Physical Internet enabled bulky goods delivery and pick up solution in city logistics

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Abstract: *Physical Internet (PI) and city logistics are two novel concepts aiming to render more economically, environmentally and socially efficient and sustainable the way, in which physical objects are transported, handled, stored, realized, supplied and used throughout the world. City logistics is a key enabler to city economy, which has been introduced to cope with the challenges of sustainable cohabitation and development of freight transportation in the city. In the city logistics operation, bulky goods delivery is big challenge since it is difficult to delivery in the "last 100 meters" in the city. This research has been motivated by real-life problem faced by our collaborating company, which is specialized in customized furniture. Following characteristics of customized furniture industry create lots of problems to delivery service providers. In order to mitigate these impacts, the model of Physical Internet enabled Bulky Goods City Logistics (PI-BGCL) is proposed. The meta-heuristic algorithm (Genetic algorithm) has been applied to compare the traditional delivery model and proposed PI-BGCL model. To validate the effect and efficiency of proposed PI-BGCL model, the case study in this paper consists of two parts. The first one is a real-life case study of a customized furniture industry in China, which demonstrates the efficiency and feasibility of the proposed mode. The second one is to validate the effectiveness of proposed algorithms. Experimental design and a set of sensitivity analyses was performed to examine the effects of several key parameters on system performance.*

Keywords: *Physical Internet; bulky goods; city logistics; simultaneous delivery and pick up; backhaul; genetic algorithm*

1 Introduction

City logistics is a key enabler to city economy, which has been introduced to cope with the challenges of sustainable cohabitation and development of freight transportation in the city (Benjelloun and Crainic, 2008) (Crainic and Montreuil, 2016). Since the bulky goods urban delivery mainly distributes the goods of small batches and multiple varities, which are difficultl to delivery in the "last 100 meters" of the supply chain (Morganti and Morganti, 2014). The bulky goods include furniture, household electrical appliances, musical instruments and indoor decorating materials. But they have been experiencing a challenge of intensified market competition, the customization and the innovation of " Industry 4.0".

Nowadays, Montreuil (2011) introduced a solution to Global Logistics Sustainability Grand Challenge, Physical Internet (PI), whose aim is to enable an efficient and sustainable logistics web at the logistics hubs as well as at the end consumer. To achieve this goal, Sallez et al. (2016) have shown that considerable gains can be achieved through the application of the PI by designing PI-containers. The containers have associated activity, which allows the PI-container to have an active role for its mission and in the PI management and operation. Following the application of the digital internet, PI enabled goods will be sent over an open and global logistics system founded on physical, digital and operational interconnectivity through encapsulation, interfaces and protocols. And city Logistics providing the final and last segments of the Physical Internet logistics and transportation networks (Crainic and Montreuil, 2016).

Customized furniture is one of the typical bulky goods. Some characteristics of customized furniture delivery bring critical challenges to the logistics service providers. In our previous research (Luo Tian & Kong 2018), the characteristics and painpoint of customized furniture city logistics have been studied and a PI enabled conceptual solution has been proposed. In this research a mathematical model has been proposed to deal with the Physical Internet enabled Bulky Goods City Logistics (PI-BGCL)

The main objectives of this paper are (1) to improve the field of bulky goods city logistics with PI concept. (2) to descript the bulky goods city logistics problem with the PI-BGCL model. (3) to design Genetic Algorithm to solve the problem. (4) to discuss the potential application bulky goods city logistics technology in the viewpoint of academic and industry.

2 Characteristics Bulky Goods Urban Delivery

Customized furniture is one of the typical bulky goods. Some characteristics of customized furniture delivery bring critical challenges to the logistics service providers. Compared to the traditional furniture industry, customized furniture industry has following characteristics:

(1) Order size is quite different. Due to the different sizes of the customers' rooms, the quantity of products contained in each order is different.

(2) Most of the product form is board–shape furniture components and a large number of metal accessories.

(3) All components are make-to-order produced, and the customized furniture produces only one single piece.

(4) Leading time is very long, usually more than 3 months, so it is impossible to predict the delivery time required by the customer when ordering. It is impossible to predict the delivery time required by customers when ordering.

(5) The delivery time window is narrow. There are only two days from the customer's delivery request to the actual delivery request.

(6) Deliver to a designated location. The customer requires all products to be moved to the designated location in the room.

Most of the customized furniture manufactures use the 3rd party logistics service to conduct the door to door delivery service. However, the characteristics of customized furniture industry are critical challenges for the delivery service providers.

