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ScienceDirect

Procedia CIRP 69 (2018) 662 – 667

www.elsevier.com/locate/procedia

25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark

IoT-enabled Dynamic Optimisation for Sustainable Reverse Logistics

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Abstract

Currently, typical challenges that logistics industry faces include the exploding logistics (including reverse logistics) tasks, the lack of real-time and accurate logistics information, and demands towards sustainable logistics. Therefore, it is difficult for logistic companies to achieve highly-efficient and sustainable reverse logistics. This paper adopts a bottom-up logistics strategy that aims to achieve the real-time information-driven dynamic optimisation distribution for logistics tasks. Under this strategic framework, an IoT-enabled real-time information sensing model is designed to sense and capture the real-time data of logistics resources, which are shared among companies after the value-added processes. Real-time information-driven dynamic optimisation for logistics tasks is proposed to optimise the configuration of logistics resources, reduce logistics cost, energy consumption and the distribution distance, and alleviate the environmental pollution. The objective of this research is to develop an innovative logistics distribution model for sustainable logistics.

Peer-review under responsibility of the scientific committee of the 25th CIRP Life Cycle Engineering (LCE) Conference

Keywords: IoT; sustainable reverse logistics; dynamic optimisation; logistics resources

Nomenclature

T	logistics task set
T_i	the serial number of task i in T
W_i	weight of task i
V_i	volume of task i
P_i	current position of task i
D_i	destination of task i
μ_i	delay penalty parameter of vehicle
C_i	cost of vehicle j accepting task i
V	logistics vehicle set
V_j	the serial number of vehicle j in V
SW_j	surplus weight of vehicle j
SV_j	surplus volume of vehicle j
P_j	current position of vehicle j
D_j	next destination of vehicle j
c_j	cost per kilometre of vehicle j
fc_j	fuel consumption per kilometre of vehicle j
L_j	current tasks list of vehicle j
d_j	covering distance of vehicle j
C_j	cost of vehicle j
d_{ij}	delivery time of vehicle j for completing task i
L_{ij}	extra distribution distance for vehicle j accepting task i

1. Introduction

Logistics tasks have shown great growth with the rapid development of logistics industry as well as related industries such as E-commerce. Consequently, the dramatically increasing demands of logistics, the sustainable cost-efficiency policies related to the logistics, and the cost-profit and environmental pressure of logistics enterprises have forced enterprises to examine their current strategic decision-making on the logistics operation and distribution. Therefore, the value of reverse logistics in a sustainable way is emerging [1]. The environment and economy, as two main pillars of the

Peer-review under responsibility of the scientific committee of the 25th CIRP Life Cycle Engineering (LCE) Conference
doi:10.1016/j.procir.2017.11.088

sustainability, are emphasized in the sustainable systems and life cycle sustainability assessment [2]. However, the typical challenges that the sustainable reverse logistics is facing are how to construct real-time information sensing model to acquire the real-time and accurate information of logistics resources actively, how to implement the sustainable optimisation configuration of logistics resources based on the logistics enterprises information integrated system (EIS), and how to reach real-time information-driven dynamic optimisation for logistics tasks and vehicles with the objectives of reducing logistics cost and energy consumption, alleviating environmental pollution, and achieving sustainable reverse logistics.

The Internet of Things technology (IoT) is a promising technology that has been applied in the manufacturing process for sensing and capturing real-time manufacturing resources data. The acquiring and sharing of real-time information of logistics activities is also the essential of the collaboration of logistics resources. Radio frequency identification (RFID)-enabled real-time information tracking infrastructure was developed to address the real-time data capturing and manufacturing information processing for the extended enterprises [3,4]. The configuration of IoT environment is the key component of the IoT-based real-time information sensing model. After capturing the dynamic information of logistics resources, instead of directly entering optimisation stage, adaptive controlling mechanisms were entailed to achieve the added value and management of real-time information [5]. Then, the framework of the Internet of Manufacturing Things to share the real-time manufacturing information, and a sensor-driven remote real-time monitoring provided a good technological reference for sharing and monitoring the real-time status of logistics resources so that real-time decision-making of logistics could be done [6,7]. The information management and communication platform are identified as the key essentials for the sustainable and strategic management [8].

