Foundation of the Information Model for Connected-Cars

Hae-Won Seo, Yong-Gu Lee

***Abstract*—**Recent progress in the next generation of automobile technology is geared towards incorporating information technology into cars. Collectively called smart cars are bringing intelligence to cars that provides comfort, convenience and safety. A branch of smart cars is connected-car system. The key concept in connected-cars is the sharing of driving information among cars through decentralized manner enabling collective intelligence. This paper proposes a foundation of the information model that is necessary to define the driving information for smart-cars. Road conditions are modeled through a unique data structure that unambiguously represent the time variant traffics in the streets. Additionally, the modeled data structure is exemplified in a navigational scenario and usage using UML. Optimal driving route searching is also discussed using the proposed data structure in a dynamically changing road conditions.

***Keywords*—**Connected-car, data modeling, route planning, navigation system.

I. Introduction

SMART cars are next generation of cars that has intelligence providing superb safety and comfort through the understanding of interior and exterior circumstances. The intelligence is realized through seamless integration of electronics, advanced control, communication and information processing technologies [3]. Through the adoption of smart cars, we foresee future transportations that greatly reduces life casualties, energy consumptions and traveling time costs. Smart cars also provide humanities because elderly citizens and people with disabilities who could travel alone will have the ability to independently go wherever and whenever they please. Due to these benefits and demands there has been active researches solving many problems at hand. One of the active research fields is connected cars. These cars are connected to each other in a distributed manner through the recently advanced network concept named "cloud." Each car is equipped with sensors that monitors the road conditions and these sensed information is processed into a more manageable form and shared among all connected cars. The sharing is real-time thus changing road conditions at least where the peer cars are located can be utilized in the drive path planning. Compare to this to the conventional car-navigation systems that only rely on road conditions monitored through closed-circuit televisions. Conventional car-navigation systems make path planning without the consideration of the dynamic road conditions. For example, these systems cannot dynamically change its pathway when there is a sudden car accident in the driving route. However, smart cars can receive the news about the accident from the crashed cars and immediately change its route based on the new road condition that knows about the road-block or congestions happening in the accident scene. Thus, the route is optimal throughout the driving course.

This paper discusses the information model that is needed for the connected cars. The information model is designed considering the distributed (cloud) and dynamic road map and conditions. The central entity in this information model is STEP that concisely represents partial segments in a driving pathway. We have designed the information model using the UML so that the model can be conveniently translated into various specific computer implementations.

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II. Definition

Driving roads on the streets and highways are now globally universal. Each road consists of multiple lanes that can be short as few tens of meters up to several tens of kilometers. Special conditions exist in the intersections and parking lots but even if there are no road marks that distinguishes each lane, there exist imaginary lanes that drivers tend to follow. These lanes can be long and short but we will conceptually divide into a manageable length of segment and define this segment as STEP. STEP is an entity that defines important attributes and it is central to our information model. The definition of STEP and its real-world analogy is shown in Figs. 1 (a) and (b), respectively. STEP includes 5 attributes. *Head position* and *tail position* are used to represent the starting and ending location of a particular STEP. Users can obtain the direction of the STEP by subtracting the head position from the tail position. *Entry* defines the time when the car enters the STEP and the duration of time the car travels inside the STEP is represented using the *duration* attribute. *Links* are pointers that allow STEPs to find joining STEPs. Series of STEPs that are joined from head to tail are called a FLOW. A passenger using the car would desire the car to provide a safe and short travelling time. In order to minimize the latter, the amount of time spent on STEP that is represented using the duration attribute should again be minimized. Unfortunately, this duration depends on many factors that can be collectively represented using the duration attribute. Better understanding can be obtained using the graph shown in Fig. 2. The horizontal axis shows the entry time of the car in to the STEP and the vertical axis shows the amount of time it would need to safely travel and exit the entered STEP. In the example, in the A section that is between 0 hours to 6 hours we see that it only takes a constant of 6 seconds to safely enter and exit the STEP. Probably this would mean very early in the morning where people who be unlikely to move. However, in the B section we see a rapid increase of the duration because of the early congestion forming by people moving to their work places. Following the B section is the C section where traffics become less up to a steady traffic as shown in the section C. We see a second bump in the vicinity of section D due to people returning from work to their home. The bump stammers slightly as it glides downward due to sudden change in the road condition, for example, a car-accident. As shown in the above example scenario, STEP can represent the essential information that can be further utilized to calculate optimal driving route planning, for individual cars as well as entire cars that are connected and sharing this information. The data in STEP is a processed form of information that is computed from various sensory reports that are fed into the cloud information management system. This processed information is mature enough to be immediately consumed for route planning. Note in order to realize this, all cars in the loop, connected cars, need to participate and share the road conditions that it acquires. The benefit would be substantial and ultimately, all cars will be traveling on the optimized routes

