manufacturing Systems* **15**(12), 2319–2327.
- Wang, Z. and Xu, X. (2011), ‘Service value dependency model based on layered hypergraph’, *Computer Integrated Manufacturing System* **17**(08), 0.

- Wang, Z., Xu, X., Chu, D. and Ma, C. (2010), A Value-Driven Approach for the Determination of Global Optimization Objective of Service Composition, in '2010 IEEE International Conference on Services Computing', pp. 210–217.
- Weigand, H., Johannesson, P., Andersson, B., Bergholtz, M. and Zdravkovic, J. (2008), 'Value-based service design based on a general service architecture', *Proceedings of BUSITAL*.
- Weijters, A., Aalst, W. and Medeiros, A. (2006), *Process Mining with the Heuristics Miner-algorithm*, Vol. 166.
- Weijters, A. J. M. M., van der Aalst, W. M. P. and de Medeiros, A. K. A. (2006), Process mining with the HeuristicsMiner algorithm.
- Weijters, A. and Ribeiro, J. T. S. (2011), Flexible heuristics miner (FHM), in '2011 IEEE Symposium on Computational Intelligence and Data Mining (CIDM)', IEEE, pp. 310–317.
- Wen, L., Wang, J., der Aalst, W.M.P., v., Huang, B. and Sun, J. (2010), 'Mining process models with prime invisible tasks', *Data and Knowledge Engineering* **69**(10), 999–1021.
- Wen, L., Wang, J., van der Aalst, W. M., Huang, B. and Sun, J. (2009), 'A novel approach for process mining based on event types', *Journal of Intelligent Information Systems* **32**(2), 163–190.
- Woitsch, R. and Utz, W. (2015), Business Process as a Service: Model Based Business and IT Cloud Alignment as a Cloud Offering, in '2015 International Conference on Enterprise Systems (ES)', pp. 121–130.
- Wong, M. T. N. (2004), Implementation of Innovative Product Service Systems in the Consumer Goods Industry, PhD thesis, University of Cambridge.
- Xing, K., Wang, H. and Qian, W. (2013), 'A sustainability-oriented multi-dimensional value assessment model for product-service development', *International Journal of Production Research* **51**(19), 5908–5933.
- Xu, H., Zhuang, Y., Gu, H., Xu, X. and Zhang, Y. (2019), 'Pattern-based service composition for user satisfaction and service revenue', *International Journal of Services Technology and Management* **25**(5-6), 585–600.
- Xu, X., Liu, Z., Wang, Z., Min, X., Liu, R. and Wang, H. (2015), 'S-ABC - Service domain-oriented artificial bee colony algorithm paradigm', *Chinese Journal of Computers* **38**, 2301–2317.

- Xu, X., Liu, Z., Wang, Z., Sheng, Q. Z., Yu, J. and Wang, X. (2017), 'S-ABC: A paradigm of service domain-oriented artificial bee colony algorithms for service selection and composition', *Future Generation Computer Systems* **68**, 304–319.
- Xu, X., Motta, G., Tu, Z., Xu, H., Wang, Z. and Wang, X. (2018), 'A new paradigm of software service engineering in big data and big service era', *Computing. Archives for Scientific Computing* **100**(4), 353–368.
- Xu, X., Sheng, Q. Z., Zhang, L., Fan, Y. and Dustdar, S. (2015), 'From big data to big service', *Computer* **48**(7), 80–83.
- Xu, X. and Wang, Z. (2008), Value-Aware Service Model Driven Architecture and Methodology, in 'E-Government Ict Professionalism and Competences Service Science', Vol. 280, Springer US, Boston, MA, pp. 277–286.
- Xu, Z., Elomri, A., Zhang, Q., Liu, C. and Shi, L. (2020), 'Status review and research strategies on product-service supply chain', *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* **234**(8), 1075–1086.
- Yan, J. and Tan, Y. (2016), 'The Construction and Deduction of Eco-Industry Value Chain Model', *Economic Geography* **68**(5), 168–174.
- Yang, M., Evans, S., Vladimirova, D. and Rana, P. (2017), 'Value uncaptured perspective for sustainable business model innovation', *Journal of Cleaner Production* **140**, 1794–1804.
- Yang, X., Yu, T. and Xu, H. (2015), 'A Survey on Workflow Verifications of Petri Nets based Service Process Management', *International Journal of Grid and Distributed Computing* **8**(6), 79–90.
- Yao, M. (2020), 'Multi-population genetic algorithm for multi-skill resource-constrained project scheduling problem', *Computer Science* **47**(S01), 6.
- Yasmin, F. A., Bemthuis, R., Elhagaly, M., Wijnhoven, F. and Bukhsh, F. A. (2020), 'A process mining starting guideline for process analysts and process owners: A practical process analytics guide using prom', *DSI technical report series* .
- Yu, J., Dong, C., Li, C., Cheng, H. and Sun, X. (2018), 'Process mining based on statistical α -algorithm', *Journal of Beijing University of Aeronautics and Astronautics* **44**(5), 895–906.
- Yu, X., Zhan, D., Nie, L., Chu, D. and Xu, X. (2010), 'Flexible resource-constrained resource leveling project scheduling problem', *Computer Integrated Manufacturing Systems* **16**(9), 1967–1976.