Sustainable logistics is one of the vital sub-components of green supply chain management process [9], which contributes to achieving a more sustainable balance between energy demand, environment, and economic health [10], such as improving economic efficiency and competitiveness that are helpful to reduce environmental concerns from green growth agenda [11]. In a logistics supply chain, in addition to managing information/knowledge, managing the flow of materials, manufacturing resources, and services are equally important [12]. Configuration and management of logistics resources provide good supports for IoT-enabled dynamic optimisation for sustainable reverse logistics in the physical layer, which is to optimise the configuration of reverse logistics resources. The methods for optimising logistics tasks distribution are also the key factor for the high-efficiency delivery for the logistics tasks such as a neuro-fuzzy approach and a block recombination approach [13,14]. In addition, Cattaruzza et al. made an overview of the literature devoted to vehicle routing optimisation in cities, and addressed four principal scientific challenges: time-dependent, multi-level, dynamic, and multi-trip vehicle routing problems [15]. These progresses in vehicle routing of the reverse logistics help improve the freight transportation services at minimum cost. The environmental issues and sustainable development related to the reverse logistics also get much more attention. Therefore, much effort on reducing energy consumption and sustainable reverse logistics was made in the supply chain management of logistics, such as the environmental concerns in sustainable reverse logistics [16,17]. Energy consumption works as a main optimisation objective in the logistics industry [18,19], and the fuel consumption is closely associated with the energy consumption and can indirectly reflect the energy consumption [20].

Despite of significant progress achieved by the researchers in the field of sustainable logistics management, major issues still exist in real-time information-driven dynamic optimisation for sustainable reverse logistics. In the actual logistics, the frequent changes of logistics tasks, and the shortage of real-time and consistent information of logistics resources result in difficulties in integrating and managing the logistics resources that could be shared among logistics enterprises. Logistics activities are an open loop that usually involves a large number of different distribution points and vehicles, and logistics vehicles with pretty low load rates and even zero load have resulted in the serious waste of logistics resources and the significant increase in cost and environmental issues in the current logistics activities that are in a point-to-point way. Besides, the routing optimisation of logistics tasks distribution and real-time information enabled routing navigation for logistics vehicles can also contribute to improving the efficiency of sustainable reverse logistics.

To address the above-mentioned challenges and issues, the IoT environment for sensing logistics resources is constructed. Based on the captured real-time logistics information, EIS is responsible for achieving the added value and sharing of logistics information among logistics enterprises. Then, real-time information-driven dynamic optimisation for logistics tasks is proposed to implement the optimal allocation of tasks and high load rates of vehicles. RFID-based loading verification service and real-time information enabled routing optimisation and navigation services are designed to provide routing optimisation and navigation for vehicles, and avoid the incorrect loading of tasks, and further achieve sustainable logistics with the low cost and energy consumption.

The rest of this paper is organized as follows, Section 2 outlines the overall architecture of the real-time information-driven dynamic optimisation for sustainable reverse logistics. Section 3 presents the IoT-based real-time information sensing model of logistics resources. The real-time information-driven dynamic optimisation is described in section 4. Simulation and conclusions are given in section 5 and 6 respectively.

2. Overall architecture of the real-time information-driven dynamic optimisation for sustainable reverse logistics

The overall architecture of the real-time information-driven dynamic optimisation for sustainable reverse logistics is shown in Fig. 1. It consists of three modules from the bottom to the top. They are the IoT-based smart vehicle terminals, EIS-enabled logistics resources management, and the dynamic optimisation services for logistics tasks. These three modules are discussed as follows.

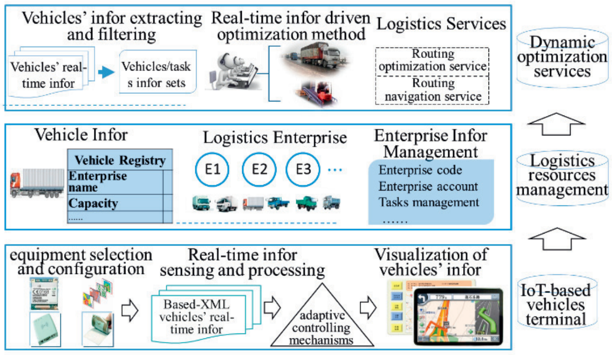

Fig. 1. The overall architecture of the real-time information-driven dynamic optimisation method for sustainable reverse logistics

The IoT-based smart vehicles terminal is used to perceive the real-time information of vehicles registered in the logistics enterprises. This module includes four sub-modules, namely automatic identification equipment selection and configuration, real-time information sensing and processing, adaptive controlling mechanisms, and visualization of vehicles' information. Firstly, automatic identification equipment such as RFID tags and readers, and wireless network, etc. is used to construct the IoT-based sensing environment and capture real-time information of tasks. Then, the acquired logistics information is processed and transmitted to achieve the added value. The real-time information sensing and processing system uploads the real-time task information of vehicles to EIS. Geographic information system (GIS) monitors current road condition and applies the path optimisation software to offer the optimal routing services based on drivers' requests on the real-time information visualization interface.

