DYNAMIC MODEL-BASED FOR INTELLIGENT TRAFFIC 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, Rodrίguez, 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](http://www.oktal.fr)
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 \( G_t(N, A, R, FG) \), 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 to dynamic nodes. \( FG \) is a finite set of nodes, divided in stationary and customer nodes.

\[ F_G \] 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:
  \[ P_S : S \rightarrow \mathbb{R} \times \mathbb{R} \times \mathbb{R}^+ \]
  \[ P_J : J \rightarrow \mathbb{R} \times \mathbb{R} \times \mathbb{R}^+ \]
  \[ P_S(S_i) = P_J(J_i) = p = (p_x, p_y, p_z) \]

- \( P_C \) and \( P_V \) are two time functions associated to C and V respectively:
  \[ P_C : C \times \mathbb{R}^+ \rightarrow \mathbb{R} \times \mathbb{R} \times \mathbb{R}^+ \]
  \[ P_C(C_i,t) = (C_x(t), C_y(t), C_z(t)) \]
  \[ P_V : V \times \mathbb{R} \rightarrow \mathbb{R} \times \mathbb{R} \times \mathbb{R}^+ \]
  \[ P_V(V_i,t) = (V_x(t), V_y(t), V_z(t)) \]

\( P_{C_i}(t) \) and \( P_{V_i}(t) \) 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 \( V \):
  \[ V : V \times \mathbb{R}^+ \rightarrow \mathbb{R}^+ \]
  \[ V(V_i,t) = \dot{V}(V_i) = v_i(t) \]

\( v_i(t) \) 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 \( V \):
  \[ E : V \times \mathbb{R} \rightarrow \{ V_{\text{fr}}, V_{\text{yl}}, V_{\text{rl}} \} \]
  \[ E(V_i,t) = e_i(t) \]

\( e_i(t) \) indicates the status of the \( i \)th vehicle at time \( t \). There are three status associated to the vehicle: normal \( V_{\text{fr}} \), failed \( V_{\text{yl}} \), and damaged \( V_{\text{rl}} \). 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 \( R \):
  \[ a : R \times \mathbb{R}^+ \rightarrow \{ 0, 1 \} \]
  \[ a(R_{i,j},t) = a_{i,j}(t) \]

\( a_{i,j}(t) \) 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 \( R \):
  \[ W : R \times \mathbb{R}^+ \rightarrow \mathbb{R}^+ \]
  \[ W(R_{i,j},t) = w_{i,j}(t) \]

\( w_{i,j}(t) \) 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 \( R_{i,j} \).
The distance between the node Ni and the node Nj (the length of the road Rij).

The distance between the node Ni and the vehicle Vk.

The distance between the node Ni and the limit distance to react before the collision of Vk and Vk+1.

The needed time to travel the road Rij in normal conditions.

The needed time to travel the distance (dij + dij+1).

The needed time to travel the distance dij+1.

The minimal value of ti,Vk+1, with 1 ≤ k ≤ nij.

Begin
For each Rij ∈ R
    Wij = 0
    If there are no vehicle on Rij (nij = 0) then
        Wij = tij
    ElseIf cij(t) = VN, ∀ k ≤ nij then
        Wij = tij
    ElseIf ∃ k ≤ nij / cij(t) = VD then
        Wij = +∞
    Else
        Repeat
            For each k ≤ nij
                If vij ≤ vik+1 then
                    If dij+1 ≤ dij then
                        calculate ti,Vk+1
                        localize the (n+1) vehicles according to min(ti,Vk+1)
                        decrease the speed of Vk+1 from vik+1 to vik
                    Wij = Wij + ti,Vk+1
                Until dij+1 > dij, ∀ k ≤ nij
        Wij = Wij + ti,Vk+1
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.

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 S1 to the destination S2:

1. S1; J3; J4; J5; J6; J10; J11; S2
2. S1; J1; J2; J4; J5; J6; J10; J11; S2
3. S1; J3; J4; J5; J7; J8; J9; J10; J11; S2
4. S1; J1; J2; J4; J5; J7; J8; J9; J10; J11; S2

Table 1: Road lengths

<table>
<thead>
<tr>
<th>Road (Rij)</th>
<th>Length (m)</th>
<th>Road (Rij)</th>
<th>Length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1J1</td>
<td>27</td>
<td>J3J7</td>
<td>32</td>
</tr>
<tr>
<td>S1J3</td>
<td>70</td>
<td>J7J10</td>
<td>44</td>
</tr>
<tr>
<td>J1J2</td>
<td>39</td>
<td>J3J8</td>
<td>32</td>
</tr>
<tr>
<td>J1J4</td>
<td>111</td>
<td>J5J9</td>
<td>26</td>
</tr>
<tr>
<td>J1J6</td>
<td>45</td>
<td>J5J10</td>
<td>29</td>
</tr>
<tr>
<td>J3J5</td>
<td>20</td>
<td>J10J11</td>
<td>12</td>
</tr>
<tr>
<td>J5J6</td>
<td>80</td>
<td>J11S2</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 2: IAVs’ information

<table>
<thead>
<tr>
<th>IAV</th>
<th>Status</th>
<th>Relative displacement To</th>
<th>Distance (m)</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>VN</td>
<td>J10</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>V2</td>
<td>Vf</td>
<td>Js</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>V3</td>
<td>VD</td>
<td>Js</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>V4</td>
<td>VN</td>
<td>Js</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>V5</td>
<td>Vf</td>
<td>Js</td>
<td>30</td>
<td>3.5</td>
</tr>
</tbody>
</table>

The following scenario shows the optimal path between the source S1 and the destination S2, 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.

<table>
<thead>
<tr>
<th>Source</th>
<th>Destination</th>
<th>IAV</th>
<th>Station Junction</th>
<th>Normal vehicle</th>
<th>Failed vehicle</th>
<th>Damaged vehicle</th>
<th>Road length</th>
</tr>
</thead>
<tbody>
<tr>
<td>J10</td>
<td>J2</td>
<td>J1</td>
<td>S1</td>
<td>70</td>
<td>39</td>
<td>27</td>
<td>111</td>
</tr>
<tr>
<td>J3</td>
<td>J4</td>
<td>J5</td>
<td>J7</td>
<td>20</td>
<td>32</td>
<td>45</td>
<td>80</td>
</tr>
<tr>
<td>J6</td>
<td>J9</td>
<td>J8</td>
<td>S2</td>
<td>32</td>
<td>26</td>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>J11</td>
<td>V6</td>
<td>V5</td>
<td>V4</td>
<td>V1</td>
<td>V3</td>
<td>V2</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5: Optimal path according to the minimal distance

Applying the first method (shortest path), we find that S1; J3; J4; J5; J7; J8; J9; J10; J11; S2 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

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

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.

Applying the second method (lowest number of involved IAVs), we find that S_1; J_1; J_2; J_6; 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 V₆ takes 84s to reach the desired destination.

While, using our algorithm, we find that the optimal path is S₁; J₃; J₄; J₅; J₁₀; J₁₁; S₂ (Figure 9), where the distance to travel is 70+45+20+80+44+12+40=311m in 78s < 84s, which is the best path.

The simulation in Figure 10 shows that the vehicle V₆ takes more than 72s, the needed time to reach the desired destination in normal conditions. This delay result after the influence of the vehicle V₅ on V₆ (to avoid the collision between them), where the speed of V₆ 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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