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Goods distribution management in city logistics environment: A systemic approach

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Abstract

The routing plan of a delivery fleet is usually developed *a priori* and provides an optimal (or near optimal) way of serving customers by taking into account certain constraints, such as vehicle capacity and delivery time windows. However, such plans may not cope adequately in a city logistics environment, in which unexpected events often occur during delivery execution (e.g. adverse traffic conditions). These events may lead to delays, higher costs, and inferior customer service. This paper presents the development and evaluation of a real-time fleet management system that handles such unforeseen events by using advanced traffic forecasting techniques and rerouting strategies coupled with telematic technology. The system monitors the delivery vehicles in real time, detects deviations from the initial distribution plan, and adjusts the schedule accordingly, by suggesting effective rerouting strategies. The system has been tested in real-life cases and the results show that delivery performance is enhanced significantly and customer satisfaction is improved accordingly.

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1 Freight delivery in a city logistics environment

Freight distribution arguably accounts for a significant portion of the total costs of logistics [1]. Techniques to minimize distribution costs typically focus on the development of near-optimal distribution plans using various types of vehicle routing algorithms. Urban distribution, however, is more susceptible to unexpected costs and delays that arise during the execution of the delivery plans due to unforeseen adverse conditions, such as traffic delays, vehicle breakdowns, road works, customer depot overload, and so on. One can distinguish three main sources of incidents:

1. *Incidents originating from the clients served:* Typical examples include order cancellation, delivery time changes, new customer requests, lack of unloading or parking space, and changes of order of deliveries and/or destination.
2. *Incidents from the road infrastructure and environment:* Traffic congestion, road construction, flea markets, rain or snow and so fourth.
3. *Incidents that arise from the delivery vehicles:* Typical examples include accidents and/or mechanical failures.

Each category of dynamic incidents has a direct effect on delivery execution. Unexpected events that stem from the road infrastructure and the environment usually result in increased vehicle travel times, whereas incidents caused by the clients, result either to increased service times, and vehicle re-routing or no service at all. Finally, for the case where the source of incident arises from the vehicle itself, the effect is usually partial or no delivery at all [20].

The use of an initial distribution plan, although necessary, is by no means sufficient to address such unexpected events that may have adverse effects on system performance [8]. Advances in mobile and positioning technologies have allowed the development of fleet management systems that enable freight carriers to monitor their fleet in real-time and to improve the performance of the delivery network by mitigating some of the aforementioned problems. However, the systems based on these technologies are not typically designed to address unforeseen events in a systemic fashion [9].

In the absence of systems capable of ‘isolating’ the part of the schedule affected by the unexpected event, to minimize the disturbance to the overall schedule, interventions are typically performed manually (for example, through voice communication between drivers and the logistics manager) and the quality of decisions taken is naturally affected.

Existing work that deals with the dynamics of the distribution process includes mainly algorithmic approaches that focus on solving the Dynamic Vehicle Routing Problem (DVRP) [2]. In addition, various systems have been developed for fleet monitoring and incident detection in urban environments [see 10, 11, 12, 13, 14, 15, 16]. However, most of these systems typically focus on handling client orders that arrive during the execution of the delivery plan and need to be assigned to moving vehicles [17, 18, 19, 20]. Dynamic ordering, however, is only a subset of unexpected events that may affect urban distribution performance. The work presented in this paper addresses a different problem of dynamic fleet management in which the distribution plan needs to be adjusted in real-time to accommodate changes in a multitude of uncontrollable environment variables.

The remainder of the paper is organized as follows. Section 2 presents the main requirements for dynamic incident handling. Section 3 gives an overview of the architecture of the real-time fleet management system whereas Section 4 analyses the operation of the system and shows results from its implementation in a third party logistics (3PL) company. Concluding remarks as well as the main benefits from the use of the system are included in Section 5.

2 User Requirements

In order to define the main attributes of the real-time fleet management system, a three-phase user requirements elicitation process [5] has been followed. The first phase (Phase 1) comprises an analysis of the transportation and logistics industry together with insights from telematics industry specialists. Phase 2 comprised the core (quantitative) analytical phase and included a survey (on-line questionnaires) focusing on the needs for real-time fleet management services with 73 responses. The output of this phase leaded to the choice of these services with a factor importance hierarchy. Finally, Phase 3 sought to examine the validity of Phase 2 results, via qualitative in-depth interviews with 15 logistics directors from Greece.