Logistics resources management is responsible for integrating and managing different logistics resources based on EIS, including the logistics tasks, vehicles, and enterprises. In this module, the logistics enterprises register their information such as company's location, vehicle's properties, etc. to EIS. The tasks and vehicles could be intensively managed in EIS and shared among logistics enterprises. Finally, the value-added information of logistics resources is transmitted to the dynamic optimisation services module.

The dynamic optimisation service module is responsible for extracting vehicle's real-time information (i.e. current location, destination, volume, load, etc.) at a certain time interval. The dynamic optimisation for logistics tasks based on the real-time information of the vehicles is designed to optimise and allocate tasks and achieve the dynamic optimisation match for tasks and vehicles. The loading optimisation service within RFID technology is used to reach the accurate loading of tasks. Routing optimisation and navigation services for vehicles, which integrate advanced technologies such as 4G, GPS, are provided to improve the efficiency of logistics. For example, when tasks attached RFID tags ship in and out from vehicles' back doors, RFID devices automatically collect information of logistics resources written in tags, and this reveals vehicles' real-time utilization rate and load. Loading verification service is to ensure the consistency of information read by RFID readers and on the loading tasks lists. If tasks are loaded wrongly, the alarming will be triggered to avoid the errors in loading tasks.

3. IoT-based real-time information sensing model for logistics resources

IoT-based real-time sensing model is the foundation of logistics resources management and dynamic optimisation services for logistics tasks, shown as the bottom-layer module of Fig. 1. The configuration of sensing devices such as RFID devices, PGS locator device, 4G communication device, and GIS is used to build the IoT-based physical sensing architecture for vehicles. As a result, the status information of vehicles could be captured and transmitted automatically. GPS is used to locate the vehicle's location; RFID information collection devices installed in the vehicle enable the vehicle to have the capacity of acquiring its real-time physical status, i.e. load, volume, and list of loading tasks. 4G communication device is responsible for the both-way transmission of logistics information. GIS is used to offer the optimal path navigation for the driver according to the real-time tasks of the vehicles.

Logistics vehicles' information has the significant dynamics, so real-time status information updating mechanism is used to renew the vehicles' surplus weight and volume, current and next destination, and current task lists. For example, the real-time values of the vehicle surplus weight and volume would be updated once the RFID readers perceive the movement of tasks, the information of the moving task would be input to the updating module. The real-time information sensing and processing system uploads the real-time task information of the vehicles to GIS that considers the current road condition and offers the optimal path in the form of maps, tables, and texts according to the drivers' requests. Visualization of vehicle's real-time information is to show the real-time information of the vehicles according to drivers' requests in the ways of the bulletin board, road news sending by speech, the optimised driving path, and the real-time vehicle and task information.

4. Real-time information-driven dynamic optimisation for logistics tasks

The real-time information-driven dynamic optimisation model for sustainable reverse logistics is established, and the flow is shown in Fig. 2.

$$T = \begin{bmatrix} T_1 & W_1 & V_1 & P_1 & D_1 & d_1 & \mu_1 \\ T_2 & W_2 & V_2 & P_2 & D_2 & d_2 & \mu_2 \\ T_3 & W_3 & V_3 & P_3 & D_3 & d_3 & \mu_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ T_i & W_i & V_i & P_i & D_i & d_i & \mu_i \end{bmatrix}$$

$$V = \begin{bmatrix} V_1 & SW_1 & SV_1 & P_1 & D_1 & C_1 & L_1 \\ V_2 & SW_2 & SV_2 & P_2 & D_2 & C_2 & L_2 \\ V_3 & SW_3 & SV_3 & P_3 & D_3 & C_3 & L_3 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ V_j & SW_j & SV_j & P_j & D_j & C_j & L_j \end{bmatrix}$$

Based on the captured real-time information of vehicles and tasks shown as the matrices V and T, vehicles and tasks are divided into n sub-regions on the basis of their current locations. Then, n tasks and m vehicles subsets are formed as $T = (t_1,t_2,t_3,\cdots,t_n)^T$, and $V = (v_1,v_2,v_3,\cdots,v_m)^T$. In this case, tasks and vehicles in the same region are divided into the identical subsets, and form the pre-optimised sets (t_i, v_j), $i\in[1,n]$, and $j\in[1,m]$. For (t_i, v_j), the current location and destination could be constructed as task vector $T_i(P_i,D_i)$ and vehicle vector $V_j(P_j,D_j)$. A dynamic pre-optimisation model for tasks is proposed shown as the following steps.

