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# Research on The Location Planning and Optimization of Express Delivery Service Based on Probabilistic Model Checking: A Computing and Improvement Perspective

Yonghua Zhu[1*], Xiaoyi Xue[1], Kai Zhang[2], Shunyi Mao[1]

[1] School of Computer Engineering and Science, Shanghai University, 200444, Shanghai, China
zyh@shu.edu.cn; f8r@qq.com

[2] School of Automation&Electrical Engineering, Lanzhou Jiaotong University, Lanzhou, China

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Abstract. With the fast development of e-commerce, thousands of express deliveries for college students are distributed to each campus every day. The storage location of commodities plays a major role in express delivery service. This paper uses probabilistic model checking to validate express delivery fetch process to plan and optimize storage location. Firstly, the express delivery fetch process between an express company and customer is formalized in the form of a Discrete-Time Markov Chain (DTMC). Secondly, Probabilistic Computation Tree Logic (PCTL) is provided as validation property to express the expected probabilistic behaviour. Thirdly, formal validations are automatically performed by probabilistic model checker PRISM to verify PCTL formula against the DTMC model. Verification results follow the Bernoulli Large Numbers Law to prove that our method is viable. Furthermore, the model of the delivery process is developed as a new structure called Ex-DTMC, which considers time, cost and punishment factors to improve the performance and probability factor. Finally, a set of experiments in this paper is compared with other methods to show our method can efficiently determine the most suitable storage location, improve service quality and increase user satisfaction.

Keywords: DTMC, location planning and optimization, PCTL, PRISM, probabilistic model checking

## 1 Introduction

With explosive development of technology and electronic commerce, delivery service has become one of the most important channel for commodity communication. The features of speed and safety of the express delivery ensure the prosperity of the express companies. Besides, the benefits of the businesses and customer satisfaction will be affected by failed express delivery fetch processes. Generally, the delivery company provides customers with home delivery service in society. In reality, the express delivery service in campuses is different from the service in society because it is difficult to send express deliveries to the students directly because of their different time schedule and the huge express quantity. Thus, delivery storage places have appeared in campuses, playing the role of campus agents. This paper focuses on the express delivery fetch processes in campuses.

Consider a campus with at least 5,000 students and more than 10,000 delivery pieces sent to the campus every day. The express deliveries cannot be delivered to the door immediately since the number of deliveries is too great and students may be absent from their dormitories because of different courses or activity arrangements. However, because of the huge delivery volume and time uncertainty, express deliveries need to be stored in a specific express storage point and waiting for students to fetch them. Besides, express deliveries will be sent back to the express companies which are not taken by students in time. If the delivery is returned, a lot of human and material waste will be generated. The failed express

* Corresponding Author

delivery process will cause serious problems to the user and express company, and may even cause express market confusion. Therefore, the place to store express deliveries affects the success rate of campus express delivery. An effective approach needs to be discovered to achieve location planning and optimization.

In recent years, many research studies have been put forward to increase the quality of express delivery service and user satisfaction [3-5]. Nevertheless, most of the existing methods neglect the planning and optimization of express delivery location. Customers are reluctant to go far to fetch deliveries because of laziness, time constraints, bad weather or other reasons. To avoid detention deliveries and returned shipments caused by these deficiencies, probabilistic model checking is adopted in this paper to analyse the process of express storage and acquisition to reduce the costs of express companies and improve the chance of success in the delivery fetch service.

Model checking has been widely used in various fields, which can ensure the correctness of systems [1-2], such as communication technology, network security, distributed algorithms and geographical science. In fact, most real applications show stochastic features, which need the method of probabilistic model checking to describe these features. Probabilistic model checking is an expanded version of model checking by adding probability specifications. It can verify a stochastic system against numerous probabilistic properties. Probabilistic models can be divided into three types: Markov Decision Process (MDP), Discrete-Time Markov Chain (DTMC) [3], and Continuous-Time Markov Chain (CTMC) [4]. Formal languages of properties include two types: Probabilistic Computation Tree Logic (PCTL) and Probabilistic Timed Computation Tree Logic (PTCTL). In brief, probabilistic verification can provide a reasonable verification result for users.

In this paper, probabilistic model checking is employed to validate express delivery service to solve the problems regarding the storage location planning and optimization of express deliveries. The express delivery fetch processes are random events which have stochastic properties because of a lot of objective and subjective factors, such as text message status, weather condition, machine error, distance and human factor. To formalize stochastic characteristics, a Discrete-Time Markov Chain (DTMC) has been adopted to simulate the process. The PCTL property is provided to verify the model, and a quantitative result can be obtained. To select the suitable storage location, time spent and cost are added in experiments. The punishment factor and user satisfaction are also added to get the best performance.

The probabilistic model checker PRISM is adopted in this paper to analysis express delivery status to get a definite result as storage location. It can reduce the cost of express companies. Moreover, it can increase customer satisfaction regarding the express delivery service.

The rest of this paper is arranged in the following order: Section 2 introduces related works. Section 3 lists the process of delivery fetch service and formalize it according to the DTMC model which has stochastic property. Section 4 evaluates the formalized model of the delivery fetch process by using the probabilistic model checker. Section 5 provides the measurable indicator of the express delivery fetch process. Section 6 provides a performance comparison with other methods. Section 7 summarizes the paper and discusses future works.

## 2 Related Work

Researchers at home and abroad have proposed various theories and methods to access delivery fetch process. Lou et al. [3] use analytic hierarchy process (AHP) to gain index weights, and generate service satisfaction to increase service quality for express company. Han et al. [4] present a new delivery management system based on encrypted QR code to surmount problems about low level of informatization, high risk of information disclosure and poor performance of freight. Qin et al. [5] put forward a delivery mode based on automatic parcel machine to optimize the delivery system. Shen et al. [20] use a two-stage method composed of the analysis methods of network programming (ANP) and goal-oriented programming (GP), which affords support for a comparative study of delivery companies. Besides, methods of SPSS [30] and SERVQUAL scale [29] are also used to improve delivery service quality.

Model checking, which can be seen as a validation method, has been adopted in many fields, such as data analysis, intelligent optimization, automation control, Biology, business, etc. Li et al. [21] develop auto-based model checking techniques in a multi-valued setting. Andreychenko et al. [22] apply parametric time model checking to define the time behaviour of biological oscillatory systems. Shi et al.

[23] use three translations from Petri nets to Modelling, Simulation and Verification Language (MSVL) programs. Hutagalung et al. [6] employ sectional evaluation on a model checking algorithm to gain an effective algorithm for the most common substring problem. Alur et al. [7] extend model-checking for the branching-time logic CTL to the analysis of real-time systems, whose correctness relies on the size of the delay. Greifeneder et al. [8] use a modular modeling method for NAS on the basis of probabilistic timed automata. The generated models permit the decision of delay times by using probabilistic model checking. Siedlecka-Lamch et al. [9] introduce the description of a new, probabilistic approach to model checking of security protocols. Lu et al. [24] provide a framework and practical application of probabilistic model checking for decision-making in collision avoidance for USVs. Soeanu et al. [25] present a method that utilizes probabilistic model checking to assess risk-related properties for transportation tasks in the presence of a choice policy over different available routing options and various degrees of uncertainty. Probabilistic model checking (PRISM) is a formal verification technique to validate some PCTL properties and improve the probabilistic behaviours. Alexiou et al. [10] use probabilistic model checking to validate the Near Field Communication (NFC) protocol, using PRISM to study how the attack can be thwarted, and discuss the successfulness of possible countermeasures. Dehnert et al. [18] launch the new probabilistic model checker Storm. It is characterized by the analysis of discrete- and continuous-time variants of both Markov chains and MDPs. Tavala et al. [19] adopt a simpler probabilistic model checking which is more consistent with classical analytical methods to study the dependency of security on the quantum channel noise.

