Multi-agent Solution for Business Processes Management of 5PL Transportation Provider

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Abstract. This paper describes a model and technology for business processes management of Fifth Party Logistics (5PL) provider in transportation industry. The proposed model provides formalization of transportation orders' assignment in the form of events able to consider the flexibility of actors' interaction. The solution is based on implementation of overlay networks for actors generated analyzing the variability of orders assignment. The results are illustrated by the description of multi-agent software-as-a-service solution implementing the proposed approach.

Keywords: Multi-agent technology, Fifth party logistics, 5PL, transportation, scheduling, decision making support.

1 Introduction

One of the most up-to-date trends in transportation logistics introduces 5PL (Fifth Party Logistics) concept [1], which is based on implementation of a number of services for customers and shippers provided by the specially designed software platform. 5PL platform is open for new transportation companies and even drivers and helps them negotiating with customers in integrated information space. For example, a new coming taxi driver can use a handheld device to register and start receiving new orders according to his current position and capabilities.

One of the main features of such an approach is high uncertainty in number and time of resources available. Each transportation company or even driver becomes an independent actor with its own objectives and constraints and is motivated mainly by his own interest. This makes it impossible to implement standard approaches for scheduling and business-process managements based on a support of the solid business process for all the orders and executors in the system.

One of the solutions can be close to subject-oriented approach for business processes management (S-BPM), which conceives a process as a collaboration of multiple subjects organized via structured communication [2]. There can be proposed a model for interaction of actors (subjects) in integrated information space of 5PL operator, which can be implemented using multi-agent software. In this paper we describe one of the possible solutions of this problem.

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2 State of the Art

The concept of Fifth Party Logistics (5PL) is introduced by analogy with 3PL that provides the process of outsourcing of transportation resources and 4PL that describes a concept of Lead logistics integrator (still there is no general definition of it in the business world) [1]. 5PL provider owns no transportation resources itself but makes available a special service able to link suppliers and buyers. This service is based on the IT infrastructure, which plays the general role in 5PL business. Customer representatives, transport managers, shippers, carriers, and even drivers become users of a certain IT platform. The purpose of this platform is to allocate incoming orders to appropriate resources, consolidate them improving consolidation and reducing idle time and generate efficient schedules for drivers and vehicles.

This idea is close to the popular SaaS (Software as a Service) business model, according to which software and associated data are centrally hosted on the cloud. Such service becomes attractive for small transportation companies and allows outsourcing dispatching functions for large logistics operators.

Still to ensure high efficiency of 5PL service both for customers and executors in terms of time and costs there is a request to implement modern technologies of business processes management based on decentralized architectures, distributed intelligence and multi-agent technology. This happens because of the increasing number of decision makers, high uncertainty and dynamics of changes, and flexibility of decision making logic. The example of using multi-agent technology for business processes simulation can be found at [3]. Also the described approach generalizes our experience of multi-agent solutions development for transportation logistics [4, 5].

As soon as the information space provided by 5PL software platform can be treated as a complex network of continuously running and co-evolving actors (or subjects), the whole solution can be based on holons paradigm [6] and bio-inspired approach [6]. This paradigm and approach offer a way of designing adaptive systems with decentralization over distributed and autonomous entities organized in hierarchical structures formed by intermediate stable forms. It's implementation in practice requires development of new methods and tools for supporting fundamental mechanisms of self-organization and evolution similar to living organisms (colonies of ants, swarms of bees, etc) [7].

The actors compete and cooperate, coordinate and adapt their behaviors, aggregate their services to users and take various requirements individually. Each event that occurs here can influence the whole network and needs a collaborative reaction from all subjects that take into account personal objectives and constraints of each decision making member. Another requirement for the decision making process based on subject' negotiation is that the final decision can require a complicated and time consuming process of data exchange between the actors. That's why it should be managed to consider time factor and assure functioning in real time.

One of the recent developments in this area [8] introduces featuring a clear separation between the local planning performed by the individual vehicles and the global coordination achieved by negotiation. To solve such a kind of problems there can be implemented a special functionality for a statistical analysis based on recent developments in cross-correlation analysis of non-equidistant time series [9]. The models and methods of such analysis were successfully probated in social management and can be reused for management of multi-agent negotiations.