This research has been motivated by real-life problem faced by our collaborating company, which is specialized in customized furniture. Following these characteristics of customized furniture industry is a big challenge to the delivery service providers of customized furniture. (1) One shipment order contains multiple product pieces. The loading/unloading and movement into customers house is very time consuming. (2) The long on-site material handling time leads to long waiting time of vehicles. The transportation efficiency is very low. (3) The dimensions of furniture parts are irregular. The space utilization of vehicles is very low. (4) The repeatedly loading and unloading operation may lead to product damage. Since the furniture is customized, one piece of furniture part damage may lead to a delay of the whole assembly project. Meanwhile, the remanufacturing cost is very high.

3 PI enabled Bulky Goods Delivery solution

In order to solve the problem of bulky goods in urban delivery, especially the pain points identified in customized furniture industry, a PI enabled Bulky Goods Delivery Solution has been propsoed (Luo Tian & Kong 2018). The key componets in the proposed soultion are PI enabled container and PI enabled Vehicle.

The design of PI enabled container are shown in Figur 1. Based on the PI concept, each container can be packing one customer order. Due to the characteristics of customized furniture industry, the product is a board-shape component. The length and width of the component have limited standards. The high dimensions depend on the quantity of component in each order. Therefore, the proposed PI container will have standardized width, length and different height. A data analysis for history order information will be conducted to determine 3-5 container types.

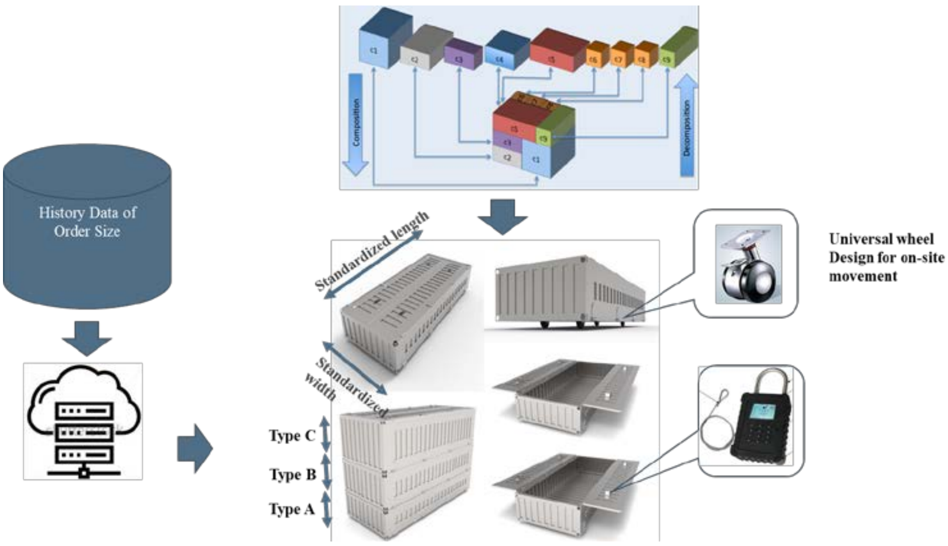

Figure 1: the design of PI enabled container

The design of PI enabled Vehicle are shown in Figur 2.In order to improve the transportation efficiency, the PI containers on one truck will be dropped on each customers' destination, one by one in a round trip. Meanwhile, the empty container will be collected. Therefore, the aim of the PI enabled vehicle design is to achieve autonomic container loading/unloading on the customer destination without forklift. Figure 4 shows the concept design of proposed PI vehicle. The vehicle-mounted loading/unloading mechanism consists of a shiftable frame, two supporting wheels with electric motor and hydromantic system.

