

SYSTEMS AND METHODS FOR SCALABLE, DECENTRALIZED AND COORDINATED LOGISTICS SCHEDULE PLANNING

FIELD OF THE INVENTION

[001] The present invention relates to logistics schedule planning, and in particular to two-level optimizing systems and methods which are scalable, decentralized, coordinated schedule planning approaches, which support multiple logistics service providers (LSP).

BACKGROUND OF THE INVENTION

[002] Pickup and delivery operations are deeply involved in the daily commercial or retail activities at many levels which may involve multiple parties, including sellers, warehouse operators, mall operators, logistics service providers (LSPs), consumers etc. Resource constraints at locations where multiple LSPs frequently visit can cause congestion, which leads to the need for coordinated planning. Typically, an LSP would have its own fleet of vehicles to serve the delivery requests it receives. Methods for generating a pickup and delivery schedule within the LSP based on the information of all its delivery requests, capacity of its fleet of vehicles and any other constraints are already commonly known.

[003] A pickup and delivery schedule generated within the scope of information limited to an LSP may appear to be a good arrangement within the LSP. However, resource constraints at different locations such as limited parking or docking bays, cargo storage spaces, or special equipment such as forklifts can cause congestion if each LSP adopts its schedule without any coordination with any other LSPs. Therefore, schedules generated within the scope of information limited to each LSP may usually be further improved if external information is taken into consideration, e.g. traffic data, when there is available docking bays for loading or unloading the goods at the pickup point or at the destination of the delivery, etc.

[004] To address such issue, collaborative planning approaches have been considered to deconflict the schedules of different LSPs, which have been shown to improve efficiency, service levels and sustainability. However, such collaborative planning approaches assume that various LSPs are willing to collaborate with each other such as by way of forming coalitions, exchanging of information and/or sharing of resources to achieve a common objective, which do not reflect the

reality that LSPs are independent entities and may not share certain information with one another for various reasons.

[005] Ideally, if there is one single agent who can control the routes and schedules of multiple LSPs with complete information and collaboration amongst the LSPs, some form of system optimality may be achieved. However, an unintended outcome is that some LSPs may suffer more loss than if they were to adopt their own planning independently. Moreover, such centralized approach is not scalable as it always requires a lot of computation and is not meaningful in solving the real-world problems as LSPs may not always be willing to collaborate with one another.

[006] Therefore, there is a need for a system and/or a method able to efficiently generate optimized routing schedules, and coordinate schedules among multiple LSPs, and at the same time assure the privacy of each LSP.

[007] It is one purpose of the present invention to provide a system and a method for generating schedules for multiple LSPs which are scalable, so that a large number of requests among multiple LSPs can be processed and optimised schedules for each individual LSP can be generated in a practically short period of time.

[008] It is another purpose of the present invention to provide a system and a method which are decentralized, so that the privacy of each LSP will not be compromised even though the schedules of each LSP are generated in a coordinated manner by taking into consideration other LSPs' schedules.

[009] It is another purpose of the present invention to provide a system and a method which are able to coordinate between multiple LSPs and ensure each individual LSP's schedules are improved and at the same time, system optimality is improved among all the LSPs.

[010] It is another purpose of the present invention to provide a system and a method which are able to provide optimized schedules to users other than LSPs, such as retailers, mall operators, warehouse operators, etc.

[011] By meeting the abovementioned purposes, the present invention offers an intelligent coordinated system across the entire logistics chain enabling system efficiency to be achieved in a win-win manner for all stakeholders. The LSPs will be able to improve their productivity and lower operational costs on a daily basis. At the same time, the participating mall operators will optimize the

use of resources such as dock capacities, resulting in reduction of congestion around the venue, while the participating retailers will have their service requirements met. The government will expect reduced carbon footprints as well as traffic congestion around the malls and warehouses to be further improved.

SUMMARY OF THE INVENTION

[012] According to one aspect of the present invention, it provides a system for generating one or more coordinated logistics schedules for one or more users, including:

at least one generic information management module, configured to store and manage generic information that is non-confidential to any user of the system;

at least one private optimizing module, configured to work privately for each user of the system, so that after a user inputs information to the at least one private optimizing module the information input by the user is kept confidential to the user itself;

at least one generic optimizing module, configured to work on a generic basis, so that it coordinates schedules among multiple users based on the non-confidential generic information stored at the at least one generic information management module;

wherein the one or more coordinated logistics schedules are generated through the below steps:

- (1) the at least one private optimizing module generates one or more initial schedules for each user based on information input by such user, and transmits the one or more initial schedules to the at least one generic optimizing module;
- (2) after receiving the one or more initial schedules, the at least one generic optimizing module generates one or more uncoordinated joint schedules based on the received one or more initial schedules, taking into consideration the generic information from the at least one generic information management module, and transmits the one or more uncoordinated joint schedules to the at least one private optimizing schedule for the respective users;
- (3) after receiving the one or more uncoordinated joint schedules, the at least one private optimizing module generates one or more coordinated schedules for each user based on the one or more uncoordinated joint schedules, taking into consideration each user's input, and forwards the one or more coordinated schedules to the at least one generic optimizing module;
- (4) after receiving one or more coordinated schedules, the at least one generic optimizing module generates one or more optimized schedules based on the one or more

coordinated schedules, taking into consideration the generic information from the at least one generic information management module;

- (5) repeat steps (3) and (4) by transmitting the one or more optimized schedules from the at least one generic optimizing module to the at least one private optimizing module for it to process as uncoordinated joint schedules, until terminating conditions are met and provide the current optimized schedules to the respective users as the one or more coordinated logistics schedules.

[013] According to another aspect of the present invention, it provides a method for generating one or more coordinated logistics schedules for one or more users, using the system, wherein the one or more coordinated logistics schedules are generated through the below steps:

- (1) using at least one private optimizing module to generate one or more initial schedules for each user based on information input by such user, and transmit the one or more initial schedules to at least one generic optimizing module;
- (2) after receiving the one or more initial schedules, using the at least one generic optimizing module to generate one or more uncoordinated joint schedules based on the received one or more initial schedules, taking into consideration generic information from at least one generic information management module, and transmit the one or more uncoordinated joint schedules to the at least one private optimizing schedule for the respective users;
- (3) after receiving the one or more uncoordinated joint schedules, using the at least one private optimizing module to generate one or more coordinated schedules for each user based on the one or more uncoordinated joint schedules, taking into consideration each user's input, and transmit the one or more coordinated schedules to the at least one generic optimizing module;
- (4) after receiving one or more coordinated schedules, using the at least one generic optimizing module to generate one or more optimized schedules based on the one or more coordinated schedules, taking into consideration the generic information from the at least one generic information management module;
- (5) repeating steps (3) and (4) by transmitting the one or more optimized schedules from the at least one generic optimizing module to the at least one private optimizing module for it to process as uncoordinated joint schedules until terminating conditions are met and providing the current optimized schedules to the respective users as the one or more coordinated logistics schedules.

[014] According to another aspect of the present invention, it provides a computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the above method.

[015] According to another aspect of the present invention, it provides a computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the above method.

