DYNAMIC MODEL-BASED FOR INTELLIGENT TAFFIC OPTIMIZATION INSIDE SEAPORT TERMINALS

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ABSTRACT
This work proposes a graphical model-based for traffic optimization of Intelligent and Autonomous Vehicles (IAVs) inside confined seaport terminals. The considered IAVs are used for the routing operations of containers. From the graphical representation, static or dynamic destinations can be reached using optimal trajectories. In order to reach the target by the $(n+1)^{th}$ IAV, the proposed algorithm gives the optimal path from the road network containing *n* IAVs. This algorithm takes in consideration the position, the speed, and the status of each IAV. Finally, a co-simulation is done using an industrial virtual port simulator. This work is done in the framework of the European project InTraDE (Intelligent Transportation for Dynamic Environment).

Keywords: Dynamic Graphical modeling, Maritime ports, Traffic Network, Optimal path, Intelligent and Autonomous Vehicles

1. INTRODUCTION

In the last decade, the seaport areas have been modernized according to the world growth. One of the main problems of the development in the ports and maritime terminals is the internal traffic management. Nowadays, the almost goods are transported using containers, because they have been designed for easy and fast handling. After arrival at the port, the containers are transferred in part to logistic area in optimal time. Automatic transport solution has been implemented by different ports from the North West Europe such as Rotterdam, Düsseldorf and Hamburg, to automate the handling of goods using Automated Guided Vehicles (AGVs). This solution has resolved some relative internal traffic issues, although it has highlighted several limitations, where these vehicles should not adapt to their surrounded environment.

Thus, one of the contributions of InTraDE project (http://www.intrade-nwe.eu) is to improve the traffic management inside confined space by developing a safe and Intelligent Transportation System (ITS) (Crainic, Gendreau, and Potvin 2009) using Intelligent and Autonomous Vehicles (IAVs). The developed ITS operates in parallel with virtual simulation software (http://www.oktal.fr) allowing a robust and real-time supervision of handling and routing operations.

As a part of InTraDE project, a dynamic graphical model for road network inside ports is proposed. In order to achieve the routing missions with safety conditions, a supervision schema of an ITS inside a confined space is proposed in Khalil, Merzouki, and Ould-Bouamama (2009). This supervision model, regroups seven phases by considering the dynamic operating modes of the involved IAVs.

The IAV routing problem is a complicated optimization problem, where containers have to be shipping, by a fleet of automated vehicles, across networks between many source and destination pairs. The graph theory has shown significant performances for modeling the transportation network. Among related works, one can cite the contribution of Hu, Jiang, Wu, Wang, and Wu (2008) in modeling urban traffic by employing a dual representation of the road network. Lin, Yu, and Chou (2009) solved the truck and trailer routing problem based on a simulated annealing heuristic. In Barcos, Rodríguez, Álvarez, and Robusté (2010) a study of routing design for less-than-truckload motor is developed. Ghaziri, and Osman (2006) studied the self-organizing feature maps for the vehicle routing problem with backhauls. Almost of these models are static and they do not consider the time dimension.

2. ITS DYNAMIC MODEL

We consider an ITS composed by stations, junctions, customers and intelligent and autonomous vehicles (IAVs). These IAVs, called *RobuTainer* (Figure 1), are 4 x 4 decentralized multi inputs multi outputs system (MIMO). They can be piloted manually or full automatically.

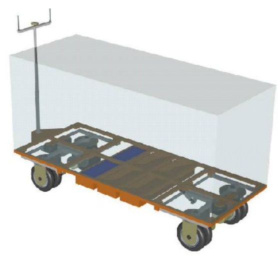

Figure 1: The IAV *RobuTainer*

Each IAV contains a real time monitoring system, makes it possible to detect and isolate the actuator and sensor faults. The MIMO structure of each IAV allows defining different control scenario to drive the IAV between two distant locations. This characteristic can be exploited to reconfigure the control system after fault diagnosis (Merzouki, Medjaher, Djeziri, and Ould-Bouamama 2007).

The dynamic model of the ITS, taking in consideration the time dimension, can be represented by a valued oriented graph $G_t(N, A, R, F_G)$, as it is shown in Figure 2, where, N is a finite set of nodes, divided in two distinct subsets: static and dynamic. The static nodes represent stations (S) and junctions (J), while the dynamic nodes represent customers (C) and vehicles (V). A is a finite set of arcs; connect static nodes to dynamic nodes. R is a finite set of arcs; connect static nodes each other, it represents roads in the transportation network.