- Zacharewicz, G., Diallo, S., Ducq, Y., Agostinho, C., Jardim-Goncalves, R., Bazoun, H., Wang, Z. and Doumeingts, G. (2017), 'Model-based approaches for interoperability of next generation enterprise information systems: State of the art and future challenges', *Information Systems and e-Business Management* **15**(2), 229–256.
- Zappatore, M., Longo, A. and Bochicchio, M. A. (2015), SLA composition in service networks: A tool for representing relationships between SLAs and contracts, *in* 'Proceedings of the 30th Annual ACM Symposium on Applied Computing', pp. 1219–1224.
- Zhai, Y., Zhang, J. and Lin, K.-J. (2009), Soa middleware support for service process re-configuration with end-to-end qos constraints, *in* '2009 IEEE International Conference on Web Services', IEEE, pp. 815–822.
- Zhan, D.-C., Zhao, X.-B., Wang, S.-Q., Cheng, Z., Zhou, X.-Q., Nie, L.-S. and Xu, X.-F. (2011), 'Cloud manufacturing service platform for group enterprises oriented to manufacturing and management', *Computer Integrated Manufacturing Systems* **17**(3), 487–494.
- Zhang, Z., Xu, D., Ostrosi, E. and Cheng, H. (2020), 'Optimization of the Product–Service System Configuration Based on a Multilayer Network', *Sustainability* **12**(2), 746.
- Zhao, M. and Wang, X. (2021), 'Perception value of product-service systems: Neural effects of service experience and customer knowledge', *Journal of Retailing and Consumer Services* **62**, 102617.
- Zhao, W. and Liu, H. (2014), 'Application of Process mining in process optimization', *Computer Integrated Manufacturing Systems* **20**(10), 2632–2642.
- Zheng, L., Pan, T. and Yan, G. (2010), Process Control and Simulation for the Fourth Party Logistics Using Value Chain Analysis, *in* '2010 International Conference on Electrical and Control Engineering', pp. 1503–1506.
- Zhuang, Y., Xu, H., Xu, X., Wang, Z. and He, T. (2016), 'Research on service pattern-based rapid service composition approach', *Computer Engineering and Applications* .

LIST OF PUBLICATIONS

1. Zhou X, Zacharewicz G, Chen D, et al. A method for building service process value model based on process mining[J]. Applied Sciences, 2020, 10(20): 7311.
2. Zhou X, Li C, Zhang H, et al. A Feature Tree and Dynamic QoS based Service Integration and Customization Model for Multi-tenant SaaS Application[C]//2020 International Conference on Service Science (ICSS). IEEE, 2020: 107-114.
3. Zhou X, Tan Y, Zacharewicz G, et al. Research on Value Based Heuristics Miner for Product Service System[C]//2021 IEEE 30th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WET-ICE). IEEE, 2021: 89-94.
4. Zhou X, Liu Y, Zacharewicz G, Zhang H and Chen D. A resource allocation method of the product-service process based on process mining [J]. Frontiers in Manufacturing Technology, 2022, 2:1008805. doi: 10.3389/fmtec.2022.1008805