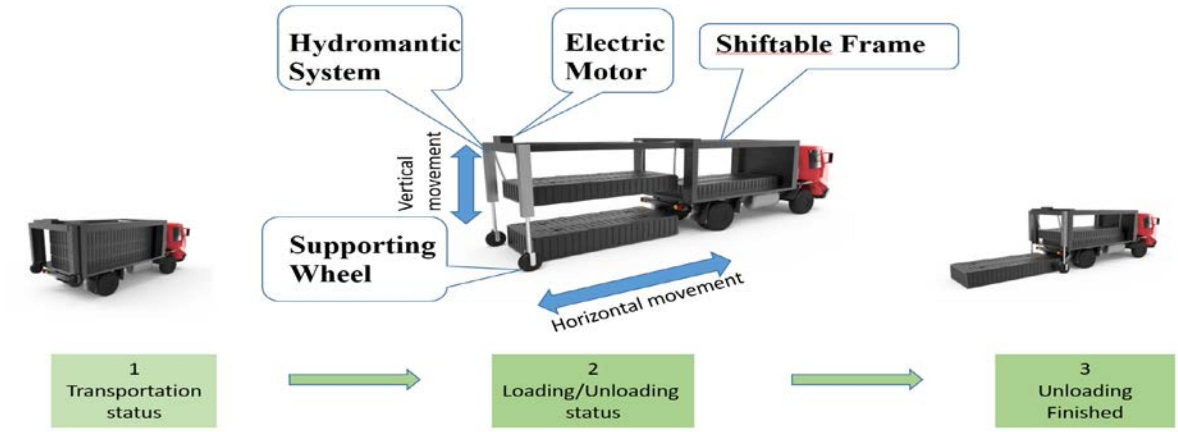

Figure 2: the design of PI enabled Vehicle

4 Problem Description

Figure 3 shows the comparison of traditional delivery process and improved delivery process based on PI-BGDS. In this case, there are 6 delivery points (Customer A, B, C, D, E and F) and 1 product warehouse in the factory. In the delivery process, one truck can load at most 3 customer orders and delivery the orders one by one in a milk run route. The transportation time between each delivery point is about 1 hours. When the PI-Vehicle arrive each delivery point, the unloading time and material moving time from PI-Vehicle to customer's house is about 3 hours.

4.1 Traditional Delivery Mode

The upper part of Figure 3 shows the traditional delivery process. In first round delivery, the normal truck loads the products of customer A, B and C at the factory. One material handing operator goes together with the truck driver. When they arrive the delivery point A, the material handing operator conducts the unloading and movement work. The truck has to wait at the delivery point, until all the material handling operation is finished. They go to the next delivery point together. When all of the delivery tasks are finished, the empty truck goes back to factory directly. Then, they can start the next delivery trip of customer D, E and F.

In traditional mode, the vehicle is used to deliver merchandise to customer. The set of delivery vertices is given by $D=\{1,\ldots,m\}$. All the trip starts and ends at same distribution center. The set of distribution center is given by vertex 0. The truck must come back to distribution center in the allowed time$[t_0,t_e]$. All the location of distribution center and customer is known. All the trucks are identical. The rated capacity of each vehicle is Q. The bulky goods have three types $\{v,2v,3v\}$. The demand of each vertices di is known. In the distribution process, the loading amount of the trucks should not pass the rated capacity. Each delivery vertex can be visited only once. One truck only completes one route. The influence of the traffic is ignored. The ultimate goal is total profit per minute during the period which equals the total revenue minus total costs then divided by the time. the total revenue equals piece rate multiplied by delivery demand, and the total costs can be divided into two parts. First part is petrol fee, equals to the petrol fee per hour multiply distribution time. The second part is fixed vehicle fee, which means the cost of invoking a vehicle per day.

4.2 Physical Internet enabled Delivery Mode

The lower part of Figure 3 shows the Physical Internet enabled delivery mode. The customer orders are reloaded in the PI container. In the first round, the truck loads the PI container A, B and C at the factory. When truck arrive each delivery point, the PI container can be landed by the vehicle-mounted unloading system and go the next delivery point immediately. When all PI-container A, B and C are delivered. The PI-Vehicle driver continues to delivery point F, E and D to pick up 3 empty PI containers back.

In this mode, the vehicle is used to pick up the empty containers and delivery containers to customer. All the trip starts and ends at same distribution center. The set of distribution center is given by vertex 0. The truck must come back to distribution center in the allowed time$[t_0,t_e]$. All the location of distribution center and customer is known. All the trucks are identical. The rated capacity of each vehicle is Q. The demand of each vertices di is known. And according to their volume, the demand of each vertex will be packaged into containers. The bulky goods have three types $\{v,2v,3v\}$. The size of the PI-container is devided into three basic type: the volumn of *S* container is *v*, the volumn of *M* container is *2v* and the volumn of *L* is *3v*. In the pick-up and distribution process, the loading amount of the trucks should not pass the rated capacity. Each pick-up vertex and delivery vertex can be visited only once by a same vehicle. After merchandise is delivered, the driver will pick up empty containers at vertex *i*. If the number of empty containers is larger than the number of containers that distribute the goods, there will be special vehicles (PI-vehicle) to recover the remaining empty containers after all the goods are delivered. The set of pick-up vertices which are brought back by delivery vehicle is given by $P=\{1,\ldots,n\}$, the set of remaining pick-up vertices is given by $P'=\{n+1,n+2\ldots,2n\}$. the set of delivery vertices is given by $D=\{1,\ldots,m\}$, All vertices completed by delivery vehicle is given by $V=P\cup D$. One truck only completes one route. The influence of the traffic is ignored. The ultimate goal is total profit per minute during the period which equals the total revenue minus total costs then divided by the time. the total revenue equals piece rate multiplied by delivery demand, and the total costs can be divided into petrol fee and fixed vehicle fee. The components of both costs are made up of two parts, the one part is used to delivery and pick up empty container simutaneously, and the other cost is used to pick up remaining empty container.