Table 1: Methodological framework for user requirements elicitation

Phase 1	a) Extensive literature review of the urban freight distribution operations; b) Insights from telematics industry specialists;	**Output:** in-depth insight into transportation industry; platform established for Phase 2 research
Phase 2	a) On-line questionnaire b) Data analysis	**Output:** actual choice of real-time services with a factor importance hierarchy
Phase 3	a) qualitative in-depth interviews with 15 logistics directors from Greece	**Output:** validation/refinement of Phase 2 results

The results from this process revealed that existing fleet management systems can fulfil only a subset of the requirements expressed by logistics operators. These requirements involve:

- Monitoring of the geographic location of vehicles in real time: This is a typical requirement, which is fulfilled through the use of satellite and terrestrial communication systems.
- Generating *a posteriori* reports of vehicle performance: This helps fleet managers to quantify the overall performance of the distribution operation, identify and correct problems in deliveries, and reduce operational costs.
- Generating proof-of-delivery (POD) statements upon completion of load delivery.

However, a number of other requirements cannot be effectively met by existing systems. These include:

- The ability to intelligently reroute a truck that is in danger of missing delivery time windows, for example due to adverse traffic conditions, in order to minimize the adverse impact on overall service quality.
- The ability to deal with vehicle breakdowns by rerouting nearby vehicles to come in assistance of the truck that is facing problems: That is, in case of mechanical failures or accidents, it is important to secure an alternative way to deliver the products of an immobilized vehicle. If a backup vehicle is not available at the depot, then a vehicle(s) that has both adequate load capacity and time availability should be identified to meet the immobilized vehicle, load its goods, and continue the delivery.

The aforementioned requirements were synthesized into design specifications that collectively define the entirety of the real-time fleet management problem. The following section provides an overview of the architecture of this system.

3 Overview of the real-time fleet management system

The proposed system depicted in Figure 1 comprises of three subsystems namely back-end, wireless communications, and front-end that include six modules that are analyzed below.

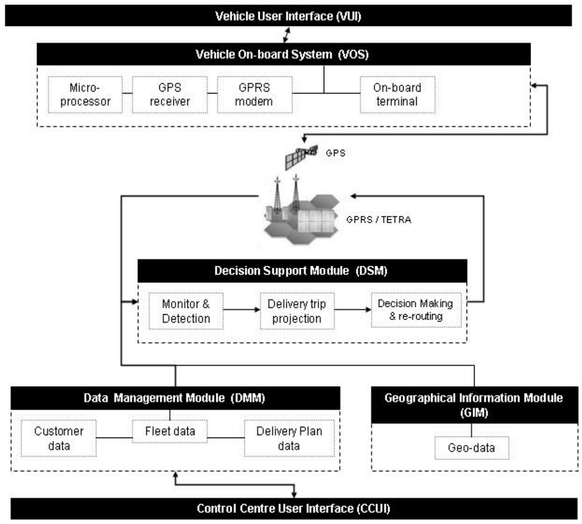

Figure 1: Architecture of Real-Time Fleet Management System for Dynamic Incident Handling

Back-end subsystem

The back-end system incorporates typical components that can be found in a fleet management system, as well as the module that is responsible for dynamical incident handling. The latter embraces a decision support mechanism that aims at supporting logistics managers by tackling dynamic events whenever needed. The modules included in the back-end are:

Geographical Information Module: GIM manipulates and maps spatial data necessary to support the Decision Support Module. The cartographic information required is derived from vector maps.

Data Management Module: DMM contains all static and dynamic information (spatial and non-spatial) related to clients, vehicles, and distribution schedules.

Decision Support Module: DSM computes and recommends all required real-time adjustments to the delivery plan, in order to meet preset goals taking into account the system's dynamic state. DSM implements the incident handling mechanism that consists of three stages: a) Monitor & Detection b) Delivery Trip Projection and c) Decision Making & Rerouting. The *Monitor & Detection component is* responsible for monitoring the dynamic state of each vehicle in the fleet (geographical position, speed, and inventory) and detecting possible deviations from the original delivery plan. The *Delivery Trip Projection component* uses a travel time estimation method in order to identify whether the remaining time from current position to the clients not yet served is less than or equal to the upper limit of the related time windows. The *Decision Making and Rerouting component* is activated when a vehicle delay or breakdown is detected and single or multiple vehicle rerouting is required. The component incorporates new vehicle routing algorithms that use the state of the delivery vehicles as input and perform the necessary revisions to the non-executed part of the delivery plan.