Appendices

Appendix A

The full figures in Section 6.2

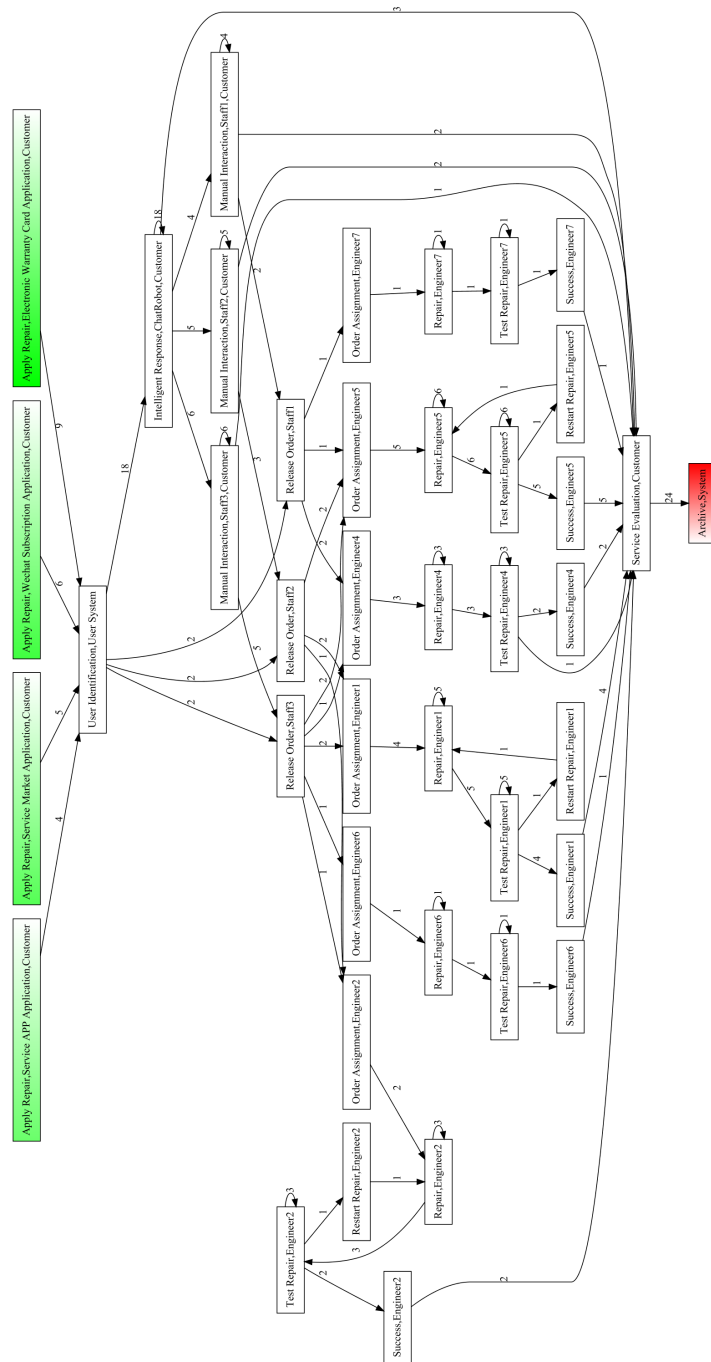


Figure A.1 Full figure of Figure 6.6.

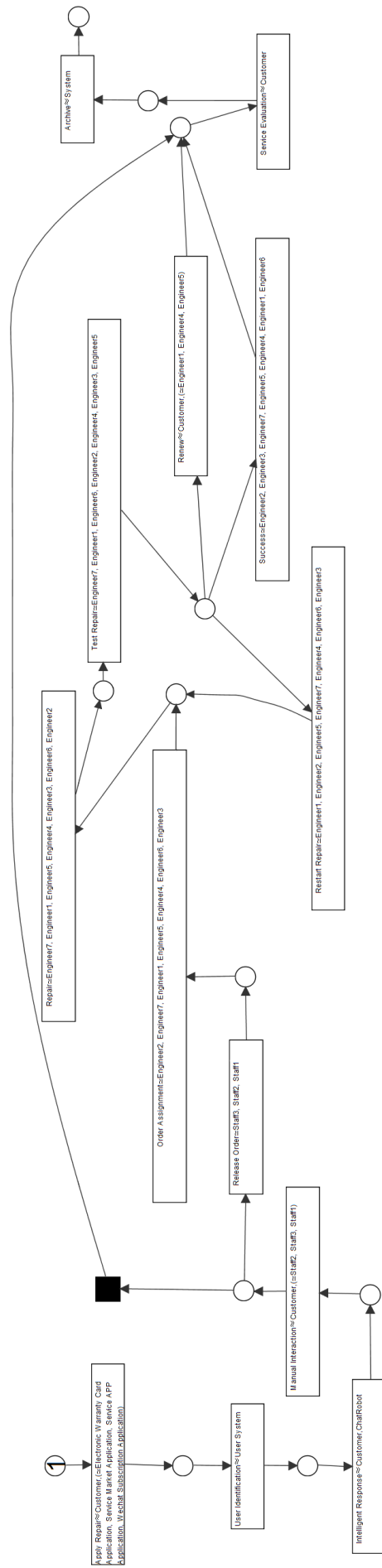


Figure A.2 Full figure of Figure 6.7.