[016] According to another aspect of the present invention, the system further includes at least one data synchronizing module, configured to retrieve external data manually or automatically and transmit such external data to the at least one generic information management module. The external data includes real-time traffic data and/or real-time weather data. If the external data affects the one or more coordinated logistics schedules, then step (1) is activated manually or automatically.

[017] According to another aspect of the present invention, wherein the one or more users include logistics service providers, retailers, and mall and/or warehouse operators. The one or more coordinated logistics schedules generated for the logistics service providers, retailers, mall and/or warehouse operators include one or more vehicle routing schedules, one or more parcel tracking schedules and one or more dock appointment schedules. When optimizing schedules for a logistics service provider, the at least one private optimizing module takes into consideration human factors of executing the schedules.

[018] According to another aspect of the present invention, the terminating conditions include:

- no improvement can be obtained to resulting schedules;
- a given time limit exceeds; and/or
- a maximum number of iterations has been reached.

[019] According to another aspect of the present invention, the information input by a user to the at least one private optimizing module includes capacity of the user's resources, the user's intended rules, information of delivery requests, and/or the user's initial proposed schedule.

[020] According to another aspect of the present invention, during the step (1) and/or the step (3), a payoff is calculated for each schedule, wherein the payoff is to be minimized for the purpose of optimizing schedules. The payoff is calculated by computing a weighted sum of the total travel time,

the total wait time, and the total time violation, or by computing a weighted sum of total travel distance and number of vehicles.

BRIEF DESCRIPTION OF THE DRAWINGS

[021] Figure 1 depicts a work flow of the system and method according to one embodiment of the present invention.

[022] Figure 2 depicts the steps S101 and S103 of Figure 1 according to one embodiment of the present invention.

[023] Figure 3 depicts the steps S105 and S107 of Figure 1 according to one embodiment of the present invention.

[024] Figure 4 depicts how the steps S105 and S107 of Figure 1 are repeated according to one embodiment of the present invention.

[025] Figure 5 depicts the route to be improved in example A of smoothing vehicle routing schedules according to one embodiment of the present invention.

[026] Figure 6 depicts the improvement of routes of two vehicles in example B of smoothing vehicle routing schedules according to one embodiment of the present invention.

[027] Figure 7 depicts the improvement of routes of two vehicles in example C of smoothing vehicle routing schedules according to one embodiment of the present invention.

[028] Figure 8 depicts how initial solution, ideal and uncoordinated solutions are derived according to one embodiment of the present invention.

[029] Figure 9 depicts one iteration of iterative best response approach according to one embodiment of the present invention.

[030] Figure 10 depicts one example of an improvement path (assuming $n = 3$) according to one embodiment of the present invention.

[031] Figure 11 depicts convergence plot of total payoffs with increasing number of iterations for 30 test instances of the experiment according to one embodiment of the present invention.

[032] Figure 12 depicts the total payoff comparison across 30 test instances of the experiment according to one embodiment of the present invention.

[033] Figure 13 depicts comparison of max payoff deviation from UB ($f'(s)$) between decentralized and centralized approaches (1 hour) model over 30 test instances of the experiment according to one embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[034] While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific embodiments will herein be described in detail. It should be understood, however, that there is no intent to limit the concepts of the present disclosure to the particular forms disclosed or terms used, but on the contrary, the intention is to cover all modifications, equivalents and alternatives consistent with the present disclosure and the appended claims.

[035] In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, that the present invention may be practised without these specific details. Well-known methods, procedures, materials and conditions have not been described in detail so as not to unnecessarily obscure aspects of the implementations.

[036] It will be appreciated that the inclusion of a schematic element in a drawing is not meant to imply that such element is required in all embodiments or that the features represented by such element may not be included in or combined with other elements in some embodiments.

[037] Several features are described hereafter, each of which may be used independently of one another or with any combination of other features. However, any individual feature may not address any of the problems discussed above or might only address one of the problems discussed above. Some of the problems discussed above might not be fully addressed by any of the features described herein. Although headings are provided, information related to a particular heading, but not found in the section having that heading, may also be found elsewhere in the specification.

[038] In this specification:

- (1) the terms “contain” and “include” and derivatives of these terms are not to be construed as being restricted or confined to the ensuing matters enumerated but as potentially encompassing other matters not so enumerated;
- (2) words in the singular shall be construed to include the plural and *vice versa*, unless the context requires or indicates otherwise;
- (3) unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by those skilled in the art to which the present invention belongs;
- (4) the terms “strategy”, “solution” and “schedule” are used interchangeably as-
 - (i) a strategy of a user (e.g. an LSP) is represented in the form of a schedule;
 - (ii) a schedule is a solution for a user, the content of which depends on the type of the user, for example:
 - a schedule for an LSP is a solution of a single-LSP VRPLC which consists of the routes (sequence of locations visited) of every vehicle and the corresponding time intervals (start and end service times) of every request served by each vehicle;
 - a schedule for a mall or warehouse operator is a solution of how the resources (such as docking/parking bays, forklifts etc) at the mall or warehouse are scheduled, which consists of the time slots of each resource being reserved and the information of such reservation;
 - a schedule for a retailer is a solution of how each parcel is being arranged for delivery, and the information of the delivery.

[039] Being able to improve system efficiency and yield a win-win solution for all stakeholders across the entire logistics chain, the system and method according to an embodiment of the present invention involves multiple stakeholders, collectively called “users” hereinafter. While the system or method can be used to generate one or more schedules for different users, such as vehicle routing schedule, vehicle assignment schedule, parcel delivery schedule, docking management schedule, the underlying problem can be seen as a Vehicle Routing Problem with Pickup and Delivery, Time Windows and Location Congestion with multiple LSPs (ML-VRPLC).

[040] To resolve the issues and meet the various purposes as mentioned above, according to an embodiment of the present invention, a two-level optimizing mechanism is adopted in the system and method, which improves the efficiency of the whole process, protects the privacy of each user, improves the performance of each and every user, and improves the system optimality among all users.

[041] According to an embodiment of the present invention, the system includes at least one generic information management module, at least one private optimizing module, at least one generic optimizing module. According to an embodiment of the present invention, the system further includes at least one data synchronizing module.

[042] According to an embodiment of the present invention, a user to the system and method can be a logistics service provider (LSP), a retailer, a mall operator, a warehouse operator, or any other party who needs to use the system and method to generate one or more logistics schedules.

[043] The at least one generic information management module is configured to manage generic information that is non-confidential to any user of the system. Such non-confidential generic information includes but not limited to: traffic data such as historical data for estimating the time to travel from one location to another location and the schedule of road maintenance work; operational constraints at one or more malls such as operating hours, number of parking lots, availability of parking/docking bays etc.; operational constraints at one or more warehouses such as operating hours, availability of parking/docking bays, availability of special equipment such as forklifts, capacity of workers, stock of goods etc.; weather data. The non-confidential generic information can be input by a user of the system, a person maintaining or operating the system, or any other authorised party.

