Towards a truck-driver model using a hysteresis based analysis and verification approach

(Extended Abstract)

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1. INTRODUCTION

Multi-agent simulation provides powerful tools to reproduce and study human and social behavior. In these applications, the agents are often modeled to reproduce human behavior which is hard to specify. They show simultaneously reactive properties (such as reflexes, collision avoidance capabilities...) and a high level of cognition (goal oriented behavior with planning and adaptation). Furthermore, agent-based models are usually created to study emergent macroscopic phenomena, which are the results of the agents interactions. Therefore to validate the properties of those models, most of the attention is dedicated to the macroscopic view, and not to the individual one. In this perspective, creating an adequate individual is a non trivial task, because the desired output of the simulation (the emergent phenomenon) is not directly specified in the model [1]. Moreover when a model produces the adequate emergent phenomena, it is generally not clear which modeling hypotheses are responsible for it [3].

Traffic simulation illustrates all of those issues. In this area, the main objective of the simulations is to study, understand and predict the properties of a traffic flow. Therefore the main concern of the modeler and users of the produced tools is placed at a macroscopic level. Since the late 50's many microscopic simulation models have been proposed and validated , but the focus of the studies is to obtain valid properties at the flow level, such as stop-and-go waves and correct flow/speed reproduction.

In this work we propose to produce a model of the behavior of truck drivers, which are known to have a significant impact on traffic congestions, by focusing on individual properties of the behavior. Since truck behavior is assumed to share similarities with car behavior, we propose to apply a test-driven inspired methodology to develop the model. The original model we propose to improve is the ARCHISIM model [2]. This methodology consists in identifying and specifying required aspects of the behavior in order to verify that the produced model matches those requirements. This paper presents one iteration on the property identification and specification, model adjustment and verification loop.

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2. HYSTERESIS BASED ANALYSIS

To study and specify the desired behabior of truck, we focus on hysteresis phenomena — which is the lag of the reaction compared to its cause — in behavior.

To study the behavior of drivers, we propose to analyze their reaction in a two dimensional space. The space represents the gap headway of the current vehicle and its speed. The gap head of the vehicle is assimilated to a constraint applied to the vehicle, and its speed is its reaction when suffering the constraint as illustrated in Figure 1. Most models from traffic literature assume a direct relation between those values. Therefore, for a given constraint, the studied vehicle is assumed to target a stable speed. Those states are called *stable states* and represent the traveling strategy of the driver in a stable traffic (i.e. a traffic without perturbation such as stop and go waves).

When the vehicle is in a non stable traffic, the constraint applied to it varies due to acceleration and deceleration of its predecessor. Analysis of the evolution of the state of the vehicle in the gap-speed plan allows to identify its behavior.

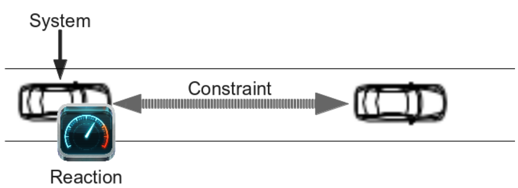

Figure 1: Subject to a constraint, a vehicle needs to adapt its speed to maintain safety. The constraint is quantified as the gap head (Δx), and the reaction is the speed ($\dot{x}$).

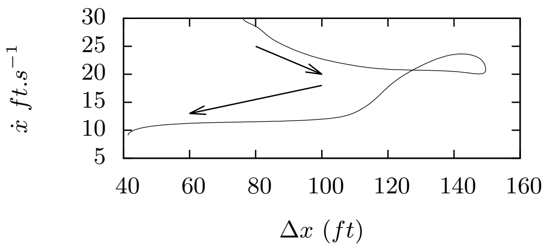

Figure 2: Hysteresis observed for the vehicle number 2851 (truck) in the US101_0750-0815 dataset. The loop turns on the clockwise direction which is the opposite direction of regular hysteresis.

Acceleration phases below equilibrium states and deceleration phases above reflects the lag of the reaction of the driver (hysteresis). Deviations from this schema reflects that the studied driver manages to adapt and anticipate the speed change it has to operate.