Control Centre User Interface: CCUI allows the route planner to interact with various functions of the system. Via this interface, information regarding the status of each vehicle is communicated to the planner in order to provide a complete view of the fleet status and the necessary data for decision making.

Wireless communication subsystem

The wireless communication sub-system consists of two parts: a) The *mobile access terrestrial network*, which is responsible for the wireless interconnection of the back-end system with the front-end on-board devices, and b) the *positioning system*, which is responsible for vehicle tracking.

The mobile access terrestrial network can be based on any of a number of existing or emerging mobile technologies. GPRS, TETRA, and UMTS can provide always-on, packet-switched connectivity and high-speed data rates. GSM is a mature technology however it cannot support high-data transmission effectively. GPRS combines high data rates, always-on connectivity, mature technology, and has also been used in fleet management systems. As far as TETRA is concerned, it is worth mentioning that it provides much better security than GPRS, as well as it supports point-to-multipoint voice broadcasting. UMTS is an emerging standard and its use cannot be assessed prior to thorough validation testing. We have decided lastly to use a GPRS network as it can support efficiently real-time transfer of data.

As far as the positioning system is concerned, positional accuracy of less than 100m is deemed acceptable for urban distribution (accuracy requirements can of course be relaxed in non-urban settings). An analysis of the technologies that can be used for location identification is provided in [6]. GPS appeared to be the most preferable solution, since it is a globally available, free-of-charge system.

Front-end subsystem

The front–end system consists of the telematic equipment that supports real-time communication and data processing, as well as a portable data terminal for use by the driver. The selection of the front-end device is important both from a user interface and from a computational performance perspective. A terminal that fulfils the requirements of the system combines ruggedized design, superior computational power, high-resolution display, wireless networking capabilities, and integrated support for peripherals. The modules included in the front-end are:

Vehicle On-board System: VOS incorporates the telematic equipment that supports real-time communication and data processing, as well as a portable data terminal for use by the driver. The system collects all data necessary to dynamically monitor a range of operational parameters relating to vehicle performance, location, and load information.

Vehicle User Interface: The decisions of the route planner are communicated to the vehicle and presented to the driver via the on-board system interface. This in-vehicle computer system allows the driver to have a bi-directional communication with the control centre by which he/she receives rerouting decisions, provides proof-of-delivery information, and alerts the control centre in case of unforeseen events.

4 System evaluation

The system has been tested extensively in a large Greek third-party (3PL) delivery company (DIAKINISIS S.A.). Initially the main operations of the 3PL carrier are described. Subsequently, the set of pilot testing parameters as well as the Key Performance Indicators (KPIs) that have been used to measure the system's performance are analyzed. The actual results from the system implementation are also discussed.

4.1 Description of company's urban distribution operations

Diakinisis S.A. is one of the largest third party logistics (3PL) companies in Greece. Its core business focuses on the storage, order management, invoicing, and distribution of goods for a large number of commercial and manufacturing companies. It is situated about 15km from the Athens and Piraeus city centers where more than 60% of its customers are concentrated. Every day, more than 150,000Kg of goods are distributed to an average of 300 clients, located at distances ranging from 10 to 40km (Attica Prefecture) from the company's main warehouse. The orders are delivered using an outsourced fleet of 80 vehicles. The company uses a customized software solution for the routing of these vehicles.

Due to the highly congested urban environment of Athens and Piraeus, the company faces various problems from unexpected events (mainly travel and service time delays), that may adversely affect the delivery process (e.g. violations of delivery time windows). Currently, when a delay occurs, interventions are often performed through voice communication between the driver and the dispatcher.

Oftentimes the effectiveness of these interventions is limited since there is no systemic way of taking into consideration the multitude of involved parameters, such as the importance of the remaining clients, time windows restrictions and so on. For that reason, we decided to test the real-time fleet management system in incident handling scenarios and evaluate its performance.