Also in this area there can be used the event processing techniques [10] for an effective continuous processing of time sensitive data in control centers. This technology deals with the analysis of streams of continuously arriving events with the goal of identifying instances of predefined meaningful patterns (complex events). Event processing offers a variety of special operations that are applied on events (e.g., event filtering, projecting, aggregating, splitting, transforming etc.), and enables a special (the event-driven) interaction model.

In many cases however, real-time awareness provided by event processing is not sufficient; real time actions need to be triggered not only by events, but also upon evaluation of additional background knowledge [11]. This knowledge captures semantic metadata descriptions (the domain of interest), and the context related to critical actions and decisions. Its purpose is to be evaluated during detection of complex events in order to on-the-fly enriched events with relevant background information or to propose certain intelligent recommendations in real time.

In this paper we introduce a model for event-based description of actors' interaction using 5PL provider and formalize a group of key performance indicators (KPIs) that help understanding its efficiency considering the uncertainty and influence of time factor inherent to its business. This approach can help rising the subjects' income and reduction of the decision making time and as a result increasing the service appeal of 5PL software platform for its users.

3 Event-Based Model for 5PL Business Processes Representation

Let us consider a generalized business model where orders (or jobs) w_i are proceeded to actors (or subjects) u_j. Any actor can be assigned to perform any order, incurring some cost that may vary depending on the exact assignment. It is required to perform all the orders by assigning exactly one order to each actor in such a way that the total cost of the assignment is minimized. The centre is introduced as a solid dispatching agent that offers the orders to actors and ensures the effectiveness of the whole system.

The objective of the order agent is to be proceeded by any actor available on time (particular the KPIs can be formulated as "early average absorption"). The actor's objective is to receive the most corresponding orders with the highest relevance.

Let us set the following order lifecycle events, represented by Boolean variables:

$e^*(w_i, t^*_i) \in \{0,1\}$ – appearance of w_i, t^*_i is the time of its appearance;

$e(w_i, u_j, t_{i,j}) \in \{0,1\}$ – offer of w_i to u_j at time $t_{i,j}$;

$e'(w_i, u_j, t'_{i,j}) \in \{0,1\}$ – assignment of w_i to u_j at time $t'_{i,j}$;

$e''(w_i, t''_i) \in \{0,1\}$ – escape of w_i at time t''_i in case of order rejection.

The cost of order w_i execution by actor u_j is $c_{i,j}$. It is determined by the actor and proposed to the center. Let us assume that one actor cannot execute several orders at a time. The allocation problem for this model can be represented as

$$\begin{aligned} &\sum_{i=1}^{N_w}\sum_{j=1}^{N_u} e'\left(w_i, u_j, t'_{i,j}\right)\cdot c_{i,j} \to \min, \\ &\sum_{j=1}^{N_u} e'\left(w_i, u_j, t'_{i,j}\right) = 1, \quad i = 1..N_w, \end{aligned} \tag{1}$$

$$\sum_{i=1}^{N_w}\sum_{j=1}^{N_u} e^*\left(w_i, t^*_i\right)\cdot e'\left(w_i, u_j, t'_{i,j}\right)\cdot \left(t'_{i,j} - t^*_i\right) \to \min\,, \tag{2}$$

where N_w is the total number of orders and N_u is the total number of actors.

For the order flow $e^*\left(w_i, t^*_i\right)$ there should be developed a strategy (schedule of offers) $e\left(w_i, u_j, t_{i,j}\right)$ for a set of u_j that will reach (1) and (2).

From the other side, each actor considering the order flow $e\left(w_i, u_j, t_{i,j}\right)$ should decide on the strategy $e'\left(w_i, u_j, t_{i,j}\right)$ that comes out at

$$\forall u_j : \sum_{i=1}^{N_w}\sum_{k=1}^{N_u} e\left(w_i, u_j, t_{i,j}\right)\cdot e'\left(w_i, u_j, t'_{i,j}\right)\cdot \left(1 - e'\left(w_i, u_k, t'_{i,k}\right)\right)\cdot c_{i,j} \to \max\,. \tag{3}$$

In case the actor starts execution as soon as the order is allocated the following limitation is valid:

$$\forall u_j : \sum_{i=1}^{N_w}\sum_{l=1}^{N_w} e'\left(w_i, u_j, t'_{i,j}\right) e'\left(w_l, u_j, t'_{l,j}\right)\cdot \left(1 - \theta\left(t'_{l,j} - t'_{i,j}\right)\cdot \theta\left(t'_{i,j} + \Delta t_{i,j} - t'_{l,j}\right)\right) = 0\,,$$

where $\theta(x)$ – Heavyside step function [12]: $\theta(x) = \begin{cases} 0, x < 0 \\ 1, x \ge 0 \end{cases}$.