[044] The at least one private optimizing module is configured to work privately for each user of the system. Each user can input its requirements such as capacity of its resources, rules, information of delivery requests (such as pickup/drop-off locations, time, type and quantity of delivery etc.), and/or its initial proposed schedule. The capacity of resources may include but not limited to: the number of vehicles, capacity of each vehicle, working hour of each driver, location of each vehicle, status of each vehicle. Rules input by a user may include but not limited to: working hours, lunch hours or any break timings, depot information, how the assignments to a vehicle can be transferred to another vehicle, max number of jobs per trip, etc. The user's input to the private optimizing module is kept confidential, so that such information will not be shared with the generic optimizing module, the generic information management module, the data synchronizing module, and any other users of the

system. According to one embodiment of the present invention, one private optimizing module may be supported by one server, different private optimizing modules may be supported by the same server or by different servers.

[045] The at least one generic optimizing module is configured to work on a generic basis, so that it can coordinate schedules among multiple users based on the non-confidential generic information stored at the generic information management module.

[046] According to one embodiment of the present invention, the at least one data synchronizing module is configured to retrieve certain external data and transmit such external data to the at least one generic information management module. For example, the at least one data synchronizing module can be configured to link the system of the present invention to external sources, so that certain information can be synchronized to the system of the present invention manually or automatically, such as real-time traffic data and weather data. The synchronized information will then be transmitted from the at least one data synchronizing module to the at least one generic information management module. If such synchronized information is considered to have affected one or more schedules of one or more users of the system, a process to optimise the schedules that have not been executed may be activated. Such activation of the process to optimise the schedules may start automatically if certain criteria are met, or it may start manually by a party who receives a prompt from the system and determines that it is necessary to activate the process.

[047] Reference is made to Figure 1, which illustrates a work flow of the system and method according to one embodiment of the present invention. As depicted in Figure 1, at least four steps of processing are conducted in the system and method, S101, S103, S105 and S107. In step S101, as depicted in Figure 2, the private optimizing module working as individual engine for each LSP generates one or more routes that it deems as the optimized routes to be the initial schedules for each user, such generation is based on the user's input. Thereafter, the private optimizing module transmits such one or more initial schedules for each user to the generic optimizing module.

[048] In step S103, as depicted in Figure 2, after receiving the initial schedules from the private optimizing module, the generic optimizing module working as the centralized engine generates uncoordinated joint schedule based on the received initial schedules, taking into consideration the non-confidential generic information from the generic information management module. After completed, the generic optimizing module forwards the uncoordinated joint schedules to the private optimizing schedule for the respective user.

[049] In step S105, as depicted in Figure 3, after receiving the uncoordinated joint schedules, the private optimizing module generates best response schedules as coordinated schedules based on the uncoordinated joint schedules, taking into consideration the user's input, and forwards the coordinated schedules to the generic optimizing module.

[050] In step S107, as depicted in Figure 3, generic optimizing module working as the centralized engine generates improved joint schedule as the optimized schedules based on the coordinated schedules, taking into consideration the non-confidential generic information.

[051] As depicted in Figure 4, steps S105 and S107 are repeated until terminating conditions are met and current optimized schedules are provided to the users as the final output. When repeating steps S105 and S107, the optimized schedules are transmitted from the generic optimizing module to the private optimizing module for it to process as uncoordinated joint schedules. The terminating conditions may include but not limited to: no improvement can be obtained to the resulting schedules, a given time limit exceeds, and/or maximum number of iterations has been reached.

[052] With the final output of the optimized schedules for each LSP, the generic optimizing module is also able to generate schedules to each of other users, such as mall operators, warehouse operators, and/or retailers.

Model

Model Formulation

[053] Multiple LSPs have to fulfil a list of pickup-delivery requests within certain period of time, such as a day or half a day. Normally, each LSP would have a fleet of vehicles, consisting of multiple vehicles. After being assigned the delivery tasks, a vehicle would need to go to one or more pickup locations to load up the goods and deliver them to one or more destinations, which could be commercial or retail locations such as warehouses and shopping malls. The vehicles need to return to their depot by a certain time and every request has a time window requirement. Each vehicle has its capacity which cannot be exceeded, and its available slots. A wait time will be incurred if the vehicle arrives early and time violations will be incurred if it serves the request late. In addition, every location (such as malls and warehouses) has a limited parking/docking bays for loading and unloading, and a designated working hours and lunch hour break or any break timings where no delivery would be allowed. As such, further wait time and time window violations will be incurred if a

vehicle arrives in a location where the parking bays are fully occupied or arrives during the designated break hour. The retailer may need the parcel to be delivered within certain time window.

[054] The main objective of each LSP is to plan for a schedule that optimises a number of goals, such as minimizing total travel time, total waiting time and total time window violations (order time window, vehicle start and end time, makespan), or minimizing total distance travelled and total number of vehicles. The main objective of each retailer is to arrange and track the logistics of its parcels and ensure it meets the delivery requirements. The main objective of each mall operator is to minimize the conflicts of use of the limited resources at the mall and avoid congestion. Similarly, the main objective of each warehouse operator is to minimize the conflicts of use of the limited resources at the warehouse and avoid congestion.

[055] To address the underlying problem and meet the objectives as mentioned above, the system and method according to an embodiment of the present invention formulate the problem as a strategic game where each LSP is a self-interested user willing to participate in a coordinated planning (without collaborating directly with other LSPs) as long as there are sufficient incentives. Through an iterative best response procedure, multiple users adjust their schedules until no further improvement can be obtained to the resulting joint schedule. The joint schedule which maximises the minimum gain achieved by any one LSP would be picked out as the best joint schedule, as LSPs are interested in how much benefit they can gain rather than achieving a system optimality. To realize such gains, according to an embodiment of the present invention, it is proposed to use maximum cost deviation from an ideal solution (a solution that assumes no other LSPs exist to compete for the limited resources) as the performance measure (See Equations (2)-(4) below). It is clear that the minimum gain is equivalent to the cost deviation of the worst performing LSP from this ideal solution.

[056] According to an embodiment of the present invention, the scalable, decentralized, coordinated planning approach is proposed based on iterative best response consisting of a metaheuristic as route optimizer with a scheduler based on Constraint Programming (CP) model to solve a large-scale ML-VRPLC.

[057] According to an embodiment of the present invention, ML-VRPLC is formulated as an n -player strategic game $\Gamma_{ML-VRPLC}$ with LSPs represented as users $i \in N$, having a finite set of strategies S_i , and sharing the same payoff function i.e. $u^1(s) = \dots = u^n(s) = u(s)$. $s \in S_1 \times \dots \times S_n$ which is a finite set since S_i is finite. To meet the requirements and improve the efficiency of the approach adopted in the systems and methods according to an embodiment of the present invention,

some functions are designed which will be discussed below. Table 1 below provides the set of notations and the corresponding descriptions used in the model.

Spatio-Temporal Distance

[058] Spatio-temporal distance which measures the distance between 2 locations while simultaneously taking into account time windows, may be used to calculate the savings for the purpose of generating or optimizing solutions. According to one embodiment of the present invention, spatio-temporal distance is used in the initial solution generator and/or in one of ALNS remove operators. With the use of spatio-temporal distance, feasible initial solution may be generated reasonably quickly. According to one embodiment of the present invention, spatio-temporal distance can be calculated by computing a weighted sum of normalized spatial distance and normalized temporal distance.