The existing studies regarding express delivery service have many shortcomings, such as the method in [3], for which the indicators of the system constructed are excessive, and the data collection causes the restrictions to some extent. The method in [4] only considers the straight-line distance of different delivery storage locations. Other methods also have various problems. For example, SPSS and SERVQUAL scale require a lot of time, that is to say, the time efficiency is low. Moreover, these methods do not consider express delivery location planning and optimization and customer satisfaction is not high. What is more advantageous than these methods is that, this paper adopts an innovative method to model delivery process to obtain the best suitable express delivery storage location. The method bases on probabilistic model checking, which can largely reduce costs and improve customer satisfaction. On the side, the method in this paper can be used in a variety of different fields, and most of the practical applications can have high time efficiency.

## 3 Modelling the Process of the Express Delivery Fetch Process

The express delivery fetch process has random features, this property is consistent with the properties of Discrete-Time Markov Chain (DTMC). This section introduces the flow of the system and models it by DTMC.

### 3.1 The Scenario of the Express Delivery Fetch System

A complete delivery system is composed of the business portion and customer portion. Customers can choose to take delivery right away or over time after they get text messages regarding the fetching of deliveries. The express delivery storage location affects the probability of the express being taken. The time spent and the money spent are different for each storage location. Fig. 1 shows the detailed process of the express delivery fetch system.

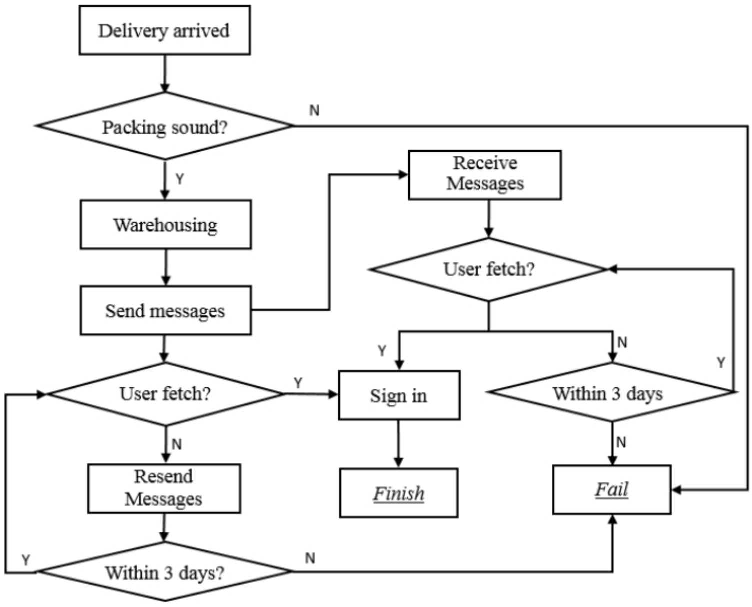



**Fig. 1.** The flow path of an intact express delivery process

**Step 1.** When business portion receipts information that the express deliveries have arrived, the express deliveries will be checked as to whether the packaging and the information on the express list are intact. If the packing is damaged, the express delivery fetch process is marked as failed, and the customers will receive the message that the delivery has been returned. Otherwise, the system sends the information that the express delivery is intact;

**Step 2.** Upon getting the instructions that the packaging is undamaged, the system sends instructions to store the deliveries. Scanning instruments begin scanning the detailed user information on the express list and the information will be stored in a special database;

**Step 3.** Once the process of warehousing completes, the business portion will send the text messages according to the registration information in the database to inform customers to take their express deliveries within a certain period of time;

**Step 4.** When the customers receive the messages about fetching their express deliveries, they can choose to fetch their express deliveries immediately or later. In fact, the user fetch status is associated with the planning of the location of express storage. For example, if the delivery storage location is too far from their dormitory or they do not have enough time to fetch the deliveries, they will not go to the storage location to fetch their deliveries;

**Step 5.** On the condition that the customers go to the storage location to fetch their express deliveries, they need to sign their names on the express list to finish the delivery process. Otherwise, text messages will always be sent to customers to fetch express deliveries within a time interval;

**Step 6.** Suppose time interval is three days. Within three days, the delivery process is set as wait state. And the express deliveries are waiting for customers to come to the express storage location to fetch. Besides, messages are resent. Once beyond this period of time, express deliveries will be returned to the business. Besides, the delivery process is marked as failure;

**Step 7.** The express delivery process will complete once the customer signs his/her name.

In express delivery process, the user fetch status is focused to validate which place is more suitable to store express deliveries. Cost, infrastructure, time spent and other factors can also influence the final evaluation result. It fits the characteristics of a Discrete-Time Markov Chain, which is the state-transition process with increasing probability. The discrete-time Markov chain is a formal method which is widely used to model probabilistic systems. Thus, it is adopted to model the express delivery system in this paper.

### 3.2 Formalism Model of the Express Delivery Fetch Process

The express delivery process is formalized by using the symbolic transition model. The formalized model is defined as a tuple $DTMC = \{S, I, R, AP, L\}$, where

- $S$ is a set of states,
- $I \subseteq S$ is an initial state,
- $R \subseteq S \times S \rightarrow [0,1], \forall s \in S, \sum_{s' \in S}(s,s') = 1$ represents the transition probability relation,
- $AP$ is a set of atomic propositions,
- $L : S \rightarrow 2^{AP}$ is the label function, mapping each state with a set of atomic propositions.

If a state has more than one subsequent state, the next state is chosen on the basis of the atomic propositions.

$$S_{\mathrm{i}} \Rightarrow p * S_{i+1}, 0 \leq i \leq n \wedge p \in R. \quad \textbf{(1)}$$

The express delivery fetch system is composed of two portions. Fig. 2 is the formalism model of the system. $S_0$ stands for the initial state; $S_8$ and $S_9$ are the final states.