4.2 Key Performance Indicators (KPIs)

We assessed the effectiveness of the proposed system by monitoring certain key performance indicators. The KPIs' definition took into account related results in performance measurements for logistics and distribution management [3]. The resulting indicators are presented in Table 2. For evaluation reasons, performance indicators that monitor operational costs were also included.

Table 2: Key Performance Indicators for the system's pilot testing

Key Performance Indicators	
Customer Service	Number of visited customers
	Importance (weight factor) of visited customers (1-10 Scale)
	Total weight of parcels delivered (kgr)
	Total number of time window violations
Operational Cost	Total distance traveled (km)
	Total travel time (hr)
	Total service time (hr)

4.3 Design parameters for pilot testing

The design of the pilot test was based on certain design parameters presented in Table 3. According to previous studies [2] these parameters affect the performance of the urban freight delivery process.

Table 3: Design parameters of the field experiment

Design parameters		*Levels*
Area	Urban	city centre
	Suburban	suburbs
Traffic	Light	high traffic flow
	Heavy	low traffic flow
Type of time windows	Accounting only the driver's shift	8.00 am- 2.00 pm
	Windows at each delivery point	posed by customers
Number of time windows	High	time restrictions in many customer
	Low	time restriction in few customer
Range of time windows	Narrow	9.00 am - 11.00 am
	Wide	9.00 am - 1.00 pm

We have adopted a field experiment approach to perform the pilot testing [4]. The eight test cases which are presented in Table 4 were designed by following the Design of Experiments (DoE) fractional factorial method [7].

The actual test of the system's performance was performed as follows. Two vehicles were engaged simultaneously in each test. The first vehicle attempted to perform the daily schedule as originally planned, whereas the second vehicle followed the directions provided by the real-time fleet management system. This approach could provide quite safe results as both vehicles were planned to visit the same delivery points under identical circumstances.

Table 4: Test case scenarios

Test case	*Area*	*Traffic*	*Type of time windows*	*Number of time windows*	*Range of time windows*
1	Sub-urban	Heavy	Driver’s shift	N/A	N/A
2	Sub-urban	Light	Driver’s shift	N/A	N/A
3	Urban	Heavy	Driver’s shift	N/A	N/A
4	Urban	Heavy	Customer’s restrictions	Small	Relaxed
6	Urban	Heavy	Customer’s restrictions	Small	Tight
6	Sub-urban	Light	Customer’s restrictions	High	Relaxed
7	Urban	Heavy	Customer’s restrictions	High	Tight
8	Sub-urban	Light	Customer’s restrictions	High	Tight

In order to force delays, the delivery period was artificially set to be less than the time usually required for a vehicle to complete the delivery plan. For instance, the delivery period was set between 8.30 am-12.30 pm, although the time usually needed to complete the delivery plan ranges from 8.30 am to 2.00 pm. In this way, we forced the incident handling system to reroute the second vehicle. At the end of each testing period, we computed the KPIs, of Table 2, for each vehicle.

4.4 System’s operation and results

A typical operation of the real-time fleet management systems is as follows. Figure 2a depicts the control centre user interface at an initial stage, when the travel estimation technique does not detect any deviation from the initial delivery plan (the column, which depicts the estimated arrival time for each customer - light grey). After a vehicle has served a number of customers, the system detects several time violations for non-served customers (certain cells of the column become dark grey), and proposes a rerouting plan (i.e. a different way for visiting the remaining customers). The new delivery plan is transmitted to the driver through the on-board terminal (Figure 3).