Table 1. Set of Notations Used in $\Gamma_{ML-VRPLC}$

Notation	Description
N	A set of LSPs, $N \in \{1, 2, \dots, n\}$.
s_i	A schedule of LSP i , $i \in N$, $s_i \in S$.
s	A joint schedule of all LSP, $s = (s_1, s_2, \dots, s_n)$, $s \in S$. $s_i = \langle s_i.routes, s_i.timeIntervals \rangle$
s_{-i}	A joint schedule of all LSP except LSP i , $s_{-i} = (s_1, \dots, s_{i-1}, s_{i+1}, \dots, s_n)$.
(s_i, s_{-i})	A joint schedule where LSP i follows a schedule s_i while the rest follows a joint schedule, s_{-i} .
$u^i(s)$	Payoff of LSP i when all LSP follows a joint schedule, s .
$B_i(s_{-i})$	Best response of LSP i when all other LSPs follow a joint schedule, s_{-i} .

Payoff Function

[059] The payoff function, $u^i(s)$ is defined as the weighted sum of the total travel times, wait times and time window violations incurred when LSP i follows a joint schedule, s . The wait times and time window violations are derived from $s_i.timeIntervals$ and the corresponding time-related requirements. The details on how to compute this payoff function will be further discussed in paragraph [079]. Payoff is defined as the cost incurred when following a given strategy. Thus, the lower the payoff, the better is the solution.

Potential Function

[060] A potential function is defined as $P(s) = \sum_{i \in N} u^i(s)$ i.e. total weighted sum of travel times, wait times and time violations when all LSPs follow a joint schedule s . $P(s)$ is an ordinal potential function for $\Gamma_{ML-VRPLC}$ since for every $i \in N$ and for every $s_{-i} \in S_{-i}$

$$u^i(s_i, s_{-i}) - u^i(s'_i, s_{-i}) > 0 \text{ iff}$$

$$P(s_i, s_{-i}) - P(s'_i, s_{-i}) > 0 \text{ for every } s_i, s'_i \in S_i \quad (1)$$

[061] Thus, $\Gamma_{ML-VRPLC}$ is a finite ordinal potential game and it possesses a pure-strategy equilibrium and has the Fictitious Play Property (FPP). Having the FPP means that every fictitious play process in $\Gamma_{ML-VRPLC}$ converges to an equilibrium. The purpose of the system and method according to one embodiment of the present invention is to find an approach that converges into equilibrium which will be shown conceptually and empirically in the later sections.

Equilibrium vs. Local Optimality

[062] Define $s' = (s'_i, s'_{-i})$ as an equilibrium if $u^i(s'_i, s'_{-i}) \leq u^i(s_i, s'_{-i})$ for all $i \in N$ where $s_i \in B_i(s_{-i})$. An equilibrium of $\Gamma_{ML-VRPLC}$ is a local optimum since no player can improve its payoff by changing its individual schedule. Conversely, every optimal solution, s^* of $\Gamma_{ML-VRPLC}$ is an equilibrium since $u^i(s^*) \leq u^i(s_i, s^*_{-i})$ for all $i \in N$ where $s_i \in B_i(s^*_{-i})$.

Objective Function

[063] The objective of the system and method according to one embodiment of the present invention is to minimize the maximum payoff deviation of any one user from an ideal solution.

$$\min_{s \in S} f(s) \quad (2)$$

$$f(s) = \max_{i \in N} \text{Deviation}_{LB}(s, i) \quad (3)$$

$$\text{Deviation}_{LB}(s, i) = \frac{u^i(s) - u^i(s^{ideal})}{u^i(s^{ideal})} \times 100\% \quad (4)$$

where s^{ideal} is defined as the joint schedule where there is no resource constraint at the locations or where all other LSPs do not exist to compete for parking bays. s^{ideal} is a Lower Bound (LB) solution since it is a solution of a relaxed $\Gamma_{ML-VRPLC}$. To provide each user the optimised solution, it would be necessary to search for solutions where each user's payoff is as close as possible to its corresponding LB solution.

[064] The objective function is not defined as $\min_{s \in S} \sum_{i \in N} u^i(s)$ because an individual user would be more concerned about how much benefits it can obtain by adopting a coordinated planning instead of planning independently, rather than how much benefits the system can obtain (total payoffs of all players). Nevertheless, minimising the payoff deviation of the worst performing user will correspondingly minimize the overall total payoffs.

Proprietary Human-factors

[065] Within the scope of an LSP, individual LSP schedules can be finetuned that may take human factors of executing the schedules into consideration, even if that means the payoff is worse off, such as smoothing the vehicle routing schedules, minimizing the occurrences of “split deliveries”, etc.

[066] Smoothness is defined as an index such that if two consecutive locations within a trip happen to be present within a certain distance Q to each other, they will have higher smoothness index. The routes are efficient if orders that are in proximity to each other are served consecutively, keeping the other constraints intact.

[067] Similarity is defined as an index such that if two locations in a pair of trips happen to be present within a certain distance F to each other, then this pair of trip will have higher similarity index. Orders can be relocated from one trip to another to reduce the similarity index, since routes are efficient if orders that are in proximity to each other are served in the same trip by the same vehicle, while keeping the other constraints intact.

[068] If the number of orders on a trip for a vehicle is less than a predetermined number (e.g. less than 2 orders), the orders may be relocated to other vehicles while keeping the other constraints intact. This is done so as to further reduce the number of vehicles used.

[069] For illustration purpose, according to one embodiment of the present invention, Table 2 provides three examples A, B and C, depicting how vehicle routing schedules can be smoothed. For each example, there are two sets of schedules showing the schedules before processed and the schedules after processed. It is evident from Table 2 that schedules are smoothed and improved after processed.

[070] Figure 5 depicts the route to be improved in example A. Figure 6 depicts the routes of vehicle 1 and vehicle 2 before processed, after processed the routing for vehicle 1 is improved to include the assignment in vehicle 2, so that vehicle 2 is no longer required to visit the location where vehicle 1

would originally be required to visit, which improves the routing of both vehicles. Similarly, Figure 7 also depicts how the work of one vehicle can be assigned to another vehicle to improve the overall performance and reduce costs.

Table 2. Examples of Smoothing Vehicle Routing Schedules

EXAMPLE		Vehicle ID	Sequence Label	Location	Qty	Arrival Time	Time From	Time To
A	Before Processed	1	B	Plaza Singapura	22	14:00	14:00	19:00
		1	C	PoMo	8	14:27	14:00	19:00
		1	:	:				
		1	H	Cathay Cineleisure	15	17:43	14:00	19:00
	After Processed	1	B	PoMo	8	14:00	14:00	19:00
		1	C	Plaza Singapura	22	14:27	14:00	19:00
		1	D	Cathay Cineleisure	15	15:15	14:00	19:00
		1	:	:				
B	Before Processed	1	B	Westmall	55	13:04	12:00	15:30
		1	C	Westmall	70	13:19	12:00	15:30
		2	B	Westmall	85	16:43	14:00	18:30
	After Processed	1	B	Westmall	55	14:54	12:00	15:30
		1	C	Westmall	70	15:24	12:00	15:30
		1	D	Westmall	85	15:29	14:00	18:30
C	Before Processed	1	F	Tampines Mall	16	14:00	14:00	19:00
		1	G	Our Tampines Hub	9	14:28	14:00	19:00
		2	B	Tampines Mall	48	9:49	7:00	11:30
	After Processed	1	E	Tampines Mall	48	11:30	7:00	11:30
		1	F	Tampines Mall	16	14:00	14:00	19:00
		1	G	Our Tampines Hub	9	14:28	14:00	19:00

Solution Approach

[071] According to one embodiment of the present invention, a chosen joint schedule can be iteratively improved by computing the best responses of a user assuming the rest of the users adopt the chosen joint schedule until the terminating conditions are met. Such approach is decentralized in nature because each user with a private optimizing module is an independent agent which computes its own routes and schedules i.e. the generic optimizing module does not dictate how each user determine their decisions.