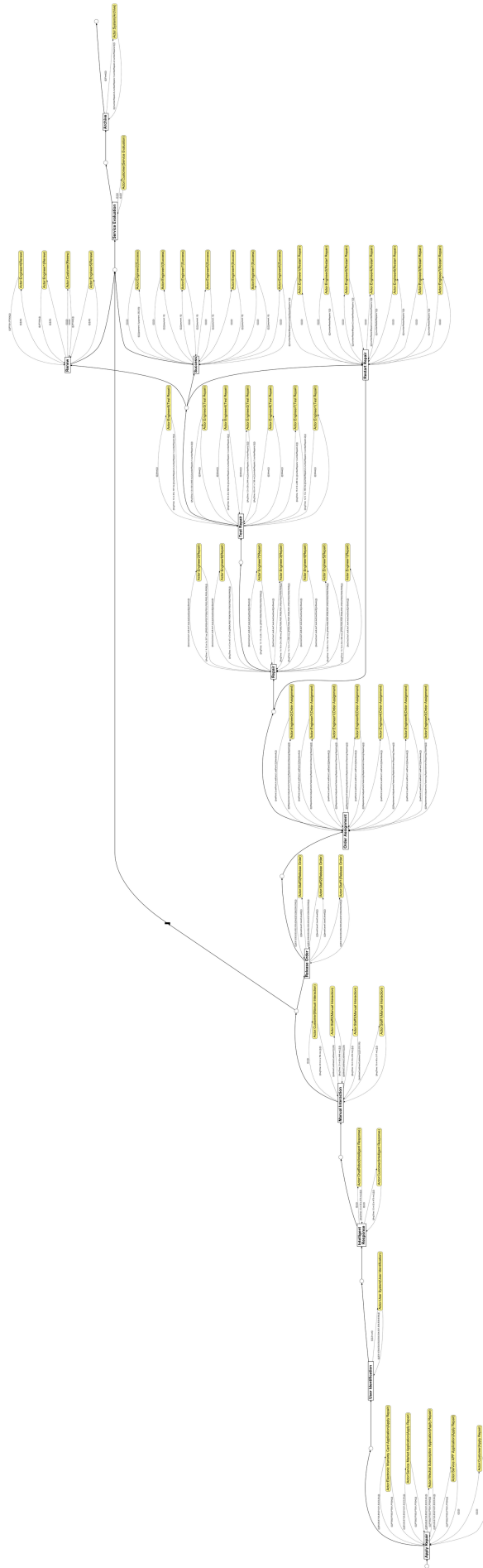


Figure A.3 Full figure of Figure 6.8.

Appendix B

The full figures in Section 6.3

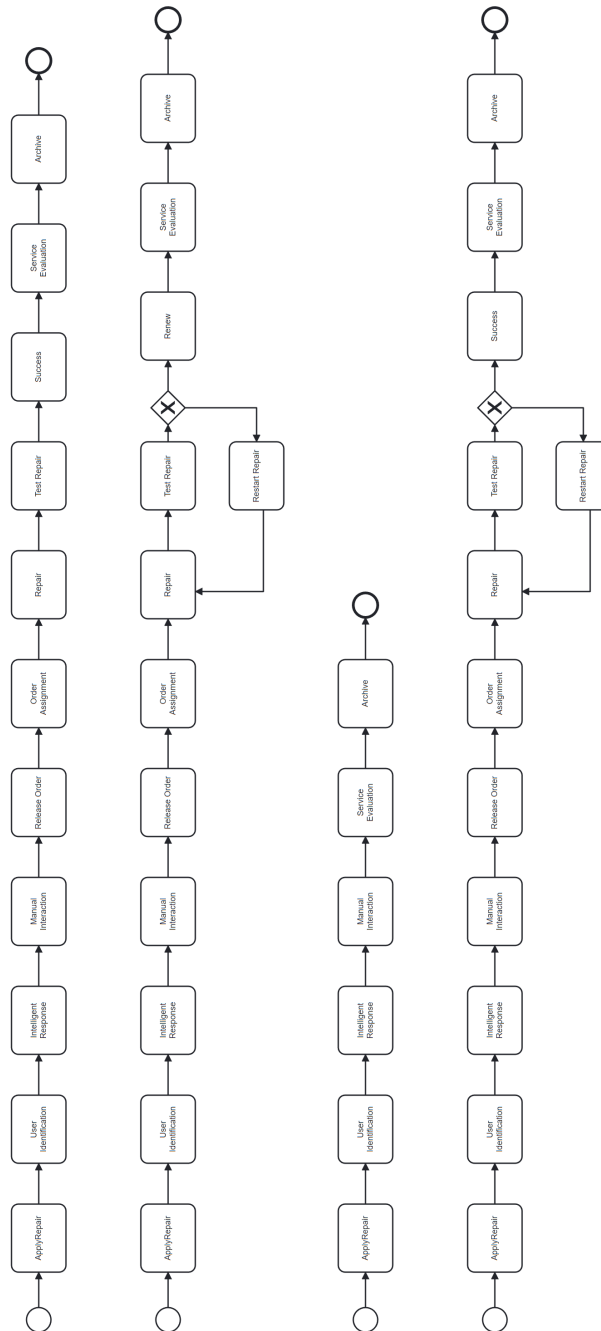


Figure B.1 Full figure of Figure 6.10.