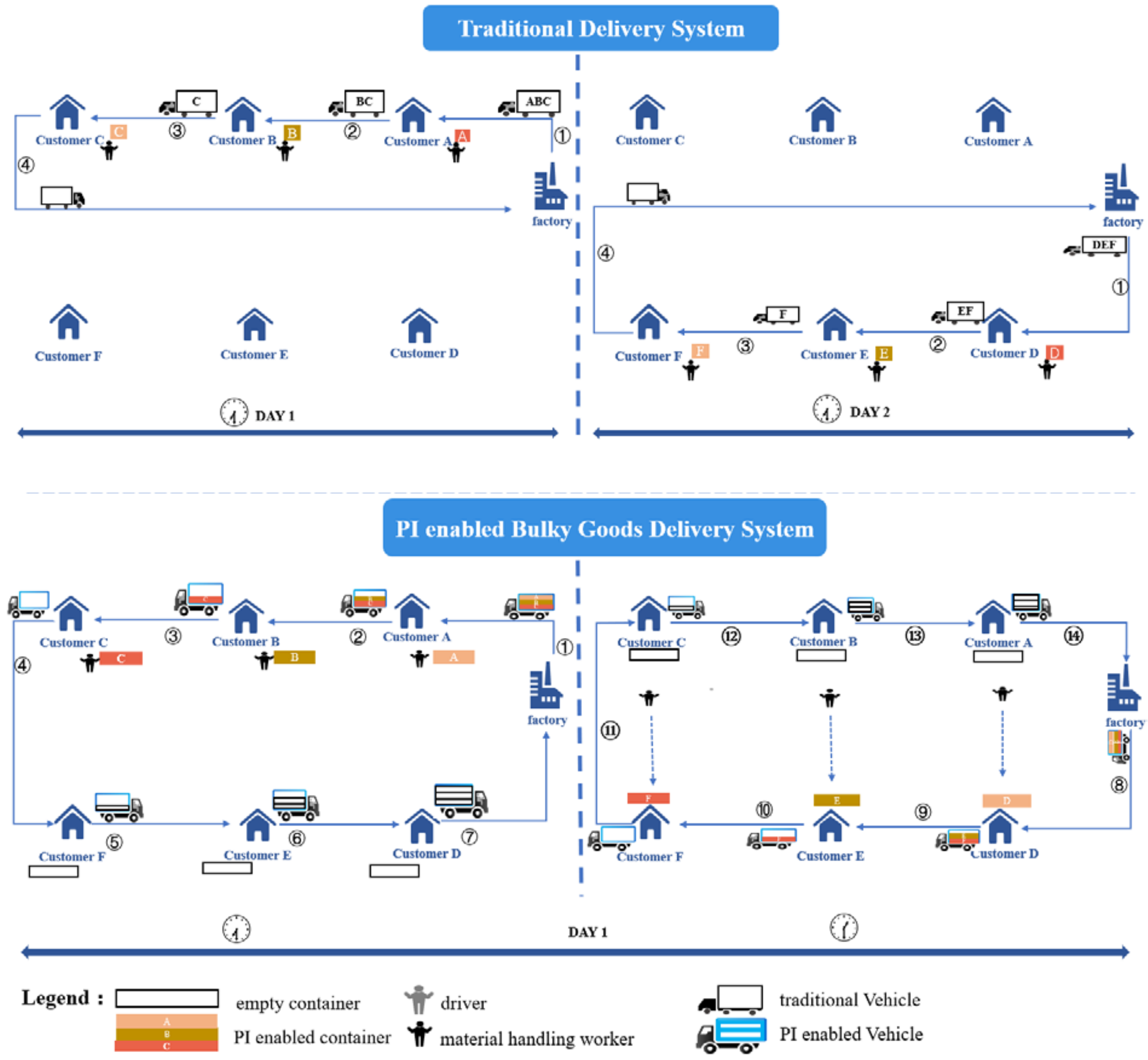

Figure 3: Illustrating comparison urban distribution between Traditional Delivery Mode and PI enabled Delivery Mode

5 Mathematical Model

5.1 Notations definition:

5.1.1 Notations

N	total number of customers which need to pick up empty container by delivery *P={1,…,n}*
N'	total number of customers which has remaining containers need to pick up separately *P'={n+1,…,2n}*
M	total number of customers which need to delivery merchandise *D={1,…,m}*
V	all the vertices by delivery vehicle *V=P∪D*
K	the set of vehicle's number, *K={1,2,…k}*
T	number of days of the period