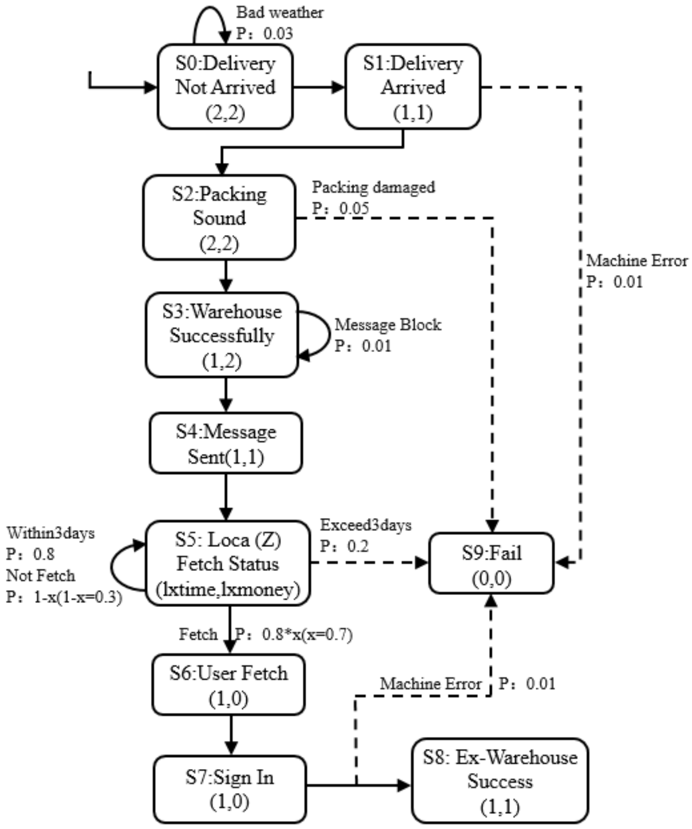



**Fig. 2.** A finite state machine of the express delivery process

Different factors can be combined to change the outcome of the express delivery system. Five factors are taken into account: weather situation, information distribution, machine state, fetch status and over time (whether customer gets his/her express delivery within 3 days). Weather conditions determine whether the express deliveries can be transported to campuses in time. Machine state impacts the entire express delivery fetch system. If there are problems with the machine, S1 in Fig. 2 will jump to S9 such that the entire service fails. Information distribution influences whether customers will get their deliveries in time. Only customers receive messages that informing them to fetch their deliveries, and they will go to the express delivery point. Otherwise, the state of the system will stay in S3. Table 1 shows the probabilities of the atomic propositions (APs). These results are based on historical experience. The preceding four items are fixed values, because they are objective factors. The last one will change because of human factors, so it is a variable factor.

**Table 1.** The probability of different APs

| AP | Prob(Good) | Prob(Bad) |
|---|---|---|
| Weather Situation | 0.97 | 0.03 |
| Machine State | 0.99 | 0.01 |
| Information Distribution | 0.99 | 0.01 |
| Within3days | 0.80 | 0.20 |
| Fetch Probability | x (0.7) | 1-x (0.3) |

Suppose that there exist four locations to store deliveries in a university, namely Loca(A), Loca(B), Loca(C), and Loca(D). They refer to S5 in Fig. 2. This paper focuses on selecting the best location to store deliveries. That is, we will choose the best location (A, B, C, or D) in S5 in Fig. 2. Loca(Z) means the location of Z. "Z" is altered from A to D. The probability that user fetches deliveries of Loca(Z) is x. Time spent, cost and user fetch probability are calculated according to the different distances between the storage locations and customers or other historical experiences. According to numerous factors, such as the transport and the pedestrian volume, the consumption and the fetch probability of each location are different.

Detailed probabilities of user fetching state (state S5) in different locations are recorded in Table 2. Prob(Z) means that the user fetch probability of location Z. For example, Prob(A) represents that the probability users come to location D to fetch express deliveries is 0.7.

**Table 2.** Time spent, cost and user fetch probability of S5

| Loca(Z) | A | B | C | D |
|---|---|---|---|---|
| Prob(Z) | 0.7 | 0.75 | 0.8 | 0.85 |
| Time(Z) | 4 | 3 | 2 | 1 |
| Money(Z) | 1 | 2 | 3 | 4 |

In Table 2, Time(Z) represents time spent, and Money(Z) represents cost of four storage locations. Time(B) means that the time consumption of location B is 3. A higher time spent Time(Z) will reduce the probability that users fetch their deliveries.

## 4 Evaluation Using the PRISM

PRISM [11, 26] is a probabilistic model checker that everyone can use. PRISM is an easy-to-use tool which is used to model and analyse systems formally. The systems display random or probabilistic behaviours. PRISM accepts specifications of logic PCTL or CSL, depending on the type of the model. It can carry out probabilistic model checking to confirm which states meet system specifications.

In this section, PRISM is used to evaluate and validate the express delivery fetch system by performing probabilistic mode checking.

### 4.1 Problem Definition

To perform verification and evaluation of the fetch system, the express delivery model DTMC will be translated into executable language in PRISM. Ten states need to be defined for the express delivery fetch process (see Fig. 2). There is a probability that each state is shifted to the next state. Table 3 lists the most representative transitions achieved through automatic exploration. There is a transition process that is most often mentioned: Path1: *S0*, *S1*, *S2*, *S3*, *S4*, *S5*, *S6*, *S7*, *S8*.

**Table 3.** State transition path of delivery process

| State Transition |
|---|
| Path1: S0, S1, S2, S3, S4, S5, S6, S7, S8 |
| Path2: S0, S0, S1, S2, S9 |
| Path3: S0, S1, S2, S3, S3, S3, S4, S5, S9 |
| Path4: S0, S1, S2, S3, S3, S4, S5, S5, S9 |
| Path5: S0, S0, S1, S2, S3, S3, S4, S5, S9 |
| Path6: ...... |

For a better explanation, Loca(A) is selected as an example. Table 4 records the probability of each state of the express delivery process (see Fig. 2). The rule for each step is that the update state which has a higher probability will be selected. For instance, there exist three update states S'=S5 (the probability is 0.24), S'=S6 (the probability is 0.56) and S'=S9 (the probability is 0.20) from S5. S'=S6 will be selected because that its probability is higher than others. By comparing the probabilities of these different storage locations, a precise result can be obtained to help business determine which place is more suitable to select to realize a successful delivery process. The business has the choice of whether to store deliveries in this storage location. Moreover, the express delivery storage location can be flexibly adjusted. If one of the storage locations has a blackout, the system will stop working.

**Table 4.** Probability of different states when x chooses 0.7 and S5 represents location A is chosen

| Step | Probability | Update State |
|---|---|---|
| S0 (Initial State) | 0.03 | S'=S0 |
| | **0.97** | **S'=S1** |
| S1 | **0.99** | **S'=S2** |
| | 0.01 | S'=S9 |
| S2 | **0.95** | **S'=S3** |
| | 0.05 | S'=S9 |
| S3 | 0.01 | S'=S3 |
| | **0.99** | **S'=S4** |
| S4 | **1.00** | **S'=S5** |
| S5 | 0.24 | S'=S5 |
| | **0.56** | **S'=S6** |
| | 0.20 | S'=S9 |
| S6 | **1.00** | **S'=S7** |
| S7 | **0.99** | **S'=S8** |
| | 0.01 | S'=S9 |
| S8 | **Finish** | |

A concise state transition condition of the delivery process can be provided from the transition path which is shown in Table 3 and the particular transition probability of each state which is shown in Table 4. Table 4 contains the most common transition trace, and the trace can be obtained from the transition probability computation or the manual experiments. In the experiment of this paper, update probability of each step remains the same except state S5 because variable control method is adopted. Besides, Table 4 is using Loca(A) to elaborate the probability of each state. Table 5 shows the update probabilities of four storage locations. Bold and underlined signs represent the most likely situation that will be executed.

**Table 5.** Update probabilities of each location

| State S5 | Probability | Update State | State S5 | Probability | Update State |
|---|---|---|---|---|---|
| | 0.24 | S'=S5 | | 0.20 | S'=S5 |
| Loca(A) | **0.56** | **S'=S6** | Loca(B) | **0.60** | **S'=S6** |
| | 0.20 | S'=S9 | | 0.20 | S'=S9 |
| | 0.16 | S'=S5 | | 0.12 | S'=S5 |
| Loca(C) | **0.64** | **S'=S6** | Loca(D) | **0.68** | **S'=S6** |
| | 0.20 | S'=S9 | | 0.20 | S'=S9 |

Take Loca(A) as a model. From Fig. 2, we can see that the probability of fetching deliveries in 3 days is 0.8, the probability of exceeding 3 days is 0.2, and the probability of not fetching is 0.3. Thus, the conclusion that the probability that S5 is selected to update is 0.24 (0.8 multiplied by 0.3), the probability that S9 is selected to update is 0.20, and the probability that S6 is selected to update is 0.56 (0.8 multiplied by 0.7) can be obtained.