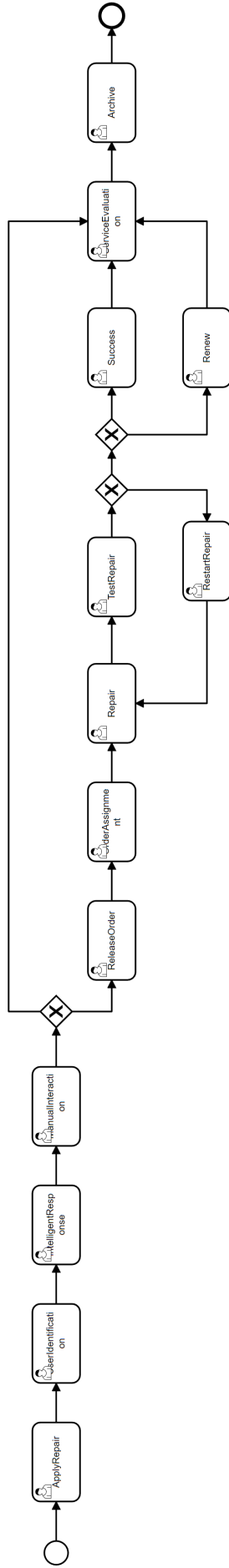


Figure B.2 Full figure of Figure 6.11.

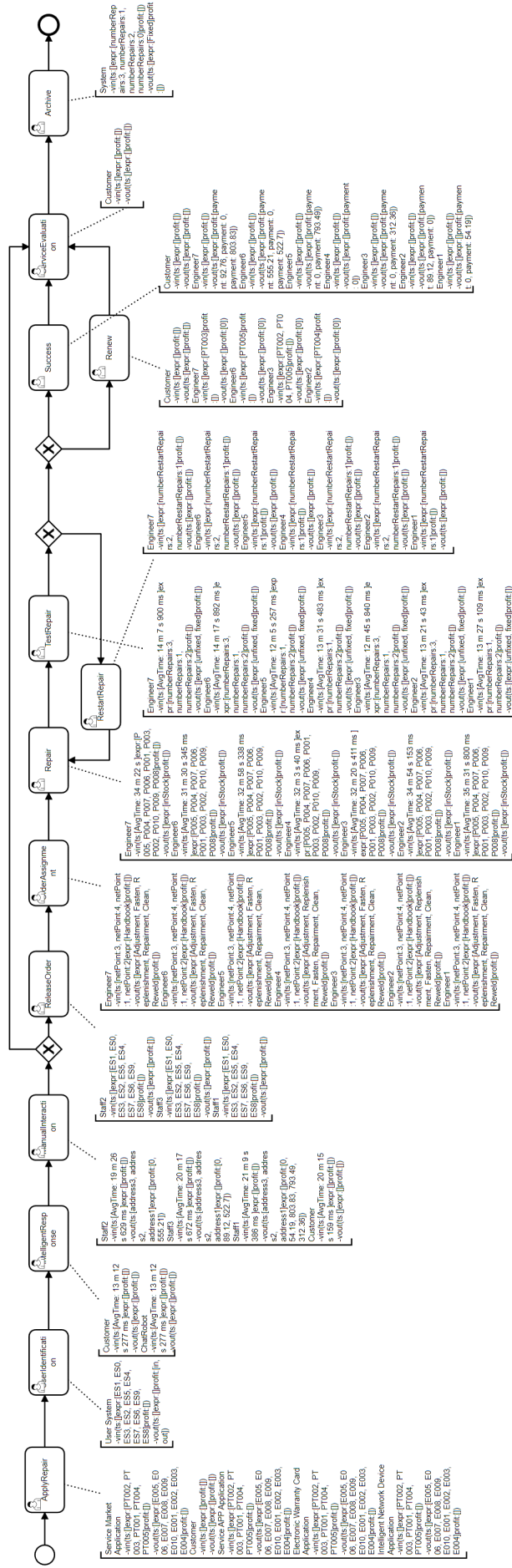


Figure B.3 Full figure of Figure 6.13.