Step 1: construct the optimisation function.

$$f(V_j) = min\,arccos[(T_iV_j)/(|T_i||V_j|)] \quad (1)$$

$$W_i \leq SW_j,\ V_i \leq SV_j,\ i\in[1,n],\ j\in[1,m] \quad (2)$$

Step 2: vehicle vector $V_j(P_j,D_j)$ and task vector $T_i(P_i,D_i)$ are substituted into Eq. 1. If D_i=free, then free T_i.

Step 3: tasks mapped with the obtained minimal value of the above-mentioned function is allocated to vehicle j. The pre-allocated set for each task is built as follows.

$$T_i = (V_1,V_2,V_3,\cdots,V_x),\ i\in[1,n],\ x\in[1,m] \quad (3)$$

Step 4: the pre-allocated sets are classified into three classes, namely Class 1: x=0, Class 2: x=1, and Class 3: $x \geq 2$.

Step 5: the optimisation function for tasks in Class 3 is formulized as follows.

$$f = min\,cost = \sum_{i=1}^{n} L_{ij}c_j + d_{ij}\mu_i \quad (4)$$

Step 6: the vehicle with the minimal value of Eq. (4) is responsible for distributing T_i. Other vehicles are free.

Step 7: tasks in Class 1 return to Step 1. The task in Class 2 is loaded and distributed to the optimised vehicle.

Step 8: End.

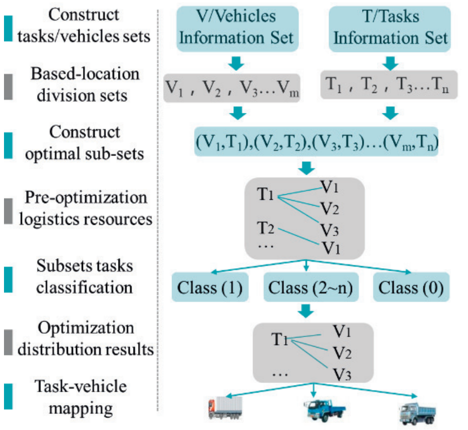

Fig. 2. The flow of real-time information-driven dynamic optimisation for logistics tasks

Eq. (5) represents the average load rate of vehicles. Eq. (6) and (7) are the average distribution distance of vehicles for finishing per unit volume and weight of tasks respectively. $\sum_j \sum_i^n L_{ij} V_i$, $\sum_j L_{ij}$, and $\sum_j SV_j$ indicate the sum of the product of the vehicle's volume and the corresponding distances, the total extra distribution distance for vehicles, and the sum of the rest volume of vehicle j finishing task i. Eq. (8) and (9) indicate the total fuel consumption, and the average fuel consumption per kilometre and per ton for vehicles. Eq. (10) and (11) represent the total cost and the total distribution distance.

$$R' = (V', W') \quad (5)$$

$$V' = (\sum_j \sum_i^n L_{ij} V_i)/\sum_j SV_j \quad (6)$$

$$W' = (\sum_j \sum_i^n L_{ij} W_i)/\sum_j SW_j \quad (7)$$

$$TFC = \sum_j L_{ij} fc_j \quad (8)$$

$$AFC = TFC/[(\sum_j L_{ij})(\sum_i SW_i)] \quad (9)$$

$$C = \sum_i C_i \quad (10)$$

$$TD = \sum_i \sum_j L_{ij} \quad (11)$$

5. Simulation

A simulation of the real-time information-driven dynamic optimisation for sustainable reverse logistics will be described as follows.

First, logistics enterprises login the resource registry platform, choose the right user roles, and enter the interface of the platform. Then, information of enterprises and vehicles can be edited and submitted to this platform. Finally, the real-time vehicle sets can be constructed and the integration of vehicles from different enterprises will be accomplished. The detailed procedure is demonstrated in Fig. 3.