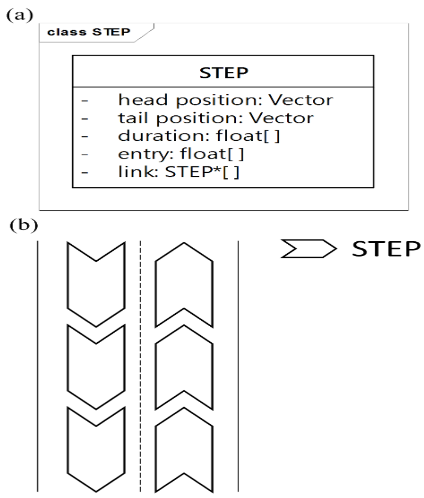

Fig. 1 (a) STEP attributes (b) STEP flow

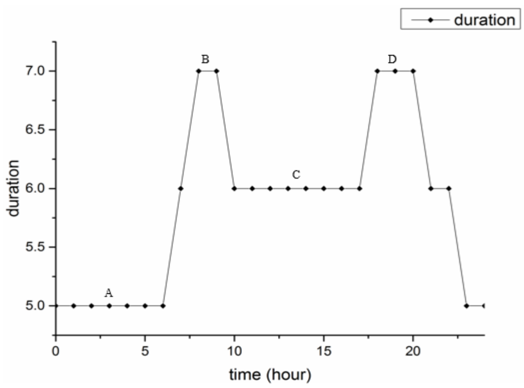

Fig. 2 Duration – entry STEP graph during a day

III. Different STEP Case

A. STEP in Traffic Light

As previously mentioned, intersections add complexity to STEP information model but we illustrate that this added complexity can be gracefully handled. Fig. 3 illustrates a cross road intersection with traffic lights signally the drivers when to pass and stop. Due to this traffic signals, the duration of time that a car requires to enter and exit a STEP that resides in the intersections is going to change systematically. For added reality, we have measured the real traffic signals in the intersection just in front of the main gate of Gwangju Institute of Science and Technology. STEP 1 in Fig. 3 travels from the South to the North and the stop signal is regulated by the traffic light. The measured entry versus duration graph of STEP 1 is shown in Fig. 4 (a). Notice the unit of time is in seconds in contrast to hours in Fig. 2 to illustrate the fine change in the duration time. The green light is on for 50 seconds, and when the car enters STEP 1 when the light is green, it will take only 6 seconds to exit STEP 1. However, when it arrives after the light turns to red, it needs to wait for the light turn to green again. The waiting time will proportionally decrease because the time for the traffic light to turn green will proportionally decrease. This is shown a section A in Fig. 4 (a). Once the traffic light turns to green, the duration will be constant again as shown in the section B in Fig. 4 (a). The two sections A and B will repeat and because it is mathematically periodic it would be more concise the entry versus duration graph using a polar coordinate system shown in Fig. 4 (b). The shape mimics a propeller as A-B sections repeat periodically.

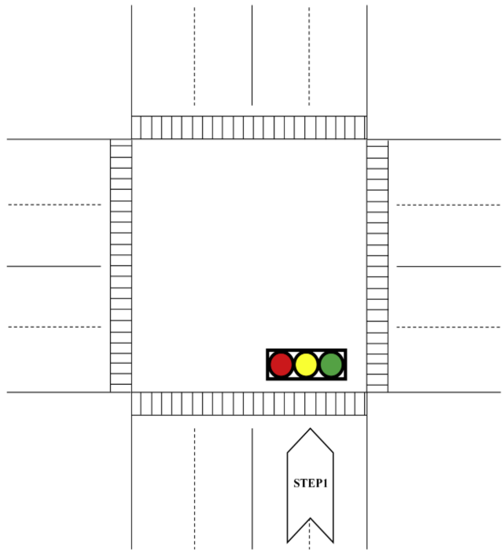

Fig. 3 STEP in the traffic light

B. STEP in Intersections

Previous discussion was a simple case for a straight course but in cross intersections, we need to consider left and right turns. These straight courses and turning courses exist from all directions South, East and West. The STEPS in the intersection will typically cross each other and a sample illustration is shown in Fig. 5. In Fig. 5, STEP1 can travel in two motions, straight or to the left. STEP2 can assume straight or right motions. To represent these variants, we branch STEP1 to STEP1S and STEP1L. Branched STEPs forms a graph and the connected STEPs are singly-linked using pointers as shown in Fig. 6.