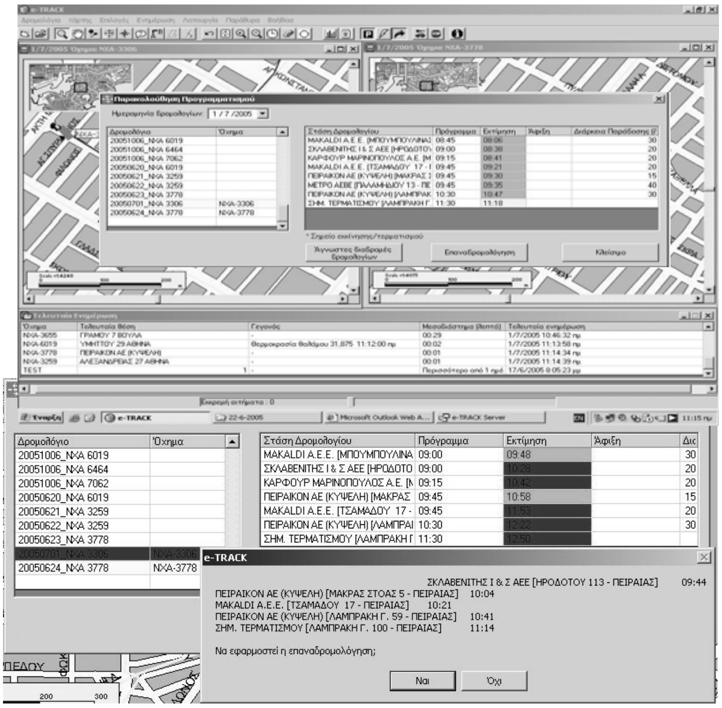

Figure 2b: Detection of delivery time violation and rerouting plan

Figure 3. On board terminal

An important finding from this pilot test has been the impact of time windows on the system's performance. Indeed, in the first three cases (Tests 1, 2 and 3) in which only the restriction of the driver's shift has been applied, the total number of served customers by Trucks A & B was almost equal. In Tests 4, 5, 6, 7 and 8, which included customer time windows (in addition to the driver's shift), the system performed better (in terms of customers served) and succeeded in reducing time windows violations.

The number of customers in the initial plan is another important issue. The higher the number of customers, the better the performance of the system becomes. This can be seen in Cases 1, 5, and 7 in which Truck B that followed system's directions visited most of the customers, and, in particular those with higher importance.

Figure 4 shows the customer service achieved for each test case. Customer service in each schedule was quantified by a factor (from 1-*less important* to 10-*very important*) according to the type of the customer and its importance. Based on this, in order to evaluate the customer service achieved by each vehicle of a certain test, we calculated the ratio derived by the sum of weights of customers visited by each truck over the total weight of all customers in the specific delivery plan (Equation 1).

$$CS_j = \frac{\sum_{i \in S_j} w_i}{\sum_{i \in S_T} w_i} \times 100 \quad j = 1, 2, ...n \qquad (1)$$

where

S_j is the set of customers visited by truck j

S_T is the entire set of all customers in the route

For all test cases, the vehicle that followed the directions provided by the real-time fleet management system (Vehicle B) provided higher customer service. For Vehicle A the average customer service for all tests reached 63.8% whereas for Vehicle B the customer service was 79.8%. Table 5 presents the results for each test case in detail.