### 4.2 Simulation in PRISM

The basis of PRISM language is interreactive modules. PRISM modules consist of parallel components. These modules are composed of variables, commands labelled with actions for synchronization, guards and probabilities [25]. The DTMC syntax in PRISM is defined as follows:

```
//State definition
s:-0..n] init 0;
//Transition definition
[]<s>-><prob>:<s’>+…+<prob>:<s’>+…+<prob>:<s’>
```

where s is a state, prob$\in$[0,1]. For each state s, it will be changed by having different subsequent transitions under different probabilities. For example, a command that “[] s=0 -> 0.04 : (s’=0) + 0.96 : (s’=1);” means that “when s=0, there is the probability of 0.04 that s still jumps to state 0 to execute s=0 (s’=0) and there is the probability of 0.96 that s jumps to state 1 to execute s=1 (s’=1).”

Simulation results are generated by using the simulation engine of PRISM. The temporal probabilistic logic PCTL is employed to specify the attributes of the fetch process. PCTL is an extended edition of the branching-time temporal logic [28]. PCTL is used to describe quantities, for instance: “the probability that aircraft will reach its destination.”

PRISM uses the manual command and PCTL property which is adopted to carry out probabilistic model checking is as follows:

```
const int sta;
P=? [F s=sta]
```

The property is the form that P=? [F phi]. It means “what is the probability from the initial state of the model to reach a state where phi is true?” [12].

The PCTL property is used to validate the express delivery system. Each state of the delivery process has a corresponding probability. Various numbers of simulation times are adopted in the experiment. Any experiment is a simulation of the real situation. If the simulation times are $\delta$, it can be seen that $\delta$ express delivery fetch processes have taken place.

**Table 6.** Probability of each state when using PRISM to verify the delivery process and x is 0.7

| | Verification Result | Simulation Times | | | | |
|---|---|---|---|---|---|---|
| | | 20 | 100 | 10000 | 100000 | 1000000 |
| S0 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| S1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| S2 | 0.990 | 1.000 | 0.990 | 0.989 | 0.989 | 0.990 |
| S3 | 0.940 | 0.900 | 0.950 | 0.935 | 0.941 | 0.940 |
| S4 | 0.940 | 0.900 | 0.950 | 0.935 | 0.941 | 0.940 |
| S5 | 0.940 | 0.900 | 0.950 | 0.935 | 0.741 | 0.940 |
| S6 | 0.717 | 0.400 | 0.780 | 0.717 | 0.717 | 0.717 |
| S7 | 0.717 | 0.400 | 0.780 | 0.717 | 0.717 | 0.717 |
| S8 | 0.710 | 0.400 | 0.770 | 0.709 | 0.709 | 0.710 |
| S9 | 0.290 | 0.600 | 0.230 | 0.291 | 0.291 | 0.290 |

Table 6 lists the experimental results under different simulation times. Fig. 3 converts Table 6 into the form of a broken line graph. It can be seen that, when the number of simulation times are increasing, the probability of each state is closer to the verification result. The result of this experiment conforms to the Bernoulli large numbers law [13]. For any $\varepsilon>0$, the following formula is proven:

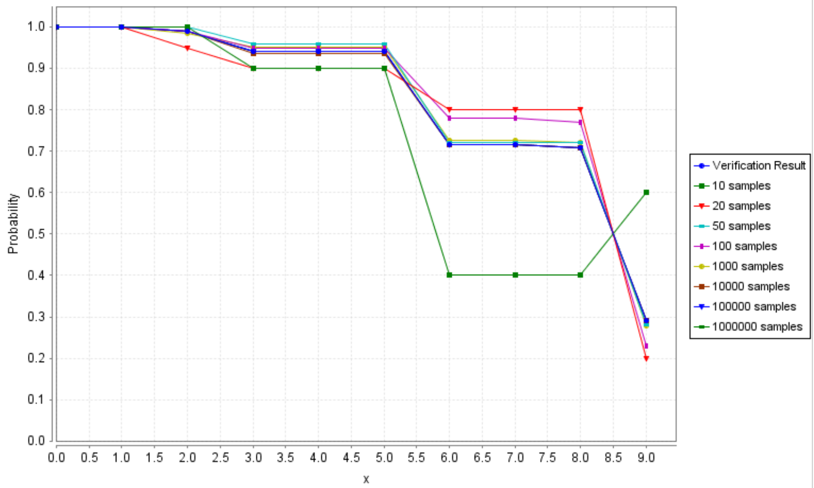



**Fig. 3.** Visualization line chart of the simulated result

$$\lim_{n\to\infty} P\{|\frac{n_x}{n} - p| < \varepsilon\} = 1. \tag{2}$$

In a series of independent experiments, the occurrence probability of a certain event $X$ has the same value $p$ ($0<p<1$), where $n_x$ is the times that event $X$ occurs in n-fold Bernoulli experiments, and $\frac{n_x}{n}$ represents the frequency of occurrence.

Therefore, the verification result can be used as a standard for the delivery location planning to get the optimal path. The express delivery fetch process in this paper is logical.

## 5 The Measurable Indicator of Express Delivery

### 5.1 Problem Definition

In practice, other related factors need to be considered to obtain maximum benefits for businesses and customers [14]. The factors include price, punctuality, vehicles, convenience, information systems and so on. Most of the existing methods ignore these factors, which play important roles in express delivery service. In the delivery process, time spent and cost are considered as main influencing factors. Therefore, the DTMC structure can be turned into the new structure *Ex-DTMC*:

$$Ex - DTMC ::= (DTMC, T(S), C(S)). \tag{3}$$

For this purpose, each step in Fig. 2 will be turned as a tuple (time, cost). Time spent represents the amount of time consumed by business portion at every stage. Cost represents the amount of money consumed by business portion at every stage.

To select a best place to store express deliveries, State 5 can be extended with (Loca(Z), Fetch Status, (Ztime, Zmoney)). The time spent, cost and user fetch probability will be changed because of different Z. The detailed data are recorded in Table 2.

The cost *C(S)* and time spent *T(S)* in the *Ex-DTMC* are calculated as follows:

**Cost:**

$$C(S) = C(S_0) + C(S_1) + \ldots + C(S_{n-1}) + C(S_n). \tag{4}$$

**Time Spent:**

$$T(S) = T(S_0) + T(S_1) + \ldots + T(S_{n-1}) + T(S_n). \tag{5}$$

The time spent and cost of each state can be referred to Fig. 2 and Table 2.

According to the path which is the most likely to happen, Path1: *S0*, *S1*, *S2*, *S3*, *S4*, *S5*, *S6*, *S7*, *S8*, cost *C(S)* and time spent *T(S)* of the entire delivery process for different storage location can be calculated as follows:

$$\begin{aligned} C(S) &= C(S_0) + C(S_1) ... + C(S_8) \\ &= 2 + 1 + 2 + ... + Zmoney + ... + 0 + 1 \\ &= 9 + Zmoney. \end{aligned} \quad \textbf{(6)}$$

$$\begin{aligned} T(S) &= T(S_0) + T(S_1) ... + T(S_8) \\ &= 2 + 1 + 2 + ... + Ztime + ... + 1 + 1 \\ &= 10 + Ztime. \end{aligned} \quad \textbf{(7)}$$

Next, $G(S)$ is set as a combined factor, which considers time spent and cost, to provide maximum benefit for business portion:

$$G(S) = \alpha T(S) + \beta C(S). \quad s.t \begin{cases} \alpha + \beta = 1 \\ \alpha > 0.5 \;\; if \;\; time \; is \; prior \\ \alpha < 0.5 \;\; if \;\; money \; is \; prior \end{cases} \quad \textbf{(8)}$$

where *α* and *β* are two adjustable factors. When time spent is more important, *α* is bigger than 0.5; When cost is more important, *α* is smaller than 0.5. If the weights of time spent is as important as cost, *α*=*β*=0.5. Besides, *α* plus *β* is always equal to 1.