The problem (1, 2, 3) is introduced as a problem of "proactive allocation". Its direct solution is not possible as soon as the number and availability time frames of resources and orders changes with time. To prove it there can be specified the following logic. Firstly, the statement (3), being summarized by u_j, results in a contradiction with (1). Secondly, to solve (1) one needs to fix the number of events considered, but at any moment of time t^* there is no information about the events $e^*\left(w_i, t^*_i\right) : t^*_i > t^*$, and there cannot be proposed any substantial approach on how to pick-out the orders w_i accepted by 5PL platform for scheduling in real time.

So there should be developed new approaches for project management of scheduling business processes.

The following challenges can be specified for a 5PL provider:

- attraction of customers and executors in order to increase the number of options for each order allocation;
- enforcing interaction conditions to support competition and cooperation between the users of 5PL platform, which is beneficial for them;
- estimation and analysis of key performance indicators (KPIs) of 5PL business processes in order to increase the level of service.

Considering the features of the proposed model and in reliance on the theory of constraints there can be formalized the following KPIs:

Total costs of the orders being allocated to a certain time frame:

$$C = \sum_{i=1}^{N_w} \sum_{j=1}^{N_u} e'\left(w_i, u_j, t'_{i,j}\right) \cdot c_{i,j} , \quad (5)$$

Average resources utilization:

$$L = \frac{1}{N_u} \sum_{i=1}^{N_w} \sum_{j=1}^{N_u} e'\left(w_i, u_j, t'_{i,j}\right) \cdot \Delta t_{i,j} , \quad (6)$$

where $\Delta t_{i,j}$ – is the duration of loading of u_j by w_i in case of corresponding allocation.

Bound order set:

$$\Theta = \frac{1}{N_w} \cdot \sum_{i=1}^{N_w} \sum_{j=1}^{N_u} e^*\left(w_i, t^*_i\right) \cdot e'\left(w_i, u_j, t'_{i,j}\right) \cdot \left(t'_{i,j} - t^*_i\right). \quad (7)$$

Statements (1 – 3) together with KPIs (5 – 7) form the event-based model for 5PL provider and can be used in multi-agent systems for simulation and evaluation of business processes in transportation logistics.

4 5PL Business Processes Management Technology

Functioning of 5PL provider contains a number of interrelated business processes for supply chain members, which proves the advantages of application of subject-oriented approach in this area. While developing multi-agent solutions for transportation logistics [4] we usually have specified two groups of agents representing demands and supplies and negotiating in order to find trade offs. For example, there can be introduced the driver agents that strive to maximize utilization and the order agents that try to allocate at lower costs.

For each group of agents there can be proposed a separate business process, which includes a number of states connected by the relations of precedence. The order can be input into the system, stay for a while in events queue, become scheduled to a certain resource, proceed to execution state after it starts and finalize being done or rejected in case of exception. Each driver repeats iteratively the states of being free or busy with order with some intermediate states of pick-ups, drops and idle moves. The generalized scheduling problem involves determination of a consistent combination of these states across the planning horizon in the near future.

Special aspects of 5PL service make it necessary to consider these business processes from a different point of view. In case of drivers' flexibility to take a certain order or reject it there can be evaluated no consistent planning horizon – the time interval of resources availability and the list of orders to be done. The center offers the orders to appropriate resources with no guaranty that they will be accepted for execution. That's why it should evaluate and analyze the probability of orders acceptance and allocation.

In transportation logistics much is determined by the network of geographical locations and roads. In case the order is associated by a location of appearance or pick-up the probability of its allocation is dependent upon the density of executors in the near area. Considering the KPIs (5 – 7) the same approach can be introduced in terms of time. The higher is the number of resources free from loading and waiting for new orders at a certain location, the higher is the probability of orders being allocated at this point.

Still we should consider two constraints:

- executors waiting too long would escape (as soon as the 5PL platform is open for entry and exit);
- drivers would congregate at locations with the highest density of orders (this is valid for taxi business: e.g. taxi drivers are attracted to airports and tourist sights).