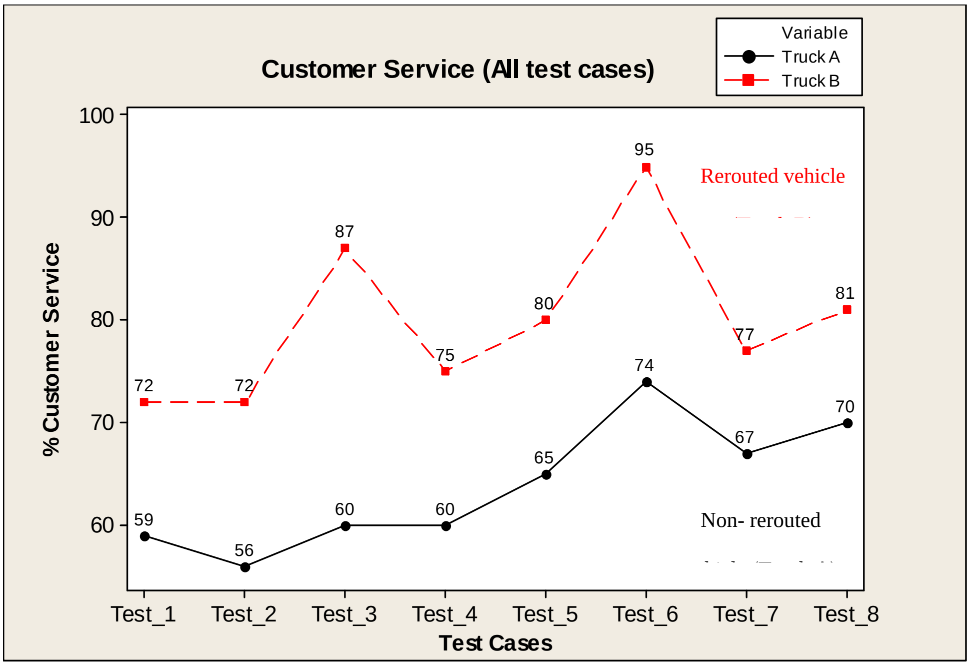

Figure 4: Results of customer service in all test cases

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Table 5: Results from the pilot testing in DIAKINISIS S.A

Test case	*Type of windows*	*Number of scheduled customers*	*Number of visited customers*		*Importance (weight) of visited customers*		*Total weight of parcels delivered (kgr)*		*Total distance traveled (km)*		*Total travel time (hr)*		*Total service time (hr)*		*Total Customer Service (%)*	
		Truck A & B	*Truck A*	*Truck B*	*Truck A*	*Truck B*	*Truck A*	*Truck B*	*Truck A*	*Truck B*	*Truck A*	*Truck B*	*Truck A*	*Truck B*	*Truck A*	*Truck B*
1	Driver's Shift	25	14	18	84	102	1112	1546	53,32	55,99	02:06	02:10	01:24	01:20	**59**	**72**
2	Driver's Shift	9	5	6	29	45	645	737	36,32	41,99	01:12	01:26	02:18	02:04	**56**	**72**
3	Driver's Shift	9	5	6	33	41	800	1045	32,14	38,45	01:55	01:53	02:05	02:07	**60**	**87**
4	Customer's restrictions	7	4	5	29	36	2012	2089	31,56	37,09	02:05	02:21	01:25	01:09	**60**	**75**
5	Customer's restrictions	25	15	22	87	106	2253	2801	59,80	67,90	02:58	03:08	03:02	02:52	**65**	**80**
6	Customer's restrictions	6	5	5	29	37	381	641	39,30	40,60	01:29	01:32	02:31	02:28	**74**	**95**
7	Customer's restrictions	21	13	15	70	81	845	925	46,67	43,78	02:28	02:21	01:32	01:39	**67**	**77**
8	Customer's restrictions	5	3	4	26	30	703	774	27,46	31,76	01:24	01:32	01:36	01:28	**70**	**81**

Note : - Truck A follows the predefined delivery schedule

- Truck B follows the directions provided by the real-time fleet management system

5 Conclusions

This paper proposed a system for dynamic incident handling with emphasis on vehicle delays. The system monitors the delivery vehicles in real time, detects deviations from the initial distribution plan, and adjusts the schedule accordingly, by suggesting effective rerouting strategies. The system has been tested in real-life cases and the results show that delivery performance is enhanced significantly and customer satisfaction is improved accordingly. Indeed the 3PL company, we cooperated with, recognized various strategic benefits such as real-time decision making, increased customer service, as well as operational benefits such as reduction of fleet management cost and dynamic incident handling capability.

Limitations of the proposed system include: a) the positioning technology used. Indeed if the vehicle does not have a clear sky view, the system is unable to track the vehicle and this has a cascading effect on estimating the expected arrival time on the remaining customers and b) user acceptance, mainly by the truck drivers, which were never exposed to a similar IT-augmented way of executing deliveries in the past and faced certain problems not only in use, but also in accepting that a control centre monitors (“watches over the drivers) the delivery in real-time.

Finally, we also consider that this real-time fleet management system, presented in this paper, may be employed by other scholars to develop focused versions of our system emphasizing on particular urban transportation applications. Indeed, researchers may develop systems for emergency services, couriers, rescue and repair services as well as taxi cab services. In each case, the main characteristics of the system as well as its functionality will be targeted to each application domain. For example, in the case of courier services, other requirements could be taken into account such as the need for pickup and delivery instead of the cases that have been developed in this research, which incorporate only delivery processes. Of course, the generic properties of the real-time fleet management system (i.e. incident handling by using dynamic travel prediction methods and rerouting algorithms), as specified in this research, will still be applicable in these applications. Hence, our system may be perceived as a superset of the others, bequeathing the generic real-time fleet management characteristics and design process guidelines to them.

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