Q	the rated capacity of truck
i,j,f,g	customer vertices, distribution center *i=0*
$[\boldsymbol{t_0},\boldsymbol{t_e}]$	the time window of distribution center
$\boldsymbol{t_{ij}}$	the travel time from vertex *i* to *j*
$\boldsymbol{L_i^k}$	driver's waiting time of vehicle *k* arrives at vertex *i*, which equals to the service time of material handling worker at vertex *i*.
$\boldsymbol{d_i^{k,r}}$	the delivery demand of vehicle *k* at vertex *i*, *r*∈ $\{\mathbf{S},\mathbf{M},\mathbf{L}\}$
$\boldsymbol{q_i^{n,r}}$	the pick up remaining empty container demand of vehicle *n* at vertex *i*
$\boldsymbol{P_{i,j}^{r,k}}$	load of vehicle *k* of resource *r* after leaving vertex *i* before visiting vertex *j*
β	the petrol fee of each vehicle per minute
$\boldsymbol{\delta}$	the fixed cost of each vehicle *k*
α	logistics service fee for each item

5.1.2 Variables

$$x_{ij}^{kl} = \begin{cases} 1, \text{if } arc(i,j) \text{ is traversed by vehicle } k \text{ on day } l \\ 0, \text{else} \end{cases}$$

$$y_i^{kl} = \begin{cases} 1, \text{if vehicle } k\ pick\ up\ or\ delivery\ container\ at\ vertex\ i\ on\ day\ l \\ 0, \text{else} \end{cases}$$

To formulate two models, the following assumptions are made.

1) The customer's location is known. And the demand of each vertices *di* is known at each vertex *i* which obeys a random probability distribution.

2) The types of the distribution quantity and empty container quantity of each vertex are composed of different size types.

3) Each merchandise are three types, and the size of the PI-container is devided into three basic types {*S*,*M*,*L*}.

4) All the trip starts and ends at same distribution center.

5) All vehicles are of the same type. A vehicle can carry up to three different sizes of customer orders.

6) The waiting time of each vehicle is equal to the working time of the material handling worker.

7) The quantity of pick up empty container today is equal to the previous day's delivery demand (in the PI-BGCL model).

8) All empty containers on that day must be picked up.

5.2 Traditional Delivery model

Objective:

$$\max\left\{\frac{\alpha\sum_{l=1}^{T}\sum_{i,j\epsilon D}\sum_{k\epsilon K}x_{ij}^{kl}d_i^l-(\beta\sum_{l=1}^{T}\sum_{k\epsilon K}\sum_{i\epsilon D}\sum_{j\epsilon D}x_{ij}^{kl}t_{ij}+\delta\sum_{l=1}^{T}\sum_{k\epsilon K}\sum_{i\epsilon D}x_{0i}^{kl})}{\sum_{l=1}^{T}(\sum_{k\epsilon K}\sum_{i\epsilon D}\sum_{j\epsilon D}x_{ij}^{kl}t_{ij}+\sum_{k\epsilon K}\sum_{i\in D}L_i^{kl})}\right\} \quad (1)$$

Subject to:

$$\sum_{k\in K}\sum_{i\in D}y_i^{kl}=1 \qquad \forall l\in T \qquad (2)$$

$$\sum_{k\in K}\sum_{j\in D} x_{ij}^{kl} = 1 \qquad \forall i \in D; \forall l \in T \qquad (3)$$

$$\sum_{i,j\epsilon D} x_{ij}^{kl} - \sum_{i,j\epsilon D} x_{ji}^{kl} = 0 \qquad \forall k \in K; \forall l \in T \qquad (4)$$

$$\sum_{j\in D} x_{0j}^{kl} = \sum_{j\in D} x_{j0}^{kl} \le 1 \qquad \forall k \in K; \forall l \in T \qquad (5)$$

$$\sum_{i\in D}\sum_{j\in D} x_{ij}^{kl} d_i^l \le Q \qquad \forall k \in K; \forall l \in T \qquad (6)$$

$$t_0 \le \sum_{i\epsilon D}\sum_{j\epsilon D} x_{ij}^{kl} t_{ij} + \sum_{i\in D} L_i^{kl} \le t_e \qquad \forall k \in K; \forall l \in T \qquad (7)$$

the objective function (1) maximizes total profit per minute during the period which equals the total revenue minus total costs then divided by the time, and the total costs including petrol fee, fixed cost of vehicle. Constraints (2) guarantee that a distribution task can only be assigned to one vehicle in day *l*. Constraints (3) guarantee that each vertex is served only once. Constraints (4) guarantee each vertex is visited by the same vehicle. Equalities (5) ensure that each vehicle starts at and returns to the depot at the end of its route. Constraints (6) guarantee during the distribution process the weight does not exceed capacity *Q*. Constraints (7) guarantee the total working times of each vehicle including travel time and service time of the vehicle are within the time window of distribution center.