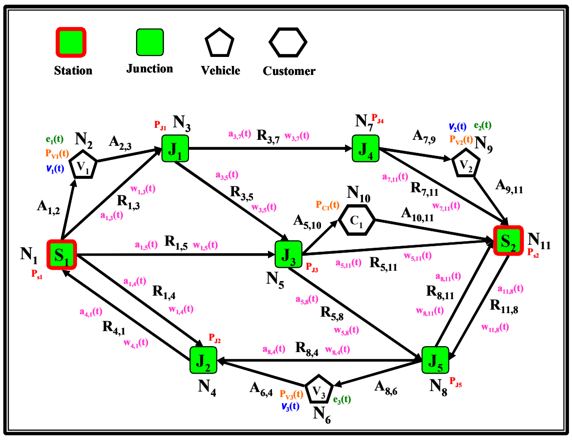

Figure 2: The ITS dynamic network $G_t(N, A, R, F_G)$

F_G is a set of time functions associated to the graph G_t. As an example, the set F_G can be described by the following functions:

- P_S and P_J are two constant functions associated to S and J respectively:

$$P_S: \quad S \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+, \qquad S_i \rightarrow P_S(S_i) = P_{Si} = (x_{Si}, y_{Si}, z_{Si})$$

$$P_J: \quad J \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+, \qquad J_j \rightarrow P_J(J_j) = P_{Jj} = (x_{Jj}, y_{Jj}, z_{Jj})$$

P_{Si} and P_{Jj} represent respectively the position of the i^{th} station and j^{th} junction. Their values are deduced from the ground mapping.

- P_C and P_V are two time functions associated to C and V respectively:

$$P_C: \quad C \times \mathbb{R}^+ \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+, \qquad (C_i,t) \rightarrow P_C(C_i,t) = P_{Ci}(t) = (x_{Ci}, y_{Ci}, z_{Ci})$$

$$P_V: \quad V \times \mathbb{R}^+ \rightarrow \mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}^+, \qquad (V_j,t) \rightarrow P_V(V_j,t) = P_{Vj}(t) = (x_{Vi}, y_{Vi}, z_{Vi})$$

$P_{Ci}(t)$ and $P_{Vj}(t)$ represent respectively the position of the i^{th} customer and j^{th} vehicle at time t. Their values are deduced using appropriate laser sensors and Global Positioning System.

- V is a time function associated to V:

$$V: \quad V \times \mathbb{R}^+ \rightarrow \mathbb{R}^+, \qquad (V_i,t) \rightarrow V(V_i,t) = v_i(t)$$

$v_i(t)$ represents the speed of the i^{th} vehicle at time t. Its value is giving by the velocity sensor associated to the i^{th} vehicle.

- E is a time function associated to V:

$$E: \quad V \times \mathbb{R}^+ \rightarrow \{V_N, V_F, V_D\}, \qquad (V_i,t) \rightarrow E(V_i,t) = e_i(t)$$

$e_i(t)$ indicates the status of the i^{th} vehicle at time t. There are three status associated to the vehicle: normal V_N, failed V_F, and damaged V_D. The vehicle is considered in failed situation, when one or two of the whole actuators are damaged, except that it is capable to reconfigure itself by using the healthy actuators. The damaged vehicle is completely stopped when more then two traction actuators are damaged.

- a is a time function associated to R:

$$a: \quad R \times \mathbb{R}^+ \rightarrow \{0, 1\}, \qquad (R_{i,j},t) \rightarrow a(R_{i,j},t) = a_{i,j}(t)$$

$a_{i,j}(t)$ represents the accessibility of the road $R_{i,j}$ at time t. Its value is equal to "1" if the road $R_{i,j}$ is accessible and "0" otherwise. $R_{i,j}$ is the road relating the i^{th} node to the j^{th} one.

- W is a time function associated to R:

$$W: \quad R \times \mathbb{R}^+ \rightarrow \mathbb{R}^+, \qquad (R_{i,j},t) \rightarrow W(R_{i,j},t) = w_{i,j}(t)$$

$w_{i,j}(t)$ needed time to cross the road $R_{i,j}$ at time t. the time function W can be defined by the estimation algorithm developed below.