### 5.2 Experiments and Analysis

In order to determine the most suitable location to store the express deliveries, $T(S)$, $C(S)$, and $G(S)$ of four storage locations need to be calculated. Because that the tool PRISM can analyze the stochastic model formally based on the rewards mechanism [15], some quantitative properties can be added to conduct experiments.

The rewards grammar of PRISM is demonstrated in this section. The code segment of rewards grammar begins with **rewards "time,"** where rewards are related to models using **rewards…endrewards** constructs [12]. The code segment consists of a single reward item. The PRISM model supports numerous reward structures [16]. Two reward structures are involved to get an optimal result in our method. They are the computation of time spent and cost, respectively, "time rewards" and "cost rewards."

The computing results of "rewards" are listed in Table 7. Ten repeated experiments are carried out for each storage location. The average values (Average) of ten experiments are calculated to acquire a relatively reasonable conclusion. *T(S)* and *C(S)* stand for the time spent and cost of final states. *G(S)* is the combine factor of *T(S)* and *C(S)*. In columns *T(S)* and *C(S)* of Table 7, bold and slanted fonts represent that the express delivery fetch process is failing and that the others are successful.

Two cases are conducted to compute the combined factor $G(S)$, namely, *α*=0.4 and *α*=0.6. From Table 7, it can be seen that, when money consumption possesses a higher weight, i.e., *α*=0.4, Loca(C) with $G(S)$=11.1 is more suitable to store deliveries. When time consumption is prioritized, i.e., *α*=0.6, Loca(D) with $G(S)$=10.86 is more suitable.

In Table 7, when *α*=0.4, location D has a bad $G(S)$ value of 11.44 (bold and underlined data in Table 7). It is the worst place to storage express deliveries. However, it has a high success rate, which can influence the result of express delivery storage location planning. In order to obtain more accurate calculation results, successful probability of *S8* and failure probability of *S9* of every location need to be calculated. Table 8 records these success rate and failure rate.

**Table 7.** Computed results of *T(S)*, *C(S)* and *G(S)*

| Loca(Z) | ExpID | T(S) | C(S) | α=0.4/β=0.6 | α=0.6/β=0.4 |
|---|---|---|---|---|---|
| Loca(A) | 1 | 17 | 10 | G(S)=12.8 | G(S)=14.2 |
| | 2 | ***11*** | ***9*** | G(S)=9.8 | G(S)=10.2 |
| | 3 | 15 | 11 | G(S)=12.6 | G(S)=13.4 |
| | 4 | 13 | 9 | G(S)=10.6 | G(S)=11.4 |
| | 5 | 13 | 9 | G(S)=10.6 | G(S)=11.4 |
| | 6 | ***11*** | ***9*** | G(S)=9.8 | G(S)=10.2 |
| | 7 | 17 | 10 | G(S)=12.8 | G(S)=14.2 |
| | 8 | 17 | 10 | G(S)=12.8 | G(S)=14.2 |
| | 9 | 13 | 9 | G(S)=10.6 | G(S)=11.4 |
| | 10 | 13 | 9 | G(S)=10.6 | G(S)=11.4 |
| | Average | 14 | 9.5 | **G(S)=11.3** | **G(S)=12.2** |
| Loca(B) | 1 | 13 | 11 | G(S)=11.8 | G(S)=12.2 |
| | 2 | 12 | 10 | G(S)=10.8 | G(S)=11.2 |
| | 3 | 14 | 12 | G(S)=12.8 | G(S)=13.2 |
| | 4 | 12 | 10 | G(S)=10.8 | G(S)=11.2 |
| | 5 | 15 | 12 | G(S)=13.2 | G(S)=13.8 |
| | 6 | ***10*** | ***10*** | G(S)=10 | G(S)=10 |
| | 7 | 12 | 10 | G(S)=10.8 | G(S)=11.2 |
| | 8 | ***10*** | ***10*** | G(S)=10 | G(S)=10 |
| | 9 | 15 | 12 | G(S)=13.2 | G(S)=13.8 |
| | 10 | 12 | 10 | G(S)=10.8 | G(S)=11.2 |
| | Average | 12.5 | 10.7 | **G(S)=11.42** | **G(S)=11.78** |
| Loca(C) | 1 | 11 | 11 | G(S)=11 | G(S)=11 |
| | 2 | 11 | 11 | G(S)=11 | G(S)=11 |
| | 3 | 11 | 11 | G(S)=11 | G(S)=11 |
| | 4 | 13 | 14 | G(S)=13.6 | G(S)=13.4 |
| | 5 | 11 | 11 | G(S)=11 | G(S)=11 |
| | 6 | 11 | 11 | G(S)=11 | G(S)=11 |
| | 7 | ***9*** | ***11*** | G(S)=10.2 | G(S)=9.8 |
| | 8 | 11 | 11 | G(S)=11 | G(S)=11 |
| | 9 | ***9*** | ***11*** | G(S)=10.2 | G(S)=9.8 |
| | 10 | 11 | 11 | G(S)=11 | G(S)=11 |
| | Average | 10.8 | 11.3 | **G(S)=11.1** | **G(S)=11** |
| Loca(D) | 1 | 10 | 12 | G(S)=11.2 | G(S)=10.8 |
| | 2 | ***9*** | ***16*** | G(S)=13.2 | G(S)=11.8 |
| | 3 | 10 | 12 | G(S)=11.2 | G(S)=10.8 |
| | 4 | 12 | 14 | G(S)=13.2 | G(S)=12.8 |
| | 5 | 10 | 12 | G(S)=11.2 | G(S)=10.8 |
| | 6 | 10 | 12 | G(S)=11.2 | G(S)=10.8 |
| | 7 | 10 | 12 | G(S)=11.2 | G(S)=10.8 |
| | 8 | ***8*** | ***12*** | G(S)=10.4 | G(S)=9.6 |
| | 9 | ***8*** | ***12*** | G(S)=10.4 | G(S)=9.6 |
| | 10 | 10 | 12 | G(S)=11.2 | G(S)=10.8 |
| | Average | 9.7 | 12.6 | **G(S)=11.44** | **G(S)=10.86** |

**Table 8.** The successful and failure rate of four locations

| Storage Location | Successful Rate | Failure Rate |
|---|---|---|
| Loca(A) | 0.722 | 0.278 |
| Loca(B) | 0.735 | 0.265 |
| Loca(C) | 0.747 | 0.253 |
| Loca(D) | 0.757 | 0.243 |

Because that the failed express delivery process can cause losses to business portion as well as customer portion [17], the evaluation factor $G(S)$ in formula (8) is supposed to add an adjustable punishment factor $\xi$ to restrain the loss. The punishment factor $\xi$>1 because a location that has a high failure rate is unsuitable to store deliveries. When the value of $\xi$ is larger, the failure rate is less tolerant.