5.3 Physical Internet enabled Delivery model

Objective:

$$\max\left\{\frac{\alpha \sum_{l=1}^{T}\sum_{i,j\epsilon D}\sum_{m\epsilon K} x_{ij}^{ml} d_i^{ml} - (\beta \sum_{l=1}^{T}\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}\sum_{j\epsilon V\cup P'} x_{ij}^{ml} t_{ij} + \delta \sum_{l=1}^{T}\sum_{m\in K}\sum_{i\epsilon V\cup P'} x_{0i}^{ml})}{\sum_{l=1}^{T}\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}\sum_{j\epsilon V\cup P'} x_{ij}^{ml} t_{ij}}\right\} \qquad (8)$$

Subject to:

$$\sum_{k\in K}\sum_{i\in V\cup P'} y_i^{kl} = 1 \qquad \forall l \in T \qquad (9)$$

$$\sum_{m\epsilon K}\sum_{i\epsilon V\cup P'}\sum_{j\epsilon V\cup P'} x_{ij}^{ml} t_{ij} = \sum_{k\epsilon K}\sum_{i\epsilon V}\sum_{j\epsilon V} x_{ij}^{kl} t_{ij} + \sum_{n\epsilon K}\sum_{f\epsilon P'}\sum_{g\epsilon P'} x_{fg}^{nl} t_{fg} \qquad \forall n,k \in K; \forall l \in T \qquad (10)$$

$$\sum_{k\in K}\sum_{j\in V} x_{ij}^{kl} = 1, \quad \sum_{n\in K}\sum_{g\in V} x_{fg}^{kl} = 1 \qquad \forall i,j \in V; \forall f \in P'; \forall l \in T \qquad (11)$$

$$\sum_{i,j\epsilon V} x_{ij}^{kl} - \sum_{i,j\epsilon V} x_{ji}^{kl} = 0, \quad \sum_{f,g\epsilon P'} x_{fg}^{nl} - \sum_{f,g\epsilon P'} x_{gf}^{nl} = 0 \qquad \forall n,k \in K; \forall l \in T \qquad (12)$$

$$\sum_{j\in V} x_{0j}^{kl} = \sum_{j\in V} x_{j0}^{kl} \le 1, \quad \sum_{g\in P'} x_{0g}^{nl} = \sum_{g\in P'} x_{g0}^{nl} \le 1 \qquad \forall n,k \in K; \forall l \in T \qquad (13)$$

$$t_0 \le \sum_{i\epsilon V}\sum_{j\epsilon V} x_{ij}^{kl} t_{ij} \le t_e, \quad t_0 \le \sum_{g\epsilon P'}\sum_{g\epsilon P'} x_{fg}^{nl} t_{fg} \le t_e \qquad \forall i,j \in V,\ \forall f,g \in P', \forall n,k \in K; \forall l \in T \qquad (14)$$

$$\sum_{k\epsilon K}\sum_{i,j\epsilon P} x_{ij}^{k} d_{il-1} = \sum_{n\epsilon K}\sum_{f,g\epsilon P'} x_{fg}^{n} q_{fl} + \sum_{k\epsilon K}\sum_{r\epsilon R}\sum_{i,j\epsilon P} x_{ij}^{k} (P_{i,j,l}^{r,k} - P_{0,i,l}^{r,k} + d_{il}) \qquad \forall n,k \in K; \forall l \in T \qquad (15)$$

$$\sum_{i\in V} d_i^{kl} \leq Q \qquad \forall i \in V, \forall k \in K; \forall l \in T \tag{16}$$

$$q_f^{nl} \leq Q \qquad \forall f \in P', \forall n \in K; \forall l \in T \tag{17}$$

$$\sum_{r\epsilon R} x_{ij}^{kl} P_{i,j}^{r,k} - \sum_{r\epsilon R} x_{0i}^{kl} P_{0,i}^{r,k} + d_i^{kl} \leq Q \qquad \forall i,j \in V, \forall k \in K; \forall l \in T \tag{18}$$

$$\sum_{r\epsilon R} x_{ij}^{kl} P_{i,j}^{r,k} \leq Q \qquad \forall i,j \in V, \forall k \in K; \forall l \in T \tag{19}$$

$$\sum_{r\epsilon R} x_{fg}^{kl} P_{f,g}^{r,n} \leq Q \qquad \forall f,g \in P', \forall n \in K; \forall l \in T \tag{20}$$