2.1. Estimation Algorithm

Let's consider the following assumptions:

- The experimental area is considered confined.
- The number and status of the vehicles are perfectly known at instant t.
- We suppose, for the used infrastructure, that a vehicle can't overtake another one, so, the followers will adapt their speed according to the leader.
- The waiting time at the junctions is neglected according to the limitation of the number of vehicles.

We denote by:

$n_{i,j}$: The number of involved vehicles on the road $R_{i,j}$.

$d_{i,j}$:	The distance between the node N_i and the node N_j (the length of the road $R_{i,j}$).
$d_{i,Vk}$:	The distance between the node N_i and the vehicle V_k.
$d_{i,Vk+1}$:	The distance between the node N_i and the limit distance to react before the collision of V_k and V_{k+1}.
$t_{i,j}$:	The needed time to travel the road $R_{i,j}$ in normal conditions.
$t_{i,Vk+1}$:	The needed time to travel the distance $(d_{i,Vk+1}-d_{i,Vk+1})$.
$t_{Vn+1,j}$:	The needed time to travel the distance $d_{Vn+1,j}$.
$\min(t_{i,Vk+1})$:	The minimal value of $t_{i,Vk+1}$, with $1 \leq k \leq n_{i,j}$.

Begin
  For each $R_{i,j} \in R$
    $W_{i,j} = 0$
    If there are no vehicle on $R_{i,j}$ ($n_{i,j} = 0$) **then**
      $W_{i,j} = t_{i,j}$
    ElseIf $e_k(t) = V_N$, $\forall k \leq n_{i,j}$ **then**
      $W_{i,j} = t_{i,j}$
    ElseIf $\exists\ k \leq n_{i,j}$ / $e_k(t) = V_D$ **then**
      $W_{i,j} = \infty$
    Else
      Repeat
        For each $k \leq n_{i,j}$
          If $v_k < v_{k+1}$ **then**
            If $d_{i,Vk+1} \leq d_{i,j}$ **then**
              calculate $t_{i,Vk+1}$
        localize the (n+1) vehicles according to $\min(t_{i,Vk+1})$
        decrease the speed of V_{k+1} from v_{k+1} to v_k
        $W_{i,j} = W_{i,j} + \min(t_{i,Vk+1})$
      Until $d_{i,Vk+1} > d_{i,j}$, $\forall k \leq n_{i,j}$
      $W_{i,j} = W_{i,j} + t_{Vn+1,j}$
End

3. SIMULATION RESULTS

The simulation is realized on SCANeR studio@ (http://www.scanersimulation.com). This latter is a dynamic and real time simulator. It can be used to supervise a fleet of vehicles using a bilateral teleoperation.

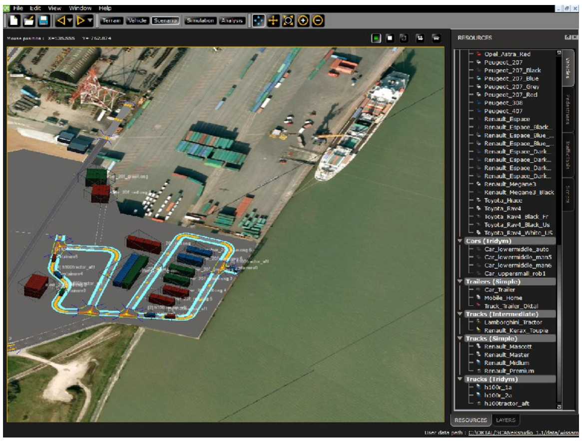

Figure 3: SCANeR studio@ for Radicatel port simulator

3.1. Terrain Description

In this section, we apply the proposed model on confined area of Radicatel terminal in Normandie (France), whose mapping is shown in Figure 3. Then, we represent the plan as an oriented valued graph in order to find the optimal path, taking in consideration the number and the status of the IAVs circulated inside the transportation network. We consider the same assumptions of the previous section.