Formula (8) is rewrote as follows,

$$\begin{aligned} Eva(S) &= G(S) + \xi Fail(S) \\ &= \alpha T(S) + \beta C(S) + \xi Fail(S). \end{aligned} \tag{9}$$

$$s.t \begin{cases} \alpha + \beta = 1 \\ \alpha > 0.5 \ \ if \ time \ is \ prior \\ \alpha < 0.5 \ \ if \ money \ is \ prior \\ \xi > 1 \end{cases}$$

In Table 9, two circumstances are selected to analysis the results, *α* is 0.4 (cost is prior) and *α* is 0.6 (time is prior). The values by using different *α* have the corresponding $G(S)$, which are recorded in Table 7. Each group in Table 9 has a corresponding punishment factor *ξ* to calculate evaluation value *Eva(S)*.

**Table 9.** Evaluation of four locations under different punishment factors

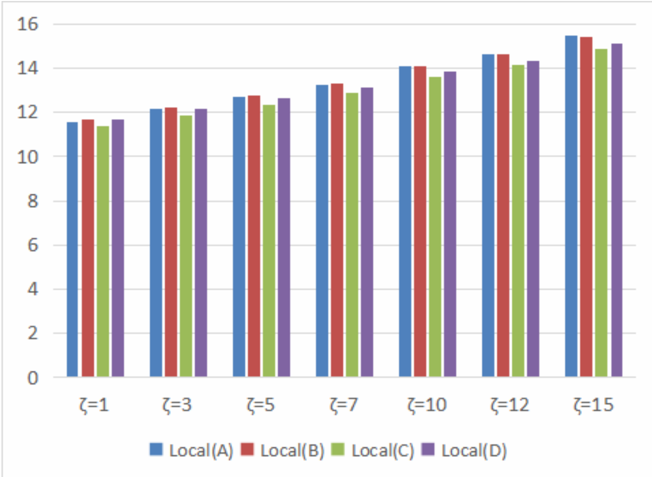
| | Loca(Z) | Loca(A) | Loca(B) | Loca(C) | Loca(D) |
|---|---|---|---|---|---|
| | Fail(S) | 0.278 | 0.265 | 0.253 | 0.243 |
| α=0.4/β=0.6 | G(S)/ξ=0 | 11.300 | 11.420 | 11.100 | 11.440 |
| | ξ=1 | 11.578 | 11.685 | 11.353 | 11.683 |
| | ξ=3 | 12.134 | 12.215 | 11.859 | 12.169 |
| | ξ=5 | 12.69 | 12.745 | 12.365 | 12.655 |
| | ξ=7 | 13.246 | 13.275 | 12.871 | 13.141 |
| | ξ=10 | 14.080 | 14.070 | 13.630 | 13.870 |
| | ξ=12 | 14.636 | 14.600 | 14.136 | 14.356 |
| | ξ=15 | 15.470 | 15.395 | 14.895 | 15.085 |
| α=0.6/β=0.4 | G(S)/ξ=0 | 12.200 | 11.780 | 11.000 | 10.860 |
| | ξ=1 | 12.478 | 12.045 | 11.253 | 11.103 |
| | ξ=3 | 13.034 | 12.575 | 11.759 | 11.589 |
| | ξ=5 | 13.590 | 13.105 | 12.265 | 12.075 |
| | ξ=7 | 14.146 | 13.635 | 12.771 | 12.561 |
| | ξ=10 | 14.980 | 14.430 | 13.530 | 13.290 |

In each comparative experiment under different *α* and *ξ*, some conclusions can be found, such as the best storage location and which location is the first to be excluded from consideration. In this analysis part, two situations are discussed and they are listed as below,

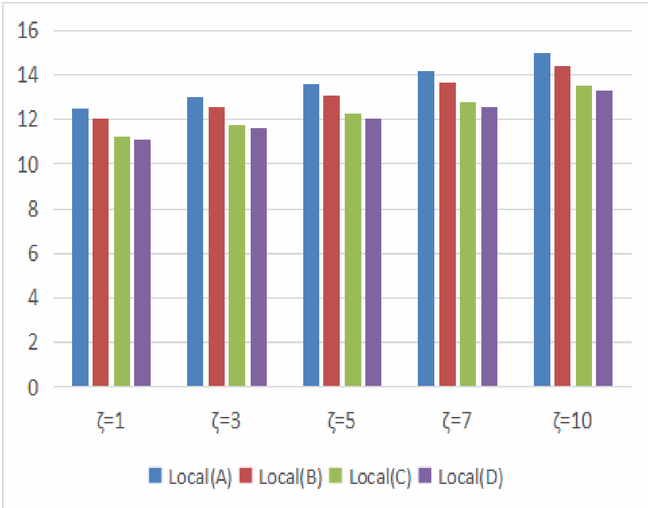
**Situation A**: expending less time is preferential;

**Situation B**: expending less money is the first consideration.

From Fig. 4(a), under Situation A, Loca(A) has a lower *Eva(S)* compared with Loca(B), so choosing Loca(A) is better. Nevertheless, when punishment factor *ξ* is increased, the adding *ξ*·Fail(S) can reduce its original advantage because that its failure rate is high. Thus, the lower cost consumption superiority of Loca(A) is reduced by the adding high failure rate. Thus, when *ξ* increases to 15, Loca(B) is more suitable rather than Loca(A). Considering Loca(C), because of its low time consumption, its advantage is obvious. Comparing the results in Table 7, the worst storage location is D. It can be seen that location D is only inferior to location C when *ξ*>3. This result is more suitable in real life. Fig. 4(b) shows the experimental result under Situation B. Loca(D) has been chosen as the best express delivery storage location, no matter how *ξ* changes. The value of *α* and *ξ* will affect the final evaluation results. When time is the prior factor and *ξ*<=3, Loca(A) and Loca(C) will be chosen. When time is the prior factor and *ξ*>3, choosing Loca(C) and Loca(D) is more suitable. Thus, when time is the prior factor, Loca(C) is the best place. When money is the prior factor, Loca(D) will be chosen as the best storage place.




(a) The value of *Eva(S)* when $\alpha$=0.4




(b) The value of *Eva(S)* when $\alpha$=0.6

**Fig. 4.** The location evaluation results under different conditions

The above method only considers the objective factors and does not take the customers' subjective factors into account. Personalized service is more and more widely used in various industries. Personalized service is implemented based on user settings. Customers can be provide relevant information according to a variety of channels to collect, sort and resources. The ultimate goal is to meet user requirements. On the whole, personalized service has broken the traditional service mode. It can make full use of all kinds of resources and actively carry out all-round services to meet the needs of customers.

To add personalized needs, the original evaluation factor *Eva(S)* is modified as follows:

$$\begin{aligned} Eva(S) &= G(S) + \xi Fail(S) + \gamma Satis(S) \\ &= \alpha T(S) + \beta C(S) + \xi Fail(S) + \gamma Satis(S). \end{aligned} \quad \textbf{(10)}$$

$$s.t \begin{cases} \alpha + \beta = 1 \\ \alpha > 0.5 \ \ if \ time \ is \ prior \\ \alpha < 0.5 \ \ if \ money \ is \ prior \\ \xi > 1 \\ -1 < \gamma < 0 \end{cases}$$

The adjustable factor $\gamma$ is between -1 and 0 because the high *Satis(S)* will decrease the total consumption. S*atis(S)* means customers' scores for four express delivery storage locations. The scores of four storage locations are divided into five classes: 1, 2, 3, 4 and 5. When customers sign for the express deliveries, they can write a score for the quality of the service. Table 10 records the scores of each storage location. The experiment results are included in Fig. 5. In this experiment, $\gamma$ = -0.2 and $\gamma$ = -0.3 are adopted.