[072] Given the problem is established as a potential game and has an FPP according to one embodiment of the present invention, such fictitious-play like approach will converge to an equilibrium which has been shown earlier to be equivalent to a local optimal solution. Therefore, such algorithm seeks to explore multiple local optimal solutions until the terminating conditions are met and returns the best one found so far.

Initial Solution, Lower Bound and Upper Bound Solutions

[073] The initial joint schedule can be initialized to any random, feasible joint schedule. According to one embodiment of the present invention, the uncoordinated joint schedule is used as the initial solution to be improved by iterative best response algorithm.

[074] To compute the initial joint schedule, $s^{initial}$, the best schedules are firstly computed for each LSP independently assuming no resource constraints. This is akin to solving a classical Vehicle Routing Problem with Pickup and Delivery, and Time Windows (VRPPDTW). The resulting joint schedule is in fact s^{ideal} and is the LB solution to $\Gamma_{ML-VRPLC}$. Next, a generic optimizing module working as a centralized engine according to an embodiment of the present invention consisting of a CP model that incorporates the resource capacity constraint at each location is solved for the combined routes of s^{ideal} . This forms an uncoordinated joint schedule, $s^{uncoord}$ which serves as an Upper Bound (UB) solution to $\Gamma_{ML-VRPLC}$ as any coordinated planning approaches should result in solutions that are better than an uncoordinated one. Figure 8 shows how these solutions are derived.

Iterative Best Response Algorithm

[075] As illustrated in Table 3, Algorithm 1 describes how the iterative best response algorithm works according to one embodiment of the present invention. Figure 9 illustrates one iteration of this iterative procedure (lines 6-25 in Table 3). At each iteration, a joint schedule is chosen from a sampling pool of previously obtained improved joint schedules or from the current best joint schedule (lines 9-10 in Table 3). An epsilon greedy sampling policy is implemented to allow for exploration of

multiple improvements paths (see Figure 10 for an example of an improvement path) to search for best joint schedule. An improvement step consisting of n best response computations is applied to the chosen joint schedule to obtain new improved joint schedules (line 13 in Table 3). Update the current best joint schedule if any of the new joint schedules have a lower $f(s)$ value than f_{min} (lines 18-20 in Table 3). Otherwise, the new improved joint schedules is put into the sampling pool for further improvement steps in the subsequent iterations (lines 21 and 23 in Table 3). The process is repeated until terminating conditions are met. Then, the current best joint schedule is used as the final output as the optimized schedules in Step 107 depicted in Figure 1.

Finite Improvement Paths & Convergence

[076] Each improved joint schedule can be represented as a node in a directed tree. A series of nodes with parent-child relationship forms an improvement path as shown in Figure 10 where $P(s^{k,i}) < P(s^{k-1,i'})$ for all $k \geq 1$ and $i, i' \in N$. Every improvement path is finite since S is a finite set. Every finite improvement path will converge to an equilibrium and every terminal point is a local optimum. However, since the best response is computed heuristically and there is no way to prove optimality, the resulting equilibrium is just an approximate. Nevertheless, experiments which will be further discussed below empirically show that such approach will converge to an approximate equilibrium solution after a certain number of iterations.

[077] In short, such approach explore multiple improvement paths to search for joint schedule that return the best objective value, $f(s)$ with the lowest total payoffs, $P(s)$ as a secondary objective.

Table 3. Algorithm 1

Algorithm 1: Iterative Best Response Algorithm to solve ML-VRPLC	
Input: Initial joint schedule $s^{initial}$, ideal joint schedule s^{ideal} , maximum iterations K , runtime limit T	
Output: Best found joint schedule s^{best}	
1	Create an empty sampling pool of joint schedules, $\mathbf{H}$
2	$s^{best} := s^{initial}$
3	$f_{min} := f(s^{initial})$
4	$k = 0$
5	while $k < K$ or cumulative run time $< T$ or $\mathbf{H}$ is not empty do
6	if $k = 0$ then
7	$s^k := s^{initial}$
8	else
9	With probability ϵ , $s^k \sim U(\mathbf{H})$
10	and with probability $1 - \epsilon$, $s^k := s^{best}$
11	end
12	Remove s^k from $\mathbf{H}$
13	Find new joint schedules $\{s^{k,1}, s^{k,2}, \dots, s^{k,n}\}$ where $s^{k,i}$ is the best response schedule from LSP i
14	if $u^i(s^k) \leq u^i(s^{k,i})$ for all $i \in N$ then
15	$k+ = 1$
16	continue
17	end
18	if $\min_{i \in N} f(s^{k,i}) \leq f_{min}$ then
19	$s^{best} := s^{k,i^*}$
20	$f_{min} := f(s^{k,i^*})$
21	put $\{s^{k,i}\}_{i \in N \setminus \{i^*\}}$ in $\mathbf{H}$
22	else
23	put $\{s^{k,i}\}_{i \in N}$ in $\mathbf{H}$
24	end
25	$k+ = 1$
26	end
27	return s^{best}

Best Response Computation

[078] At every iteration, best response to a chosen joint schedule, s^k is computed for each LSP (line 13 in Table 3). The best response computation of single LSP is equivalent to solving a single-LSP VRPLC where the resource constraint is determined by the resource utilization of each location by all other LSPs based on s_{-i}^k . Table 4 below shows the notations used in this single-LSP VRPLC model.

Table 4. Set of Notations Used in the Single-LSP VRPLC Model

Notation	Description
V	A set of vehicles.
R	A set of all requests.
M	A set of all locations.
R_v	A set of requests served by vehicle v .
O_m	A set of requests at location $m \in M$.
$C_{m,t}$	Resource capacity at location m at time t .
$e_{r,v}$	Lower time window of request r served by vehicle v .
$l_{r,v}$	Upper time window of request r served by vehicle v .
$prev(r)$	Previous request served prior to request r , $prev(r)$, $r \in R_v$.
$d_{x,y}$	Travel time from location of request x to location of request y .
$timeInterval_{r,v}$	Time interval when request r in vehicle v is being served, consisting of start and end time.