the objective function (8) maximizes total profit per minute during the period which equals the total revenue minus total costs then divided by the time, the total revenue equals piece rate multiplied by delivery demand, and the total costs including petrol fee, fixed cost of vehicle. Constraints (9) guarantee that a distribution task can only be assigned to one vehicle in day *l*. Constraints (10) guarantee that the total traval time consists of two parts, the one part is the time of delivery and pick up empty container simutaneously, and the other is the time of pick up remaining empty container. In addition, the bottom *m* means the total number of vehicles in use which equals the number of vehicle *k* plus *n*. Constraints (11) guarantee that each vertex is served only once. Constraints (12) guarantee each vertex is visited by the same vehicle. Equalities (13) ensure that each vehicle starts at and returns to the depot at the end of its route. Constraints (14) guarantee the total working times of each vehicle including travel time and pick up remaining empty time of the vehicle are within the time window of distribution center. Equalities (15) express that total amount of delivery demand in the previous day equals to the total quantity of pick up empty containers today. Constraints (16) (17) (18) guarantee during the pick up empty container and distribution process the weight does not exceed capacity. the total amount of demand on delivery process on day *l* is less than the maximum capacity of the vehicle by constraints (16). the amount of pick up empty container by delivery process at vertex *i* is less than the maximum capacity of the vehicle by constraints (17). The amount of pick up remaining empty container at vertex *i* is less than the maximum capacity of the vehicle by constraints (18). Consistency with respect to resource and load variables is guaranteed by constraints (19) (20).

6 Solution Methodology

Based on each of the above introduced formulations, A meta-heutistic Genetic algorithm (GA) is proposed to compare feasible routing solution of traditional delivery model and the PI-BGCL model, which is in order to mitigate the impacts of bulky goods in urban delivery. And algorithm rule is used to deal with constraint and objective.

Geneticl Algorithm, as a population-based optimization method (Salhi and Petch, 2007). it starts from a randomly generated initial population of solutions. The main steps that solve the problem are decribed as follows:

Step 1: Initialise five algorithm parameters, namely the number of populations (*Pop*), the number of generations (*Gen*), crossover probability (P_c), mutation probability (P_m), the number of iterations in GA (*Iter*). the initial solution is randomly generated.

Step 2: The fitness of a chromosome is evaluates as follows: $f(x) = {}^{1}/_{F(x)}$. Where *F(x)* is the total cost of a chromosome.

Step 3: Randomly generate an initial population of *Pop* chromosomes (solutions) and find out the best chromosome Chm_{best}.

Step 4: Let *Gencur* = 1. Repeat Steps 5-8 until *Gencur* > *Gen*.

Step 5: Perform the roulette wheel method to select parent chromosomes for reproduction.

Step 6: Apply the modified two-point crossover operator with crossover probability P_c to produce new offspring.

Step 7: Apply the single-point mutation operator with mutation probability P_m to perturb the structure of selected offspring.

Step 8: Let *Gencur* = *Gencur* + 1 and updating *Chmbest* if necessary.

Step 9: Return the best solution Chmbest with the minimum total cost T_{cost} and total time T_{time} (including transportaion time and service time) of delivery container (and pick up empty container in the PI-BGCL).

Step 10: Return T_{cost} within a period (day *l=1: T*) to calculate the objective function $Profit_{min}$. First, calculate the total revenue $T_{revenue}$ on day *l*.The total profit T_{profit} on day *l equals* $T_{revenue}$ minus T_{cost}. Finally, the objective function $Profit_{min}$ is calculated by T_{profit} over T_{time}.

7 Numerical study

In this section a numerical study has been conducted to evaluate and compare performance between the traditional delivery mode and PI-BGCL. In order to make the simulation results more realistic, the parameter as follows are changed to compare two model results.

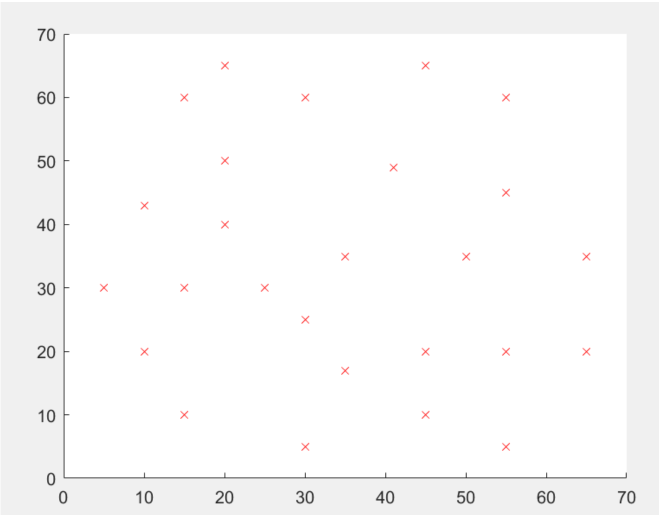

Figure 4: Location of customers in test problem

The locations of the 30 customers in *figure 4* are randomly generated using a procedure prensented by solomn (1987). This procedure generates locations grouped around a certain number of centers. The demands of the period *T* are eatablished randomly and follows a normal distribution [150, 20]. The several variable paremeters of the model are showed (Table 1) as follow:

Table 1 ： The Variable Parameters of the model

Variable parameters	Value
Logistics service fee for each item *(α)*	*20 RMB / item*
The fixed cost of each vehicle *(σ)*	*300 RMB / vehicle*
The petrol fee of each vehicle per minute *(β)*	*0.05 RMB / minute*
The time window of distribution center $[\boldsymbol{t_0},\boldsymbol{t_e}]$	*[0,840] (minute)*
The rated capacity of truck *(Q)*	*100 items*
The number of populations *(Pop)*	*100*
The number of generations *(Gen)*	*300*
Crossover probability *(Pc)*	*0.8*
Mutation probability *(Pm)*	*0.3*

Table 2 ： Compare the experimental results of traditional delivery model and PI-BGCL

		day 1	day 2	day 3	day 4	day 5	day 6	day 7	average
	Quantity of delivery	147	156	157	155	134	163	177	155.6
Tradition-al model	Time (minute)	655.2	719.4	717.8	715.1	563.6	767.9	769.6	701.22
	Number of vehicle	2	2	2	2	2	2	2	2.00
	Total revenue	2940	3120	3140	3100	2680	3260	3540	3111.43
	Total cost	620.5	619.6	620.5	619.2	623.3	619.3	618.8	620.17
	Total profit	2319.5	2500.4	2519.5	2480.8	2056.7	2640.7	2921.3	2491.3
	Total profit per minute	3.54	3.48	3.51	3.47	3.65	3.44	3.80	3.55
PI-BGCL model	Time (minute)	146.3	193.5	170.4	212.9	137.1	190.2	196.4	178.1
	Number of vehicle	2	2	2	2	2	2	2	2.00
	Total	2940	3120	3140	3100	2680	3260	3540	3111.4

	revenue							
	Total cost	620.5	621.5	619.5	621.4	620.2	619.4	620.2	620.4
	Total profit	2319.5	2498.5	2520.5	2478.6	2059.8	2640.7	2919.8	2491.1
	Total profit per minute	15.86	12.91	14.80	11.64	15.02	13.89	14.87	14.14
	%	4.48	3.72	4.22	3.36	4.12	4.03	3.92	3.98

Table 2 presents the experimental results of traditional delivery model and PI-BGCL model were generated. The line *Quantity of delivery* of the period *T*, are eatablished randomly and follows a normal distribution [150, 20]. the quantity of pick up empty container next day is equal to quantity of delivery today. By the way, the delivery demand of each customer on day *l are* randomly generated, which consist of three size (*v*, *2v*, *3v*). The line *Time in the traditional delivery model* including transportation time and the vehicle waiting time (equals handling worker's service time), the line *Time in PI-BGCL* is made up of the transportation between pick up empty container by delivery and ipck up remaining empty container. The line *Total cost of two models* shows the minimum total const concluding transportation cost and vehicle fixed cost. The line *Total profit per minute* shows maximum total profit per time of two models.

According to the experimental results of meta-heuristic in Table 2, it can be seen that the PI-BGCL result is better than traditional delivery model. The numbers of vehicle which are identical in two models, play an important role both in the traditional delivery model and PI-BGCL model. It is obvious that the several empty container picked up by vehicle in PI-BGCL are not uesd extra vehicle. That means the vehicle fixed cost of PI-BGCL is not more than traditonal model. The time of the PI_BGCL are far less than traditional delivery model, which means PI-BGCL solution greatly save time and improve efficiency. The last line shows the total profit per minute of PI-BGCL model is far more than traditional delivery model.

8 Conclusion

In this study, the bulky goods delivery problem in a customized furniture industry has been addressed. The problems are characterized in 4 aspects, heavy workload of material handling, unclear responsibility for operators, high risk of product damage and complicated human and vehicle resource planning. In order to solve the problem a PI enabled Bulky Goods City Logistics (PI-BGCL) solution is proposed. The propose system is driven by some key PI concepts, including design of standard container size and PI-Vehicle. In order to clarify the application of the proposed system further, a case study of bulky goods urban delivery in customized furniture industry is conducted. To maximize the total profit per minute of PI-BGCL, the meta-heuristic is developed to compare the experimental results between traditional delivery system and PI-BGCL.

This study has made several contributions: (1) to improve the field of bulky goods city logistics with PI concept. (2) to descript the bulky goods city logistics problem with the PI-BGCL model. A Physical Internet enabled Bulky Goods City Logistics (PI-BGCL) solution is proposed, especially which apply to customized furniture industry is identified. (3) the case study in the customized furniture company indicates that the proposed solution can improve the efficiency of transportation by designing the PI-Container and PI-Vehicle. (4) to discuss the potential application bulky goods city logistics technology in the viewpoint of academic and industry.

Several research problems need further investigation. Future studies will focus on making the proposed solutions more practical. How to generalize the results of such a small sample to a broader context will become the next step for our research and development. And the sensity analyse will be studied on next work.

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