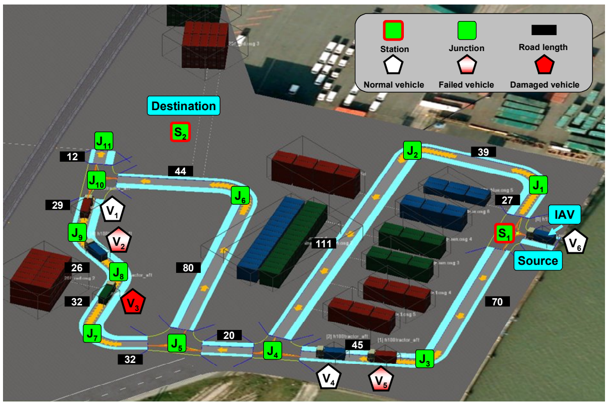

Figure 4: Port dynamic graph

3.2. Case Study

Let the graph of Figure 4, represents the studied part of the above port. As we can see, there are four possible routes relate the source S_1 to the destination S_2:

1. S_1; J_3; J_4; J_5; J_6; J_{10}; J_{11}; S_2
2. S_1; J_1; J_2; J_4; J_5; J_6; J_{10}; J_{11}; S_2
3. S_1; J_3; J_4; J_5; J_7; J_8; J_9; J_{10}; J_{11}; S_2
4. S_1; J_1; J_2; J_4; J_5; J_7; J_8; J_9; J_{10}; J_{11}; S_2

Table 1: Road lengths

Road ($R_{i,j}$)	Length (m)	Road ($R_{i,j}$)	Length (m)
S_1J_1	27	J_5J_7	32
S_1J_3	70	J_6J_{10}	44
J_1J_2	39	J_7J_8	32
J_2J_4	111	J_8J_9	26
J_3J_4	45	J_9J_{10}	29
J_4J_5	20	$J_{10}J_{11}$	12
J_5J_6	80	$J_{11}S_2$	40

Table 2: IAVs' information

IAV	Status	Relative displacement		Speed
		To	Distance (m)	(m/s)
V_1	V_N	J_{10}	7	5
V_2	V_F	J_9	11	3
V_3	V_D	J_8	9	0
V_4	V_N	J_4	15	5
V_5	V_F	J_4	30	3.5

The following scenario shows the optimal path between the source S_1 and the destination S_2, using three methods. The two first methods are classics, where the first one chooses the shortest path (the minimal distance) as optimal; the second method chooses the path, where the number of involved IAVs is the lowest, while the third one applies the estimation algorithm developed in this paper.

The road lengths of the road traffic network are showed in Table 1, while Table 2 shows some supposed information related to the five involved IAVs.

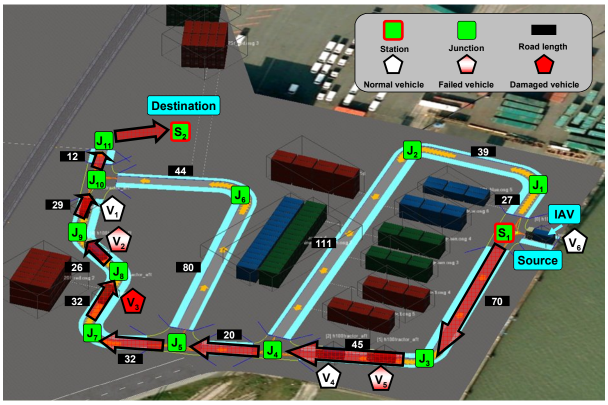

Figure 5: Optimal path according to the minimal distance

Applying the first method (shortest path), we find that S_1; J_3; J_4; J_5; J_7; J_8; J_9; J_{10}; J_{11}; S_2 is the optimal path (Figure 5), where the distance to travel is 70+45+20+32+26+29+12+40=306m in 70s.