**Table 10.** The scores of four different storage locations

| Loca(Z) | A | B | C | D |
|---|---|---|---|---|
| Score(Z) | 4 | 2 | 2 | 3 |

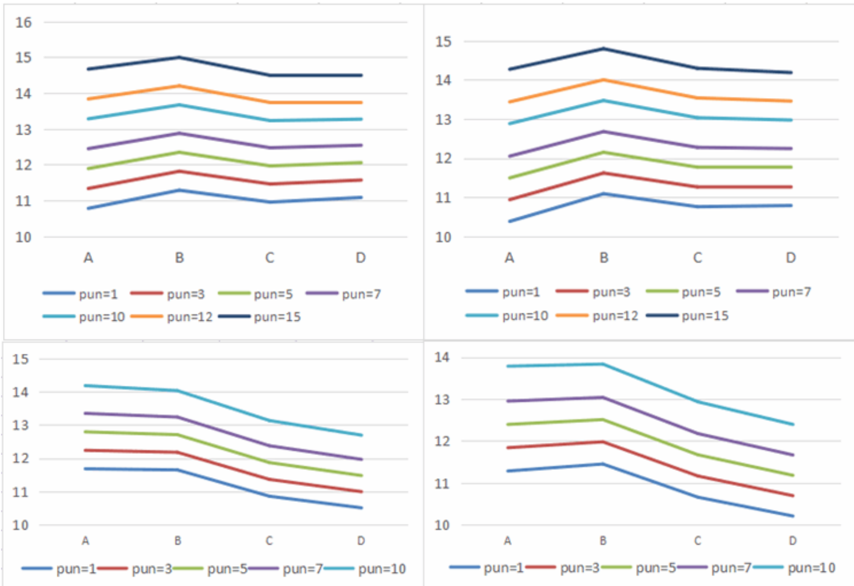



**Fig. 5.** Line chart of location evaluation under personalized service when $\gamma$ = -0.2, -0.3

The upper half of the graph adopts $\alpha$=0.4, and the lower half of the graph adopts $\alpha$=0.6. The left half of the graph adopts $\gamma$ = -0.2, and the right half of the graph adopts $\gamma$ = -0.3.

From Fig. 5, we can see that, when α=0.4, $\gamma$ = -0.2 and $\xi$<=7, Loca(A) is the better place; when $\xi$>7, Loca(C) becomes the better place. When $\alpha$=0.4 and $\gamma$ = -0.3, Loca(C) is always the better place. When $\alpha$=0.6, Loca(D) is the best place to store deliveries regardless of $\gamma$. The conclusion can be that, when customers' opinions account for a larger proportion, the location that has a higher score will be chosen as the most appropriate place.

## 6 Performance Analysis

In general, there are some existing methods for choosing the express delivery storage locations, such as shortest distance, AHP and SERVQUAL. In this section, the method of using probabilistic model checking will be compared with two classical methods.

### 6.1 Comparison with Shortest Distance

In the past, most people used the shortest distance method to select the optimal locations. For example, the dormitories in a campus are divided into three categories, Dormitory(1), Dormitory(2) and Dormitory(3). Then, the business calculates the shortest distance between dormitories and express delivery storage locations. The data is listed in Table 11.

**Table 11.** The distance between dormitories and storage locations

| Loca(Z) | A | B | C | D |
|---|---|---|---|---|
| Dormitory(1) | 4 | 2 | 5 | 3 |
| Dormitory(2) | 4 | 6 | 3 | 5 |
| Dormitory(3) | 3 | 2 | 5 | 4 |

From Table 11, the average cost of the four storage locations can be obtained. In the same situation, the method of using probabilistic model checking should choose the same $\alpha$ and $\beta$ ($\alpha$=$\beta$=0.5) in Table 7. The detailed experimental result is shown in Table 12 and Fig. 6.

**Table 12.** The results of using shortest distance and probabilistic model checking, respectively

| Loca(Z) | SD | Loca(Z) | PMC |
|---|---|---|---|
| A | 3.67 | A | 11.75 |
| B | 3.33 | B | 11.6 |
| C | 4.33 | C | 11.05 |
| D | 4.00 | D | 11.15 |


**Fig. 6.** The chart result of two methods

The left part of Table 12 is the result of using shortest distance, and the right part is using probabilistic model checking. SD expresses the method of shortest distance, and PMC means the method of probabilistic model checking. From the method of shortest distance, Loca(B) is the most appropriate storage location. However, when using probabilistic model checking under the same condition, Loca(C) is the most appropriate. The reason for this situation is that probabilistic model checking considers most of the factors, such as weather, information status, machine status, distance, traffic conditions, time, and costs. As mentioned above in Table 8, the success rates of the four locations are respectively 0.722, 0.735, 0.747 and 0.757. Except for location D, choosing location C is better. Thus, the use of probability model checking can come to a better conclusion with regard to increasing express storage service quality than the use of Shortest Distance. Moreover, when the influencing factors are changed, the result will be changed by probabilistic model checking.

To summarize, the traditional method cannot play a good role in the express delivery industry. However, when using our method, most of the factors can be considered, and a better solution can be obtained.

### 6.2 Comparison with AHP

The analytic hierarchy process (AHP) [27] is an efficient multi-objective decision making method which can carry out qualitative analysis and quantitative analysis. It is a process of modeling and quantifying the decision-making process of decision makers to complex systems. It can give a set of priorities of alternatives according to the decision maker's judgements to provide an optimal solution.

With AHP, the factors that influence the speed of fetching express delivery by students are distance, weather, costs and user ratings. The hierarchical structure model is shown in Fig. 7.

The first layer is the target layer, the second layer is the criterion layer, and the third layer is the scheme layer. AHP adopts the method of 1-9 scale and different situations can get the quantity scale. The scale is always set by users. The weight among the four factors can be obtained from the scale which has been set in advance. Then, the alternative results can be easily found by the tool YAAHP. Experimental results are recorded in Table 13.

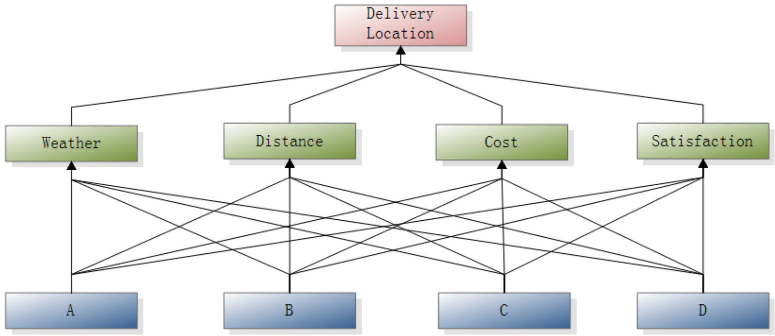
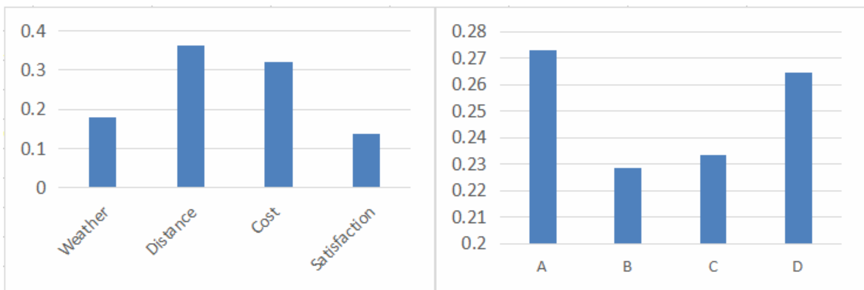