[079] According to one embodiment of the present invention, a heuristic consisting of Adaptive Large Neighbourhood Search (ALNS) is proposed as route optimizer and a scheduler based on a CP model to solve this single-LSP VRPLC. Heuristic is proposed as it is more scalable for a real-world problem setting. ALNS is used to search for better routes and the CP model based on the resulting routes is then solved to produce a schedule that meets the resource and time-related constraints. For illustrating purpose, according to one embodiment of the present invention, Table 5 provides an example of the algorithm, Algorithm 2, which proposes a best response computation consisting of ALNS and CP model. At each step of Algorithm 2, in order to compute the time intervals and the corresponding payoff of the updated solution, a CP model is solved. As a key of the algorithm, payoff is calculated (line 8 of Table 5) for each schedule by computing a weighted sum of three components: the total travel time, the total wait time, and the total time violation (i.e. not being able to meet the time windows), which is to be minimized for the purpose of optimizing schedules. According to one embodiment of the present invention, different LSPs may have different weightages depending on their mode of operations. For example, LSP1 may wish to place a higher weightage on the total travel time, while LSP2 may prefer a higher weightage on time violation. According to one embodiment of the present invention, the payoff function is a component within the algorithm that can be replaced with another other payoff function, such as minimizing total distance travelled, number of vehicles, etc. According to one embodiment of the present invention, the formula of the payoff function is calculated by computing a weighted sum of the total travel time, the total wait time, and the total time violation is as follow:

$$\begin{aligned}
u^i(s_i) = & w_1 \times totalTravelTime(s_i.routes) + \\
& minimise \sum_{v \in V} \{w_2 \times \sum_{r \in R_v} waitTime_{r,v} \\
& + w_3 \times \sum_{r \in R_v} timeViolation_{r,v}\} \tag{5}
\end{aligned}$$

Where

w_1, w_2, w_3 are predetermined set of weights,

$waitTime_{r,v} = \min\{0, (start(timeInterval_{r,v}) - end(timeInterval_{prev(r),v}) - d_{prev(r),r})\},$

$timeViolation_{r,v} = \min\{0, (end(timeInterval_{r,v}) - l_{r,v})\},$

$s_i.timeIntervals = \{timeInterval_{r,v}\}_{r \in R_v, v \in V}$

[080] The second term of Equation (5) is the objective value of the CP model with the start and end times of each activity $\{timeInterval_{r,v}\}_{r \in R_v, v \in V}$ as the primary decision variables of the model. The key constraints of the CP model are to ensure that temporal relationships are handled correctly, there are no overlapping activities, and that the resource capacity at each location at a given time is not violated, as follow:

$$CUMULATIVE(\{timeInterval_{r,v} : v \in V, r \in R_v \cap O_m\}, 1, C_{m,t}), \forall m \in M \tag{6}$$

$$noOverlap(\{timeInterval_{r,v} : r \in R_v\}), \forall v \in V \tag{7}$$

$$start(timeInterval_{r,v}) \geq end(timeInterval_{prev(r),v}) + d_{prev(r),r}, \forall r \in R_v, v \in V \tag{8}$$

$$start(timeInterval_{r,v}) \geq e_{r,v}, \forall r \in R_v, v \in V \tag{9}$$

[081] Constraint (6) is used to model the resource capacity constraint at each location at a given time t where $start(timeInterval_{r,v}) \leq t \leq end(timeInterval_{r,v})$ and $C_{m,t}$ is determined by the resource utilization of all other LSPs based on s_{-i}^k . Constraint (7) ensures that the time intervals of requests within a route do not overlap. Constraints (8) and (9) ensure that the start time of a request must at least be later than the end time of the previous request plus the corresponding travel time and it should not start before its lower time window. Other constraints relating to operational requirements such as no delivery within break hours, operating hours of the locations and vehicles are omitted to simplify the discussion as it is fairly straightforward to incorporate these constraints.

Table 5. Best Response Computation Consisting of ALNS and CP Model

Algorithm 2: Best Response Computation

Input : Maximum iteration number N , stagnation limit M , $timeLimit$,
Chosen solution s^k , initial temperature $\bar{T}_0$, score
increment $\pi_1 > \pi_2 > \pi_3$, reset iteration K ,
 $coolingRate$, $baseNumIterations$

Output: s_i^{best} (best response schedule of LSP i)

```

1  $t := 0$ ;  $stagnantCounter := 0$ ;  $s_i^{best} := s_i^k$ ;  $\bar{T} = \bar{T}_0$ 
2 Initialise the scores of the remove and insert operators to be 1
3 while  $i < N$  or  $stagnantCounter < M$  or within timeLimit do
4    $s'_i := s_i$ 
5   Select removal and insert operators via roulette wheel mechanism
6   Apply the selected removal operator to remove the orders from  $s'_i$ 
7   Apply the selected insert operator to insert the orders into  $s'_i$ 
8   Calculate the cost/payoff,  $u^i(s'_i, s_{-i}^k)$  and update  $s'_i.timeIntervals$ 
9   if  $u^i(s'_i, s_{-i}^k) < u^i(s_i^{best}, s_{-i}^k)$  then
10      $s_i^{best} := s'_i$ ,  $s_i := s'_i$ 
11      $stagnantCounter := 0$ 
12     Update the scores of selected remove and insert operators by  $\pi_1$ 
13   else
14     if  $u^i(s'_i, s_{-i}^k) < u^i(s_i, s_{-i}^k)$  then
15        $s_i := s'_i$ 
16       Update the scores of selected remove and insert operators by  $\pi_2$ 
17     else
18        $s_i := s'_i$  with probability,  $\min\{1, e^{(u^i(s_i, s_{-i}^k) - u^i(s'_i, s_{-i}^k)) / \bar{T}}\}$ 
19       Update the scores of selected remove and insert operators by  $\pi_3$ 
20     end
21   end
22   Reset the scores of the operators every  $K$  iterations
23    $\bar{T} := \bar{T} * coolingRate$ 
24   if  $t > baseNumIterations$  then
25      $stagnantCounter := stagnantCounter + 1$ 
26   end
27    $t := t + 1$ 
28 end
29 return  $s_i^{best}$ 

```

Scalability and Flexibility

[082] By enabling the best response computations for every LSP to be done in parallel using the two-level optimizing mechanism, the systems and methods according to the present invention provide a scalable approach, which can be computed efficiently. The systems and methods are also flexible as they also allow any other forms of solution approach to single-LSP VRPLC to be used to compute the best response.

[083] It is appreciated that the best-response algorithm and the payoff functions of private optimizing module for each user (such as each LSP) can be identical or different. Moreover, even with non-identical payoff functions, the inequality condition in Equation (1) will still be valid and therefore ensure the approach according to the present invention converge to an approximated equilibrium. However, as a preferred embodiment of the present invention, the payoff function as defined in equation (5) may be adopted.

Experiments

[084] Experiments are conducted to empirically verify whether the systems and methods according to the present invention converge to an equilibrium for the real-world problem, and to evaluate the quality of solutions produced by the systems and methods adopting the decentralized approach according to the present invention against a centralized approach with respect to s^{ideal} (LB) and $s^{uncoord}$ (UB). As an improved performance, the approach adopted in the systems and methods according to the present invention is expected to return solutions with lower payoff/cost than UB solution and within a reasonable deviation from LB solution.