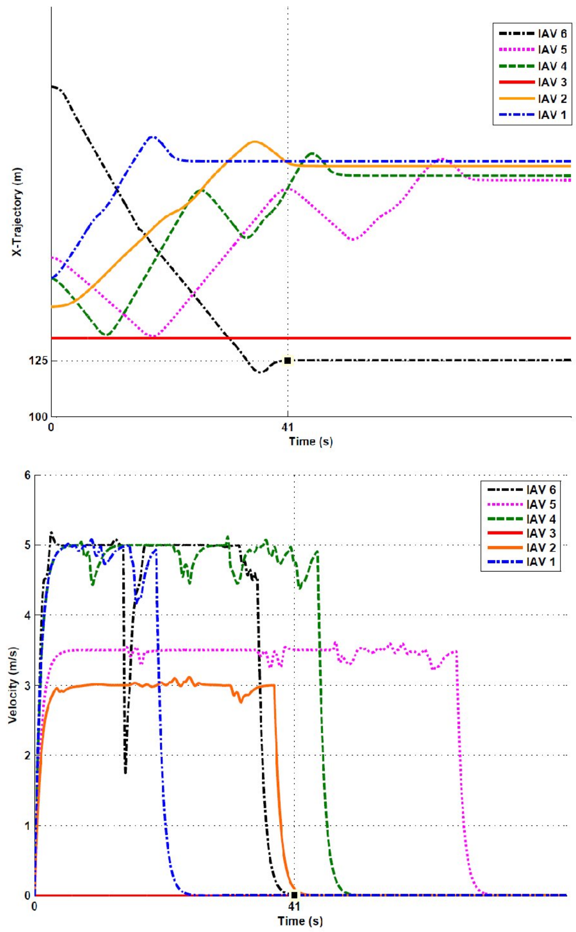

Figure 6: The vehicle V_6 can not reach its destination

In practice, the needed time to browse this path is ∞ because of the completely stopped vehicle V_3 on the road J_7J_8, which force the vehicle V_6 to stop after 41s as we can see in the simulation of Figure 6.

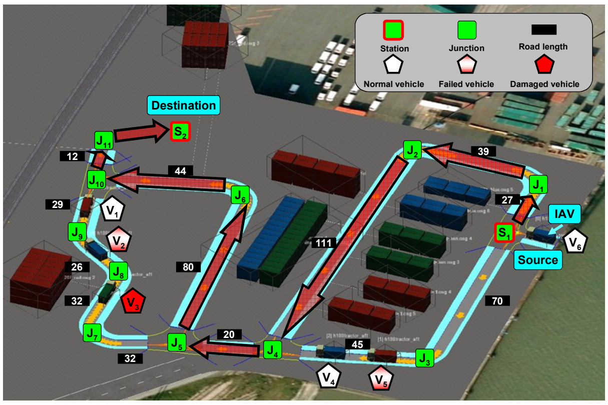

Figure 7: Optimal path according to the lowest number of involved vehicles

Applying the second method (lowest number of involved IAVs), we find that S_1; J_1; J_2; J_4; J_5; J_6; J_{10}; J_{11}; S_2 is the optimal path (Figure 7), where there aren't any IAV. Then the distance to travel become 27+39+111+20+80+44+12+40=373m in 84s.

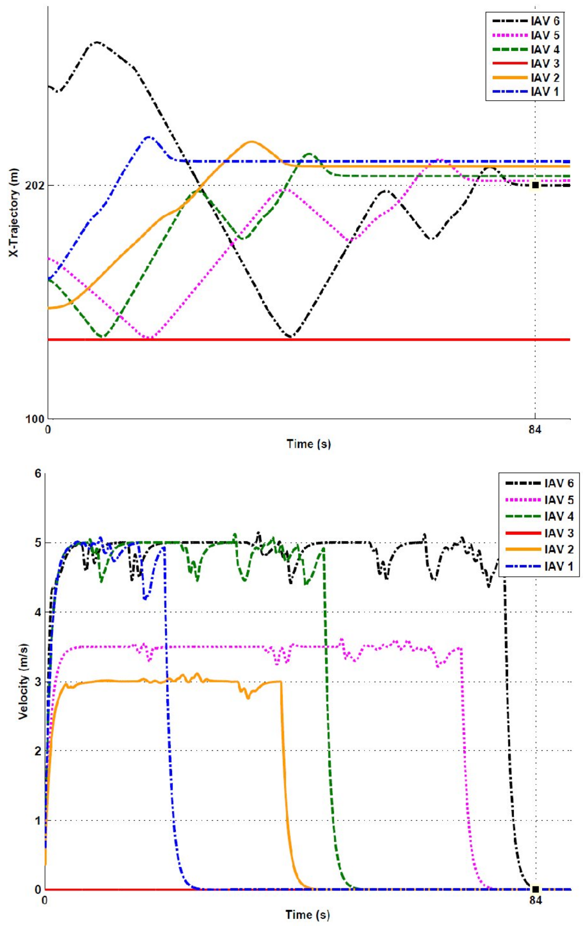

Figure 8: Reaching the destination S_2 after 84s

As we can deduce, this path is better than the first one (84s < ∞), even if the distance to travel is longer (373m > 306m).