**Fig. 7.** Hierarchical structure model in the tool YAAHP

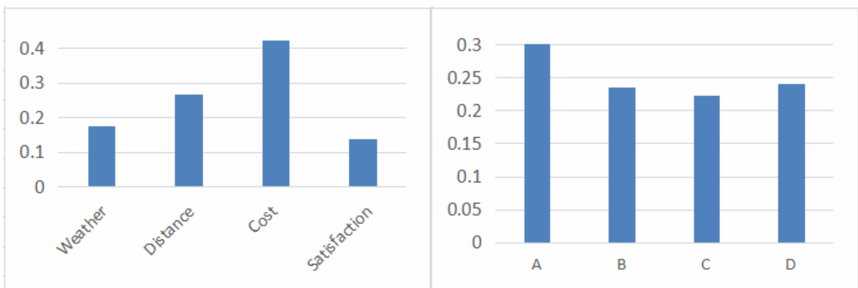
**Table 13.** The experimental results of AHP

| Element | Exp | Weather | Distance | Cost | Satisfaction |
|---|---|---|---|---|---|
| | 1 | 0.1744 | 0.2656 | 0.4228 | 0.1372 |
| | 2 | 0.1788 | 0.3632 | 0.3198 | 0.1382 |
| Weight | 3 | 0.1752 | 0.3835 | 0.3068 | 0.1346 |
| | 4 | 0.4236 | 0.2270 | 0.2270 | 0.1223 |
| | 5 | 0.1223 | 0.2270 | 0.2270 | 0.4236 |
| Loca(Z) | Exp | A | B | C | D |
| | 1 | *0.3009* | 0.2354 | 0.2237 | 0.2399 |
| | 2 | *0.2732* | 0.2287 | 0.2336 | 0.2645 |
| Weight | 3 | 0.2678 | 0.2280 | 0.2356 | *0.2686* |
| | 4 | *0.2757* | 0.2335 | 0.2344 | 0.2565 |
| | 5 | *0.3376* | 0.2006 | 0.2015 | 0.2603 |

Table 13 includes five sets of data. Numbers 1 through 5 are one-to-one correspondences. The top half part of Table 13 means the weight between the four factors (weather, distance, cost, and Satisfaction). The rest is the alternative options among storage locations. The red and italic fonts are used to denote the best appropriate storage location. Then, the first and second groups of data are converted into Fig. 8.




(a) The result of AHP that the weight of Distance is greater than Cost




(b) The result of AHP that the weight of Distance is less than Cost

**Fig. 8.** Histogram of the first and second group of experiment results

The left parts of Fig. 8(a) and Fig. 8(b) are weight settings, and the right parts are decision goals. These two conditions are just part of the experiment results. From Fig. 8(a), when Distance's weight is the biggest and Cost is the second, the system recommends that the business choose location A; on the contrary, location A is still recommended. The reason for this condition is that, in these two groups of experiments, location A has an extremely large advantage on both the distance and the cost. When using probabilistic model checking, the weight of the cost is set as the largest.

From Table 13, it can be seen that location A is always chosen as the most suitable path. Fig. 9 shows the result of using probabilistic model checking. It considers the condition that money is a prior factor. It can be seen that the use of probabilistic model checking yields location C as the storage place. Under the same condition, the method of AHP chooses location A. The success rates of each location are shown in Table 8. The success rate of location C, 0.747, shows that it is more suitable than location A with 0.722. Thus, when compared with AHP, our method is still able to achieve better results.

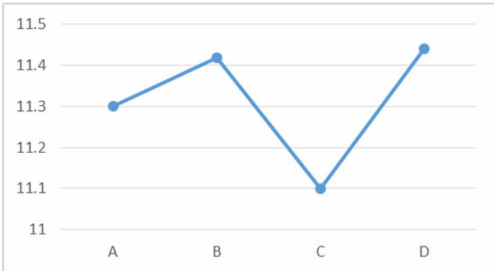



**Fig. 9.** Experimental result of using probabilistic model checking when money is the prior factor

AHP puts emphasis on the goal situation, ignoring other processes. However, when using PRISM, the probability of each stage can be easily found, the costing can be given to the business, and the business can have more space to choose the best location independently. However, the method of AHP uses "scale" to get the determining weights. It will require a large cost to determine weights. Moreover, users' subjective factors account for a large part of the final result.

According to our experiment, under the same conditions, the times spent for 10000 iterations in the tool PRISM and in the tool YAAHP are shown in Fig. 10. Five sets of data were recorded. The conclusion can be drawn that the time efficiency of PRISM is always higher than that of YAAHP. The use of probabilistic model checking can save more time and achieve better results.

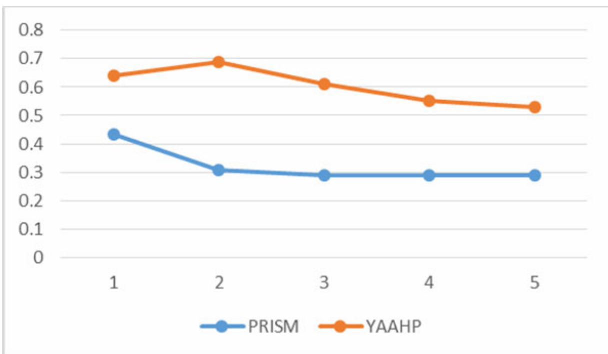



**Fig. 10.** Time expenditure in PRISM and YAAHP

From the above, the use of probabilistic model checking can not only select a better storage path but also yield a lower time cost. It can improve the quality of whole delivery service.

## 7 Conclusion and Future Works

With explosive development of e-commerce, people are eager for faster and accurater delivery services. Researchers have used many means and techniques, such as AHP and Shortest Distance, to analyse the quality of express delivery service. These methods do not consider location planning and optimization.

Nevertheless, the location planning and optimization play an important role in delivery service because it is associated with factors such as probability, time and cost, as well as many other factors. In this paper, probabilistic model checking is employed, which can give a formal method for selecting the best place to store deliveries. Express deliveries will be storied in the storage location, waiting for students to fetch. Temporal probabilistic logic (PCTL) is provided as a verification property to specify requirements of an express delivery system. By using PCTL, a quantitative result can be obtained. The probabilistic model checker PRISM can simulate the express delivery fetch process in real life. Besides, it is used to conduct quantitative analysis for each step in delivery process, which can validate delivery status as well as improve the quality of delivery process. Furthermore, time spent and cost are considered to improve the quality of delivery system, as well as the probability factor. The punishment factor and user satisfaction are also added to improve performance. What's more, the method in this paper is compared with the traditional methods of shortest distance and AHP. The experiments in this paper demonstrate the high efficiency of our method, which can accurately choose an optimal location to get the minimum costs for the business portions and the maximal satisfaction for the customers.

In future research work, experiments will focus on the application of large data records in logistics system. Moreover, user preference has not been perfected. We will stand in the user's perspective to achieve a better personalized recommendation. In addition, the method proposed in this paper is tried to be applied in other fields, such as commerce, manufacture, finance and so on.

## Acknowledgements

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