Experimental Setup

[085] To simulate a month's worth of pickup-delivery requests for 20 LSPs, 30 test instances are synthetically generated. Each test instances consists of 100 requests per LSP and each LSP has 10 vehicles. To simulate congestion at the delivery locations, delivery locations are narrowed down to 15 unique shopping malls with maximum parking/docking bay capacity of 4 slots per location. The test instances are synthetically generated based on existing datasets of trials with several local LSPs. The iterative best response approach is implemented with K set at 300 with $T = 60$ minutes.

[086] The solution approach is implemented in Java while the IBM CP Optimizer ver. 12.8 is used to solve the CP model. The experiments are run on a server with the following configurations: CentOS 8 with 24 CPU Cores and 32GB RAM.

Benchmark Algorithm

[087] A centralized, non-collaborative planning approach is chosen as a benchmark algorithm. It is centralized since all LSPs are treated as one single LSP and the central agent makes the routing and scheduling decision on behalf of the LSPs. It is non-collaborative as no exchange of requests or sharing

of vehicles are allowed i.e. each vehicle can only serve requests from the LSP they belong to. A heuristic approach combining ALNS and CP model is used, similar to the one used to compute best response to solve this single-LSP VRPLC. The initial solution is constructed via randomized Clarke-Wright Savings Heuristics. The algorithm is run for an 1-hour and 2-hour period for each test instance. Such design of the benchmark algorithm ensures a fair comparison.

Performance Measures

[088] Upon investigation, it is found that in most cases, the gap between UB and LB solutions of an LSP is narrow and therefore the corresponding improvement will proportionally be smaller. Thus, besides $f(s)$ (See Equation (3)), other performance measures have been introduced in the experiments for a more comprehensive evaluation, which are explained as follows:

- Maximum payoff deviation from an uncoordinated solution. $f'(s)$ measures the payoff deviation of the worst performing LSP from the payoff if it follows a schedule based on an uncoordinated planning. A negative deviation value indicates reduction in cost and the lower the value, the higher the improvement gained from the UB solution.

$$f'(s) = \max_{i \in N} \text{Deviation}_{UB}(s, i) \quad (10)$$

$$\text{Deviation}_{UB}(s, i) = \frac{u^i(s) - u^i(s^{uncoord})}{u^i(s^{uncoord})} \times 100\% \quad (11)$$

- Average payoff deviation from an ideal solution. The lower the value, the closer the solution is to the LB solution.

$$g(s) = \frac{1}{n} \times \sum_{i \in N} \text{Deviation}_{LB}(s, i) \quad (12)$$

- Average payoff deviation from an uncoordinated solution. Similar to Equation (10), a negative deviation value indicates reduction in cost.

$$g'(s) = \frac{1}{n} \times \sum_{i \in N} \text{Deviation}_{UB}(s, i) \quad (13)$$

Experimental Results

Convergence

[089] Figure 11 depicts the convergence plot of total payoffs with increasing number of iterations for 30 test instances. Each coloured line represents the result of one test instance. The results in Figure 11 demonstrate that the total payoffs of all players converged after 200 iterations on average for all 30 test instances. This is consistent with the earlier deduction that $\Gamma_{ML-VRPLC}$ possesses an FPP, and that the algorithm proposed according to one embodiment of the present invention explores multiple improvement path that will converge to an approximate equilibrium. Meanwhile, the average run-time for 200 iterations is about 1 hour.

Decentralized vs. Centralized

[090] Figure 12 shows that the decentralized approach according to one embodiment of the present invention (indicated as “Our Approach”) returns solutions with total payoff lower than that of the centralized approach and well within the UB and LB solutions in all 30 test instances. The comparison of performance between the decentralized and centralized approaches are summarized in Table 6.

[091] Overall speaking, Table 6 shows that the decentralized approach according to one embodiment of the present invention outperforms the centralized approach on every performance measures even when the run-time for the centralized approach is increased to 2 hours. In terms of the performance of the worst LSP, the decentralized approach is able to ensure that on average, the payoff of the worst performing LSP is still within about 20% from the LB solution and at least gain about 2.6% improvement over uncoordinated solution. Meanwhile, even with a doubled run-time (2 hours), the centralized approach can only manage to reach a result that the payoff of the worst performing LSP is within 31.6% from the LB solution while incurring a 12.9% additional cost as compared to an uncoordinated planning.

Table 6. Comparison of Performance Between Decentralized and Centralized Approaches

Performance Measure	Decentralized	Centralized	
	(1 hour)	(1 hour)	(2 hours)
Average max payoff deviation from LB ($f(s)$)	20.7%	34.2%	31.6%
Average max payoff deviation from UB ($f'(s)$)	-2.6%	12.9%	12.9%
Average payoff deviation from LB ($g(s)$)	8.3%	16.9%	14.4%
Average payoff deviation from UB ($g'(s)$)	-11.2%	-4.1%	-6.1%

[092] On average, across all LSPs, the decentralized approach returns solutions that are well within 8.3% deviation from the LB solution and improve the payoff of the LSPs by an average of 11.2% from an uncoordinated planning approach. This is contrasted with the centralized approach which can only manage to return solutions that are within 14.4% of LB solution on average and an improvement at an average of 6.1% from the UB solution even when the run-time is doubled.

[093] It is observed that the worst performing LSP in centralized approach consistently returns f' values that are positive (with only one exceptional instance which is negative, see Figure 13) which indicates that generally the solution for the worst performing LSP is even worse than that of an uncoordinated planning approach. This is because the centralized approach only concerns about the system optimality and not on the performance of each individual LSP. This reiterates the point that a centralized approach may result in some LSPs performing worse than if they are to plan independently.

[094] It is also observed from the average f' values of the decentralized approach according to an embodiment of the present invention that even the worst performing LSP also receives an improvement comparing to it performing a selfish, independent planning, although on average such improvement may not be significant high (an average of about 2.6%, see Figure 13). Such observation illustrates that

all users of the systems and methods according to the present invention will be benefited, including the worst performing user.

Experiment Discussion

[095] From the above results, it is appreciated that the decentralized approach proposed according to one embodiment of the present invention outperforms the centralized approach given the available run-time limit of 1 hour in all 30 test instances and in all 4 performance measures. Furthermore, it is also found that the centralized approach is computationally more expensive, and therefore not as scalable as the decentralized approach according to the present invention as it needs longer run-time (double or more) to return solutions that are at least comparable to the decentralized approach (or may even not be comparable to the decentralized approach).

[096] Overall, even though there will be LSPs who gain more than others, based on the experiments, the approach adopted in the systems and methods according to the present invention ensures that there are enough incentives for LSPs to adopt this coordinated planning as compared to them performing their own selfish, independent planning. Generally, the systems and methods according to the present invention reduce operation cost arising from travel distance & time which according to an experiment provides a reduction of about 15-20%, and the utilisation of vehicle can also be improved which according to an experiment provides a saving of about 10%. One would also appreciate that the systems and methods proposed by the present invention provide a faster turnaround time and improve the service levels and resource management.

[097] Therefore, it is appreciated that the systems and methods according to the present invention provide a scalable, decentralized and coordinated planning approach that can be extended for any large-scale optimization problems involving multiple "loosely coupled" entities competing for shared resources.