The simulation in Figure 8 shows that the vehicle V_6 takes 84s to reach the desired destination.

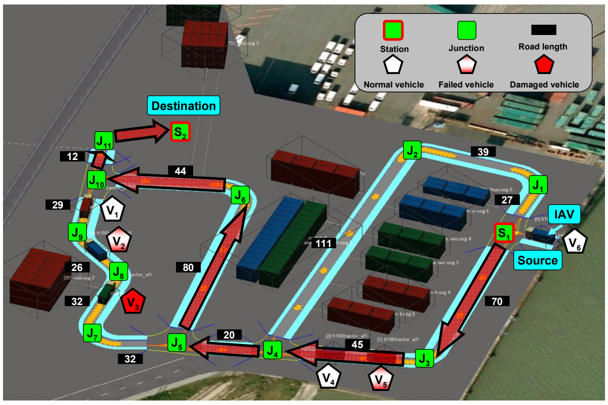

Figure 9: Optimal path according to the proposed algorithm

While, using our algorithm, we find that the optimal path is S_1; J_3; J_4; J_5; J_6; J_{10}; J_{11}; S_2 (Figure 9), where the distance to travel is 70+45+20+80+44+12+40=311m in 78s < 84s, which is the best path.

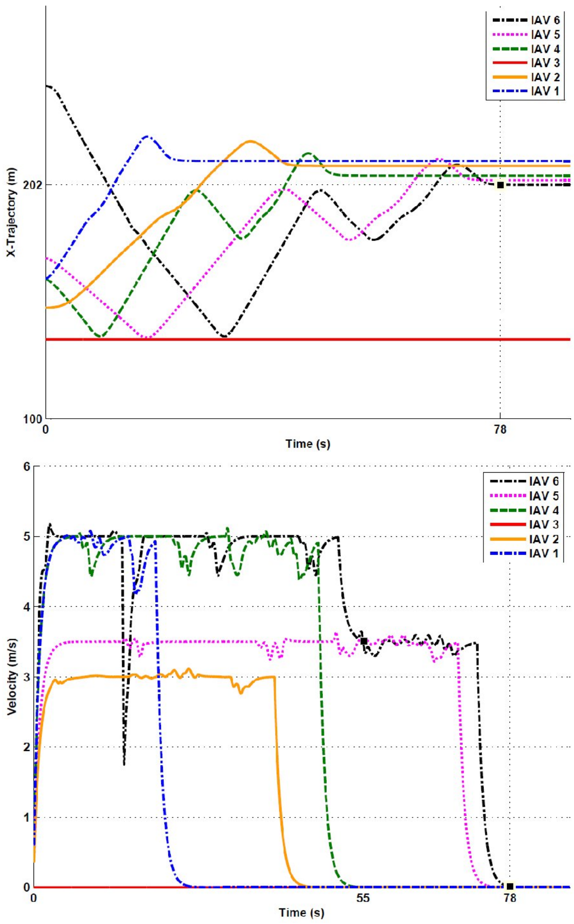

Figure 10: Reaching the destination S_2 with the optimal time

The simulation in Figure 10 shows that the vehicle V_6 takes more than 72s, the needed time to reach the desired destination in normal conditions. This delay result after the influence of the vehicle V_5 on V_6 (to avoid the collision between them), where the speed of V_6 is decreased from 5m/s to 3.5m/s at t=55s.

4. CONCLUSION

In this work, a dynamic model is developed for road traffic inside confined seaport terminal using intelligent and autonomous vehicles. This model allows implementing an adaptive estimated time algorithm for optimal path for each involved vehicle, according to the traffic and network situations. Simulation tests are done with a real mapping and traffic operations of port terminal, show the interest of dynamic model in improving the performance of the seaport internal traffic.

ACKNOWLEDGMENTS

This work was supported by European funds in the framework of InTraDE (Intelligent Transportation for Dynamic Environment), Interreg IVB, 091C North West Europe zone.

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