Both factors influence the service level and lower the force of attraction of 5PL provider. To overcome this challenges the dispatching center of 5PL provider should attract the actors' interest and aggregate drivers at proper areas.

The event flow of orders' appearance $e^*(w_i, t^*_i)$ in non-equidistant. According to the statement (3) of the problem definition there should be the minimum time between order income and assignment.

The way to solve this problem is to specify such an event flow of assignments $e'(w_i, u_j, t'_{i,j})$ that will reduce the variability of assignments in reaction to the irregular event flow of incoming orders with minimum waiting time. This is similarly to providing line balancing in production project management. One of the solutions runs out of the combination of (6) and (8) – we suggest introducing the rhythmical assignment:

$$\rho'_k(k \cdot \Delta\tau) = \sum_{i=1}^{N_w} \sum_{j=1}^{N_u} e'(w_i, u_j, t'_{i,j}) \cdot \theta(k \cdot \Delta\tau - t'_{i,j}) \cdot \theta(t'_{i,j} - (k-1) \cdot \Delta\tau) \to const. \quad (8)$$

where $\Delta\tau$ is the time sampling interval,
N_w is the total number of orders and N_u is the total number of actors,
and $\theta(x)$ – Heavyside step function (introduced above).

This schedule of assignments sets up the moments, before which the center needs to determine the options and send the offers to the actors according to the priority of waiting time. The statement (8) can be used in practice to prioritize the orders taken out for scheduling.

Therefore the set of offers $e(w_i, u_j, t_{i,j})$ can differ for each actor, and the same orders can be offered for several different actors. In addition to this the representation of the current transportation network for each actor can vary as soon as the center provides limited information about the orders and the current transportation situation. Let us call such subset of data a Virtual Overlay Network – a graph, which contains nodes representing geographical locations and links simulating distances between them. For every node there can be specified a set of orders with the same pick-up point corresponding to this node. The virtual overlay network can be specific for each actor describing the current situation in the individual scene and change with time.

This concept is given by analogy with peer-to-peer (P2P) networks in telecommunications where an overlay network is usually a computer network which is built on the top of another network. Nodes in the overlay can be thought of as being connected by virtual or logical links, each of which corresponds to a path, perhaps through many physical links, in the underlying network.

One of the possible technologies implementing virtual overlay networks is P2P outsourcing [13] based on the series of virtual auctions among the executors. Getting the incoming events of orders' appearance the centre generates offers or bids $e(w_i, u_j, t_{i,j})$ to the actors (the candidates are determined according to geography, their current position and adaptive planning horizon). One order can be offered to several actors. The actors that have received a number of offers can choose the most profitable for them and commit the assignments $e'(w_i, u_j, t'_{i,j})$. This negotiation scheme allows putting into practice the schemes that force competition among the actors (to win the most profitable order) and cooperation between them (by creating temporal groups in the areas of orders' high frequency). In such a way the center does not distribute all the orders directly to actors, but initiate a competition between them.

It should be mentioned, that generating of $e(w_i, u_j, t_{i,j})$ means not only developing a number of bids (what order to offer to which actor), but also decision on time when to send them. Thus the center can hold back recent orders and give higher priority to the orders that are waiting for a long time. To make this decision the center should consider the indicators, introduced above.

The proposed approach is illustrated in Fig. 1. In the given example the order 5 (that came later than others) is reduced from the view of Actor 1. Besides the set of orders 2, 3, and 4 are hidden from Actor 2. As a result both actors are interested in order 1. Is should be mentioned that the hidden data will appear for the actors with time, so in any case they retain an option to wait till the situation changes.

Fig. 2. describes the results of simulation carried out for a transportation network. Several strategies were implemented to compare directive allocation with management based on constructing of overlay networks. The first graph represents the dependence of effectiveness of orders allocation (ratio of total load time to total idle time). The results are quite close depending on the number of locations. The second graph presents average decision making time – one can see that introducing overlay networks allows to minimize the complexity of decision making and as a result to reduce time spent by orders to wait for an allocation, which supports the statement (7). Average decision

making time characterizes time frame between the time of appearance and assignment for each order. In case it is lower the KPI for the bound orders set (7) is minimized.