[098] While the disclosure contained herein has set forth some of the preferred embodiments of the present invention, as well as exemplary examples, it is not intended to limit or confine the present invention only to such embodiments or examples. It will be appreciated by those skilled in the art that variations to the modules and steps disclosed may be made without departing from the scope and spirit of the invention. Such variations may include, but are not limited to, selection of alternate practical modules, algorithms, steps, and application of the process for other purposes or occasions that are not specifically mentioned above.

CLAIMS

1. A system for generating one or more coordinated logistics schedules for one or more users, including:

at least one generic information management module, configured to store and manage generic information that is non-confidential to any user of the system;

at least one private optimizing module, configured to work privately for each user of the system, so that after a user inputs information to the at least one private optimizing module the information input by the user is kept confidential to the user itself;

at least one generic optimizing module, configured to work on a generic basis, so that it coordinates schedules among multiple users based on the non-confidential generic information stored at the at least one generic information management module;

wherein the one or more coordinated logistics schedules are generated through the below steps:

- (1) the at least one private optimizing module generates one or more initial schedules for each user based on information input by such user, and transmits the one or more initial schedules to the at least one generic optimizing module;
- (2) after receiving the one or more initial schedules, the at least one generic optimizing module generates one or more uncoordinated joint schedules based on the received one or more initial schedules, taking into consideration the non-confidential generic information from the at least one generic information management module, and transmits the one or more uncoordinated joint schedules to the at least one private optimizing schedule for the respective users;
- (3) after receiving the one or more uncoordinated joint schedules, the at least one private optimizing module generates one or more coordinated schedules for each user based on the one or more uncoordinated joint schedules, taking into consideration each user's input, and forwards the one or more coordinated schedules to the at least one generic optimizing module;
- (4) after receiving one or more coordinated schedules, the at least one generic optimizing module generates one or more optimized schedules based on the one or more coordinated schedules, taking into consideration the non-confidential generic information from the at least one generic information management module;
- (5) repeat steps (3) and (4) by transmitting the one or more optimized schedules from the at least one generic optimizing module to the at least one private optimizing module for it to process as uncoordinated joint schedules, until terminating conditions are met and provide the current optimized schedules to the respective users as the one or more coordinated logistics schedules.

2. The system according to claim 1, wherein the system further includes at least one data synchronizing module, configured to retrieve external data manually or automatically and transmit such external data to the at least one generic information management module.
3. The system according to claim 2, wherein the external data includes real-time traffic data and/or real-time weather data.
4. The system according to claim 2 or 3, wherein if the external data affects the one or more coordinated logistics schedules, then step (1) is activated manually or automatically.
5. The system according to any of the preceding claims, wherein the one or more users include logistics service providers, retailers, and mall and/or warehouse operators.
6. The system according to claim 5, wherein the one or more coordinated logistics schedules generated for the logistics service providers, retailers, mall and/or warehouse operators include one or more vehicle routing schedules, one or more parcel tracking schedules and one or more dock appointment schedules.
7. The system according to claim 5 or 6, wherein when optimizing schedules for a logistics service provider, the at least one private optimizing module takes into consideration human factors of executing the schedules.
8. The system according to any of the preceding claims, wherein the terminating conditions include:
 - no improvement can be obtained to resulting schedules;
 - a given time limit exceeds; and/or
 - a maximum number of iterations has been reached.
9. The system according to any of the preceding claims, wherein the information input by a user to the at least one private optimizing module includes capacity of the user's resources, the user's intended rules, information of delivery requests, and/or the user's initial proposed schedule.
10. The system according to any of the preceding claims, wherein during the step (1) and/or the step (3), a payoff is calculated for each schedule, wherein the payoff is to be minimized for the purpose of optimizing schedules.
11. The system according to claim 10, the payoff is calculated by computing a weighted sum of the total travel time, the total wait time, and the total time violation, or by computing a weighted sum of total travel distance and number of vehicles.

12. A method for generating one or more coordinated logistics schedules for one or more users, using the system according to any of claims 1-11, wherein the one or more coordinated logistics schedules are generated through the below steps:

- (1) using at least one private optimizing module to generate one or more initial schedules for each user based on information input by such user, and transmit the one or more initial schedules to at least one generic optimizing module;
- (2) after receiving the one or more initial schedules, using the at least one generic optimizing module to generate one or more uncoordinated joint schedules based on the received one or more initial schedules, taking into consideration non-confidential generic information from at least one generic information management module, and transmit the one or more uncoordinated joint schedules to the at least one private optimizing schedule for the respective users;
- (3) after receiving the one or more uncoordinated joint schedules, using the at least one private optimizing module to generate one or more coordinated schedules for each user based on the one or more uncoordinated joint schedules, taking into consideration each user's input, and transmit the one or more coordinated schedules to the at least one generic optimizing module;
- (4) after receiving one or more coordinated schedules, using the at least one generic optimizing module to generate one or more optimized schedules based on the one or more coordinated schedules, taking into consideration the non-confidential generic information from the at least one generic information management module;
- (5) repeating steps (3) and (4) by transmitting the one or more optimized schedules from the at least one generic optimizing module to the at least one private optimizing module for it to process as uncoordinated joint schedules, until terminating conditions are met and providing the current optimized schedules to the respective users as the one or more coordinated logistics schedules.

13. The method according to claim 12, wherein the method further includes using at least one data synchronizing module to retrieve external data manually or automatically.

14. The method according to claim 13, wherein the external data includes real-time traffic data and/or real-time weather data.

15. The method according to claim 13 or 14, wherein if the external data affects the one or more coordinated logistics schedules, then step (1) is activated manually or automatically.

16. The method according to any of claims 12-15, wherein the one or more users include logistics service providers, retailers, and mall and/or warehouse operators.

17. The method according to any of claims 12-16, wherein the one or more coordinated logistics schedules generated for the logistics service providers, retailers, mall and/or warehouse operators

include one or more vehicle routing schedules, parcel tracking schedules and dock appointment schedules.

18. The method according to claim 16 or 17, wherein when optimizing schedules for a logistics service provider, the at least one private optimizing module takes into consideration human factors of executing the schedules.

19. The method according to any of claims 12-18, wherein the terminating conditions include:

- no improvement can be obtained to resulting schedules;
- a given time limit exceeds; and/or
- a maximum number of iterations has been reached.

20. The method according to any of claims 12-19, wherein the information input by a user to the at least one private optimizing module includes capacity of the user's resources, the user's intended rules, information of delivery requests, and/or the user's initial proposed schedule.

21. The method according to any of claims 12-20, wherein during the step (1) and/or the step (3), a payoff is calculated for each schedule, wherein the payoff is to be minimized for the purpose of optimizing schedules.

22. The system according to claim 21, the payoff is calculated by computing a weighted sum of the total travel time, the total wait time, and the total time violation, or by computing a weighted sum of total travel distance and number of vehicles.

23. A computer program comprising instructions which, when the program is executed by a computer, cause the computer to carry out the method according to any one of claims 12-22.

24. A computer-readable medium comprising instructions which, when executed by a computer, cause the computer to carry out the method according to any one of claims 12-22.