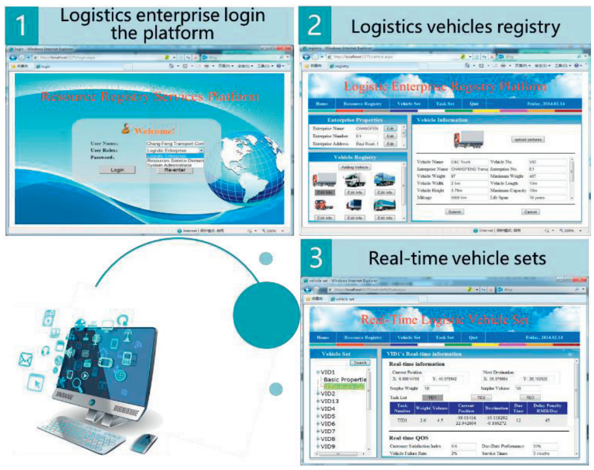

Fig. 3. Logistics resource registry and integration

The logistics delivery center will manage the whole logistics scheduling. Table 1 and 2 show the real-time information of vehicles and tasks in the logistics delivery center at time t. Table 3 is the task list information of vehicles. The whole optimal procedures are described as follows.

Table 1 Real-time information of vehicles at time t

V	SW	SV	P		D		C	L
			x	y	x	y		
V_1	12	17	6.09	40.08	56.97	20.15	1.8	L_1
V_2	13	15	33.09	-10.72	5.98	-18.83	1.8	L_2
V_3	11	16	55.38	68.37	70.09	2.10	1.8	L_3
V_4	5.4	8.1	-28.14	33.46	-14.00	14.46	1.8	L_4
V_5	7.5	9.3	-31.74	20.86	-5.07	1.30	1.8	L_5
V_6	12	16	-29.76	-32.44	45.59	-12.78	1.8	L_6
V_7	6.8	13	-27.13	-49.38	-77.25	-21.25	1.8	L_7

V_8	9	12	-97.96	1.14	-8.10	18.69	2.1	L_8
V_9	17	21	-19.54	-75.76	-38.64	-70.32	2.1	L_9
V_{10}	16	13	-37.77	-12.87	2.51	-37.12	2.1	L_{10}
V_{11}	16	16	8.81	-49.07	-38.34	-56.97	2.1	L_{11}
V_{12}	17	26	31.31	-83.80	9.52	-31.02	2.1	L_{12}
V_{13}	16	27	36.91	-56.62	80.39	-7.51	2.6	L_{13}
V_{14}	15	31	43.91	10.75	81.77	21.75	2.6	L_{14}
V_{15}	16	23	21.12	-22.78	28.51	-35.42	2.6	L_{15}
V_{16}	21	27	-25.80	68.70	52.51	33.66	2.6	L_{16}
V_{17}	10	21	31.45	-26.13	41.22	-53.38	2.6	L_{17}
V_{18}	16	32	5.78	70.80	60.16	-8.67	2.6	L_{18}
V_{19}	17	24	0.78	68.67	71.17	-5.22	2.6	L_{19}
V_{20}	21	36	6.14	87.13	87.35	-21.03	2.6	L_{20}

Table 2 Real-time information of tasks at time t

T	W	V	P		D		d	μ
			x	y	x	y		
T_1	2.6	4.5	-39.01	22.94	-10.12	-0.19	1	45
T_2	6.2	14	35.31	12.49	64.95	19.389	1.2	32
T_3	6.3	7	15.80	-88.04	0.56	-20.129	1.4	47
T_4	8.2	13	21.37	-57.19	-18.90	-36.10	2.1	23
T_5	7.4	7.1	-80.13	1.73	-18.03	33.07	2.8	65
T_6	4.5	9	-34.43	-17.86	20.37	-34.95	1.7	53
T_7	10	15	33.53	-18.45	64.88	-43.74	1.8	57
T_8	7	13	55.18	39.39	62.36	-3.32	1.3	48
T_9	14	18	56.17	-51.61	81.38	-17.62	1.6	53
T_{10}	4.8	6.3	-19.19	-57.45	-72.69	-23.16	2.3	65