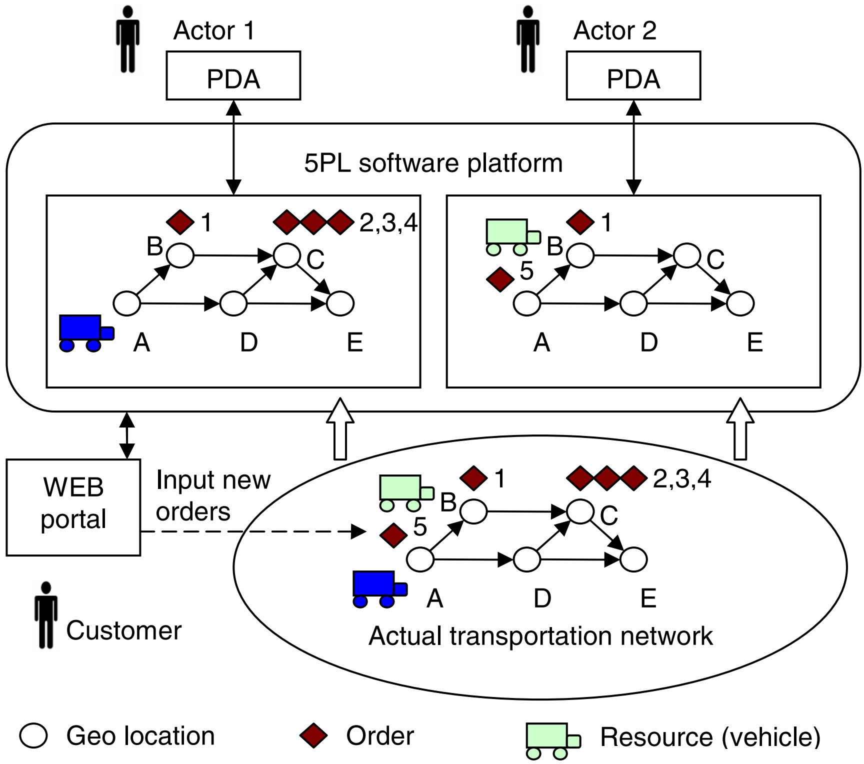

Fig. 1. 5PL provider software platform architecture: Both actors-executors are stimulated to compete for order in location A

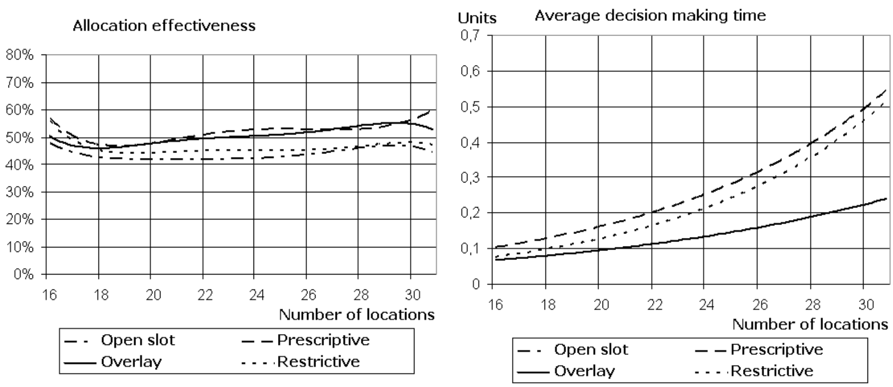

Fig. 2. Simulation results

5 Maxoptra Solution

The described approach was implemented in the Maxoptra Web based solution (see Fig. 3) that functions on a Software as a Service (SaaS) basis and is available from any PC with Internet access. Scheduling screen is presented in Fig. 4.

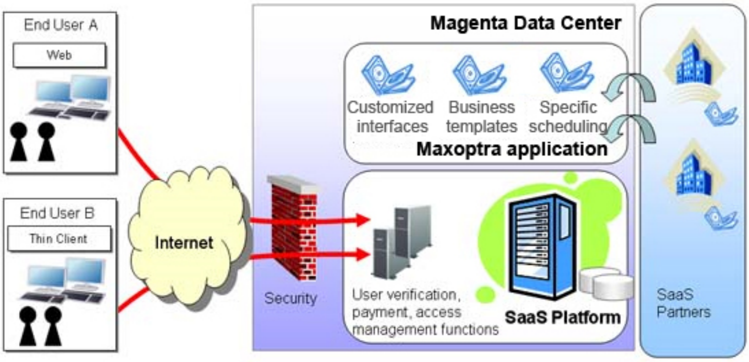

Fig. 3. Maxoptra logical architecture

The Maxoptra functionality includes:

- order entry: manual order file upload and integration with an existing order management solution;
- manual or automatic jobs scheduling;
- orders allocation to vehicles and optimal vehicle route creation;
- dynamic and batch scheduling support;
- adjustable scheduling objectives: cost reduction, mileage reduction, optimized own resource utilization, etc.;
- manual plan adjustment by means of a ‘drag and drop’ mechanism;
- vehicle capacity planning;
- visualization of: delivery routes on the map, real time mileage and cost KPIs;
- workflow management, printed manifests and management reports;
- planned vs. actual analysis of: vehicle locations, delivery times, followed routes;
- proof of delivery signature captured and password protected administration.

Available resources (including drivers and vehicles) and customer data is captured in a knowledge base (ontology). It is very important to capture statistics and link it to the knowledge about orders and resources (e.g. certain VIP clients prefer to take specific drivers, some drivers prefer certain locations or are not allowed to visit specific locations, etc.) This can be used in order to introduce special client management and pricing schemes and enrich the agents decision making logic.

One of the features is that the drivers are included into the scheduling process not only as providers of actual data, but also as decision makers. When several orders can be scheduled to one driver these can be sent to his handheld device. So that the driver can make a choice between several orders or consolidate them if it is possible. As soon as the same proposals can be sent to different drivers the system can initiate a competitive process of orders assignment (auctioning). In addition to this, the data flow generated for each driver forms a virtual overlay network for him. The number and sequence of orders sent to drivers can be used for manipulation. In such conditions drivers are free to make their own decisions to some extent, but, nevertheless, stay under the dispatcher's control.

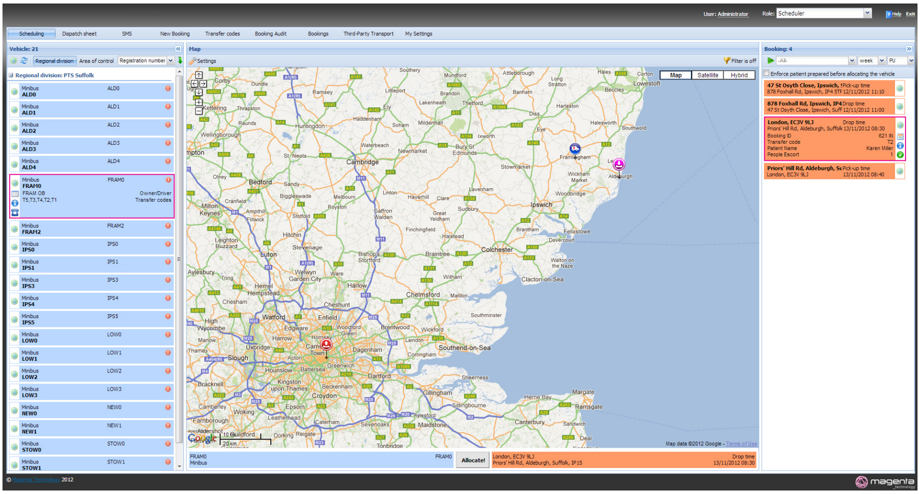

Fig. 4. Scheduling screen

As the result the Maxoptra solution provides:

- advanced booking facilities for customers to enable a quick, streamlined booking process including return bookings;
- automatic real-time dynamic scheduling of orders to ensure effective and cost efficient transportation operations through the following: notification of optimum booking preferences at the time of booking; real time tracking of vehicles' location; fleet optimization based on a variety of criteria to minimize empty mileage and maximize vehicle capacity utilization, reduce operational costs, and meet agreed customer service levels;
- a secure yet easy way to access and manage data through the web, available for vehicle suppliers (to access vehicle details and data on resource availability).

6 Conclusion

In this paper we have proposed a solution for business processes management of Fifth Party Logistics (5PL) provider in transportation industry. This solution is based on multi-agent approach and introduces the event-based model for simulation and analysis of 5PL transportation logistics, the technology for transportation orders proactive allocation based on the implementation of virtual overlay networks, and the multi-agent software solution that illustrates the validation.

One of the main benefits of the proposed solution is that it considers the flexibility of actors' interaction. The users of 5PL software platform act as independent decision makers and require subject-oriented business processes management to be supported. In this paper we have considered some special aspects and peculiarities of such an approach and provided a technology of how to implement it in practice.

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