This analysis method is consistent with the widely accepted psychological framework proposed by [4]. This framework proposes to analyze the be behavior as the aggregation of three layers : 1) the strategic layer that manages long term strategy, that influences the equilibrium states; 2) the maneuver layer that deals with short term actions. It influences the position of the hysteresis loop (below or above the equilibrium states, rotation direction . . .); 3) the control layer responsible for low level actions. This layer influences the magnitude of the hysteresis phenomena.

3. TOWARDS A TRUCK MODEL

Using the hysteresis based analysis method, we study truck's behavior from observed data. The dataset used is provided by the NGSIM project (`http://ngsim-community.org`). The observations are used to specify the desired properties our final model must show.

We focus trucks behavior during deceleration phases of the traffic. Observation shows that most trucks shows strong anticipation capabilities, required by their limited dynamic capabilities. Figure 2 shows how a truck decelerates prior its predecessor (a car). In similar situation, none of the simulated vehicles can reproduce such behavior.

As mentioned previously, deviation from regular hysteresis reflects the influence of maneuver layer of the behavior. Therefore only this aspect of the model is altered.

During deliberation phase, the truck agent computes its acceleration based on the behavior of surrounding vehicles. For each slower vehicle down the road (called constraint), the agent evaluates the needed acceleration to reach its stable following position. This stable position is reached when the current agent speed is equal to the constraint speed, and when the gap between the two vehicles is equal to the security distance — a stable state — proposed by the strategic level (including possible vehicles in between). This state can thus be defined as follows:

$$\begin{cases} x_c(\tau) - x_a(\tau) = \mathcal{G} \\ \dot{x}_c(\tau) = \dot{x}_a(\tau) \end{cases} \quad (1)$$

where τ is the time when the agent reaches the stable following situation, $x_a(\tau)$ its position when the state is reached and $\dot{x}_a(\tau)$ its velocity at this time. $x_c(\tau)$ and $\dot{x}_c(\tau)$ respectively represent the position and velocity of the constraint. $\mathcal{G}$ is the safe gap between the two vehicles:

$$\mathcal{G} = \Delta x_{\text{safe}}(a) + \sum_{i \in \mathcal{B}} \text{length}(i) + \Delta x_{\text{safe}(i)} + \text{length}(c)$$

where $\mathcal{B}$ represents the set of vehicles between the agent and its target constraint (c). length(i) is the length of the i^{th} vehicle, and $\Delta x_{\text{safe}}(i)$ is the gap the agent believes the i^{th} agent will adopt when time τ comes.

The acceleration γ the vehicle adopts in order to reach the target state (Equation 1) is given by:

$$\gamma = \frac{[v_c(0) - v_a(0)]^2}{2\,[-x_c(0) + x_a(0) + \mathcal{G}]} \quad (2)$$

Note that we assume that the constraint will adopt a constant speed ($\forall t \leq \tau, \ddot{x}_c(t) = 0$).

Finally, the actual deceleration generated by the constraint is given by

$$\gamma_{\text{final}} = \begin{cases} \gamma & \text{if } \gamma \leq \gamma_{\text{reac}} \\ 0 & \text{otherwise} \end{cases}$$

where γ_{reac} is the maximal deceleration that triggers a reaction.

The remaining aspects of the maneuver layer in Archisim are not modified. So an agent selects the biggest constraint down the road and adapts its acceleration to it :

$$\ddot{x} = \min\left(\left\{\gamma^k_{\text{final}}, k \in \mathcal{B}\right\}\right)$$

Given those modifications of the model, we are able to reproduce the desired hysteresis loop shown in Figure 1. Moreover, we are able to reproduce important properties of traffic flow such as local capacity drop around truck in unstable traffic that tend to degrate the traffic situation.

This work shows that a test driven approach that focuses on specific aspects of the behavior helps to acheave sophisticated human behaviors, and the emergent phenomena they generate. Further validation work is needed to highlight the improvement of the resulting model over the original approach.

4. REFERENCES

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