Table 3 Task list information of the vehicles

L	T	W	V	P		D		d	μ
				x	y	x	y		
L_1	T_{11}	4.3	5	6.09	40.08	56.97	20.15	0.5	60
	T_{12}	7.6	4.5	6.09	40.08	60.99	23.45	1	80
L_2	T_{11}	6.5	1	33.09	-10.71	5.98	-18.83	0.46	45
L_3	T_{11}	8.1	3	55.38	68.37	70.09	2.10	0.6	65
L_4	T_{11}	9.6	4	-28.14	33.46	-14.00	14.46	0.7	56
L_5	T_{11}	7.5	6	-31.74	20.86	-5.06	1.30	0.8	42
L_6	T_{11}	5	6.9	-29.76	-32.44	45.59	-12.78	0.4	35
L_7	T_{11}	11	5	-27.13	-49.38	-77.25	-21.25	1	27
L_9	T_{11}	9	3	-19.54	-75.76	-38.64	-70.33	1.2	34
L_{10}	T_{11}	6.3	4	-37.78	-12.87	2.51	-37.13	1.1	54
L_{11}	T_{11}	5.5	2.8	8.81	-49.07	-38.34	-56.97	0.7	25
	T_{12}	9	4.3	8.81	-49.07	-48.85	-32.76	0.8	47
L_{13}	T_{11}	6.8	3.2	36.91	-56.62	80.39	-7.52	0.9	35
L_{14}	T_{11}	7.9	6	43.91	10.75	81.77	21.76	0.8	41
L_{15}	T_{11}	6.2	2	21.12	-22.78	28.51	-35.43	1.4	24
L_{16}	T_{11}	4	1.5	-25.80	68.70	52.51	33.66	1.3	35
L_{17}	T_{11}	1	3	31.45	-26.13	41.23	-53.38	0.5	29
	T_{12}	3	2	31.45	-26.13	59.63	-50.01	0.9	54
L_{18}	T_{11}	6	3.5	62.02	-34.14	60.16	-8.67	1.2	42
L_{19}	T_{11}	10.9	6	48.82	48.29	71.17	-5.22	1.1	39
L_{20}	T_{11}	4	2	86.24	-12.43	87.35	-21.03	0.8	43
	T_{12}	5.2	3.2	86.24	-12.43	87.35	3.50	1.2	48

Here, twenty logistics vehicles and ten tasks are chosen as the simulated objects randomly. By the circular region partition method, different circle domains of tasks are identified. For each determinate circle domain, tasks meeting all the constraints are selected. Otherwise, tasks dissatisfying any constraint return to the dynamic task information sets, and are rescheduled at the next cycle. For tasks in the intersections of the circle domains, the task with the shortest distance from the center of the circle is assigned to the vehicle.

Based on the objectives of minimising the total costs and energy consumption, and improving the load rate and the efficiency of logistics resources, the final optimal distribution results for sustainable reverse logistics are established as shown in Table 4.

Table 4 The final optimal distribution results of dynamic method

T	V	fc_j	L_{ij}	C_i	TFC_i
T_1	V_5	0.24	16.77	30.19	4.02
T_2	V_1	0.24	14.64	26.35	3.51
T_3	V_{12}	0.32	30.45	63.95	9.74
T_4	V_{11}	0.32	41.13	115.37	13.16
T_5	V_8	0.32	13.32	27.97	4.26
T_6	V_{10}	0.32	18.63	39.12	5.96
T_7	V_{17}	0.4	22.93	59.62	9.17
T_8	V_{19}	0.4	5.27	13.70	2.11
T_9	V_{13}	0.32	6.78	14.24	2.17
T_{10}	V_7	0.24	22.33	40.19	5.36
SUM			192.25	430.70	59.46

The same logistics tasks in Table 2 are also optimised by the traditional method (TM), which is common in practice at the logistics activities, under the same constraints and optimal objectives in section 4. The traditional logistics activities are in a point-to-point way, and it is assumed that vehicles do not return after finishing logistics tasks in this simulation. The optimal results are shown in Table 5.

Table 5 The optimal distribution results of TM

V	T	fc_j	d_j	C_j	TFC_j
V_1	T_1	0.24	37.01	66.62	8.88
V_2	T_2	0.24	30.43	54.77	7.30
V_3	T_3	0.24	69.60	125.28	16.70
V_4	T_4	0.24	45.46	81.83	10.91
V_5	T_5	0.24	69.56	125.21	16.69
V_6	T_6	0.24	57.4	103.32	13.78
V_7	T_7	0.24	40.28	72.50	9.67
V_8	T_8	0.32	43.31	90.95	13.86
V_9	T_9	0.32	42.32	88.87	13.54
V_{10}	T_{10}	0.32	63.55	133.46	20.34
SUM			498.92	942.81	131.67

Fig. 4 shows the optimal results of these two methods for sustainable reverse logistics, the average distance of finishing per unit volume and weight of tasks, and average energy consumption of vehicles in the reverse logistics.

From Fig. 4-(a), (b), and (c), C , TD and TFC of accomplishing the logistics tasks for real-time information-driven dynamic optimisation method (RIDOM) are 430.70, 192.25, and 59.48 respectively. By contrast, those of TM are 942.81, 498.82, and 131.67 respectively. It is clear that the proposed RIDOM for smart vehicles and logistics tasks in the sustainable reverse logistics has significant advantages on reducing the cost, the total distance, and energy consumption, compared with TM. Based on the optimal results of RIDOM, the total cost, distance, and energy consumption for finishing extra ten logistics tasks are reduced by 54.32%, 61.46%, and 54.82%. The reduce in the distribution distance, and energy consumption can reduce the greenhouse emission and achieve energy conservation, further contribute to the optimal configuration of logistics resources and the sustainable reverse logistics.

From Fig. 4-(d) and (e) show $V^{`}$ and $W^{`}$ of two kinds of methods and indicates the average distribution distance for finishing per unit volume and weight of tasks respectively. In comparison to R` of TM: $R^{`} = (V^{`}, W^{`}) = (28.10, 27.28)$, R` of RIDOM is $R^{`} = (V^{`}, W^{`}) = (11.02, 10.32)$. The average distribution distance of the latter for finishing per unit volume and weight of tasks is reduced by 62.17% and 60.78%. In addition, Fig.4-(f) shows the average fuel consumption per kilometre and per ton for vehicles. AFC of RIDOM is 0.004356, while that of TM is 0.003717. The cause behind this is the fuel consumption per kilometre of vehicle selected by RIDOM is higher than that in TM. It should be pointed out that the fuel consumption per kilometre of vehicle is the statistical one. The higher the total weight of vehicles, the higher the actual fuel consumption per kilometre is. This is also a factor that leads to high fuel consumption per kilometre of vehicles for RIDOM. Note that the total number of the vehicle for finishing logistics tasks in TM increases by 10 in this case, compared with that of RIDOM. Therefore, it can be concluded that the proposed method for the sustainable reverse logistics can reduce the total logistics cost and distance, energy consumption, and optimise the configuration of logistics resources.

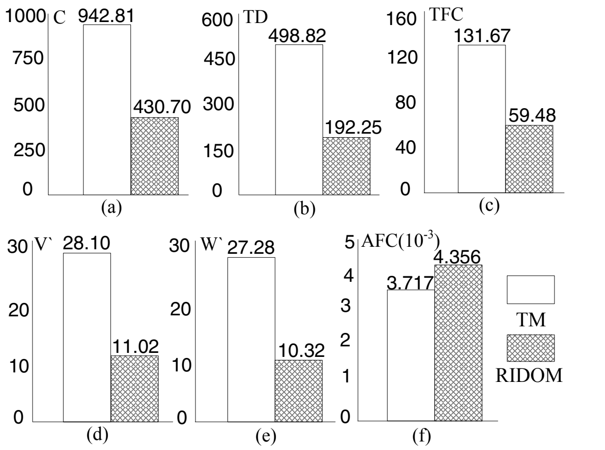

Fig. 4 (a), (b), (c), (d), (e), (f): C, TD, TFC, V`, W`, and AFC of two kinds of methods for finishing 10 tasks.

6. Conclusions

This paper proposes a systematic architecture of real-time information-driven dynamic optimisation for sustainable reverse logistics. The Internet of Things technology is used to build IoT-enabled environment for sensing and capturing the real-time, accurate, and consistent information of logistics resources. The captured logistics information could be processed to achieve the added value and managed by the logistics enterprise resources management system. The value-added logistics information could be shared among the enterprises. A real-time information-driven dynamic optimisation for logistics tasks is proposed to optimise the logistics tasks and vehicles and achieve the optimal allocation between tasks and vehicles under constraints. RFID-based loading verification service and real-time information-enabled routing optimisation and navigation services are constructed for logistics vehicles, and to avoid the incorrect loading of logistics tasks. The proposed method can reduce the total logistics cost, energy consumption, and the total logistics distance, optimise the configuration of logistics resources, and achieve sustainable reverse logistics services.

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