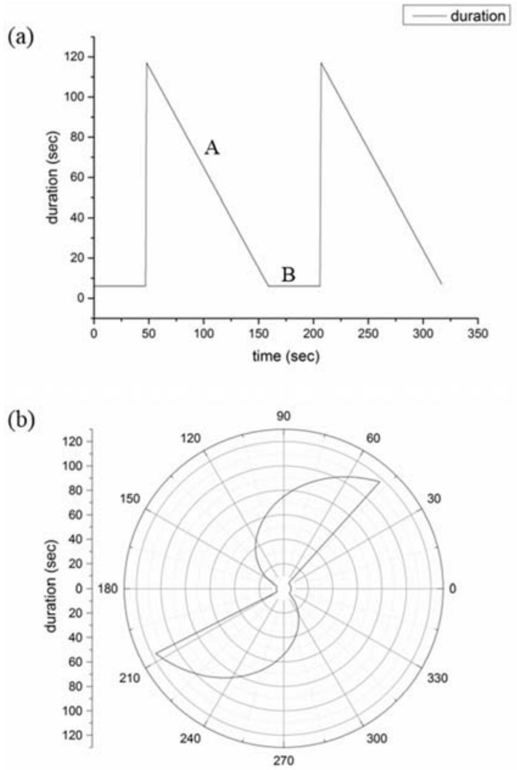

Fig. 4 (a) Duration – entry traffic light step graph (b) Duration – entry traffic light step in polar coordinates

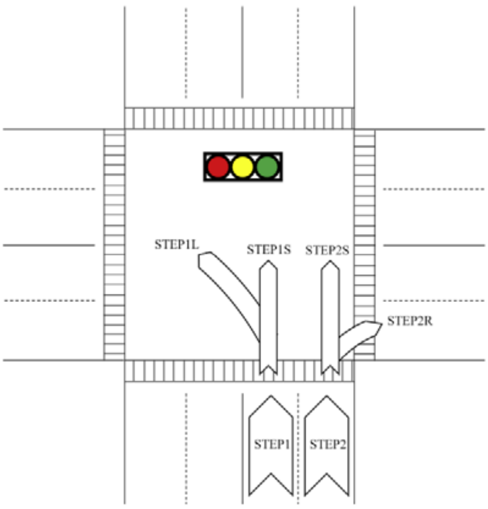

Fig. 5 Branched STEP in the intersection

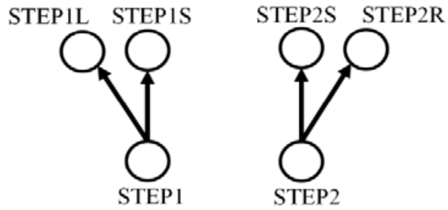

Fig. 6 STEP data structure in the intersection

C. Relations between STEPs

The courses emanating from all directions are not very dependent to each other. Otherwise, cars will crash. In the real world, traffics implicitly enforce these rules. However, in the information modeling space, we need to provide a mechanism that constraints all the different types of courses represented using the STEP information model. For a simple example with cars passing only straight at the intersections as shown in Fig. 7, we can construct a logic table NAND between STEP1 and STEP2 as tabulated in Table I. In this table, '1' denotes cars can pass the intersection while '0' denotes otherwise. Notice the relation between STEP1 and STEP2 allows the first three rows and the last row is prohibited. These logical relations exist not only between STEP1-STEP2 but also for STEP2-STEP3, STEP3-STEP4 and STEP4-STEP1. The relation between STEP1 and STEP3 depends on the local traffic light rules. For example, in Korea, the straight crossing and the left turn are either allowed concurrently as shown in Fig. 8 (a) or sequentially as shown in Fig. 8 (b). For the concurrent case depicted in Fig. 8 (a), the relation between STEP1 and STEP3 forms a NAND logic as shown in Table II. For the sequential case as shown in Fig. 8 (b), STEP1 and STEP3 form a NXOR logic as shown in Table III. These logical relations can be also applied similarly to STEP2-STEP4.

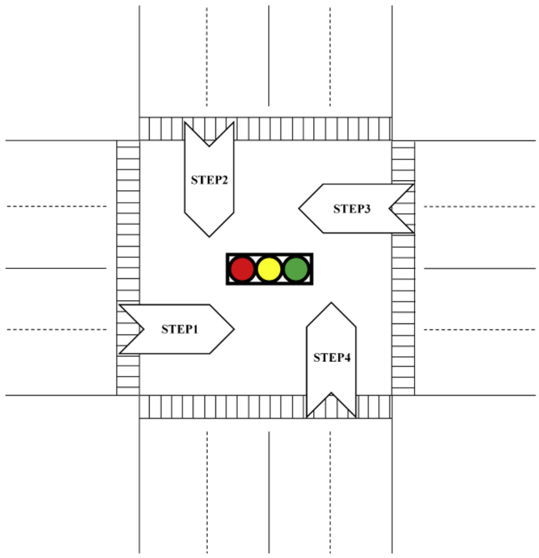

Fig. 7 Intersection STEP

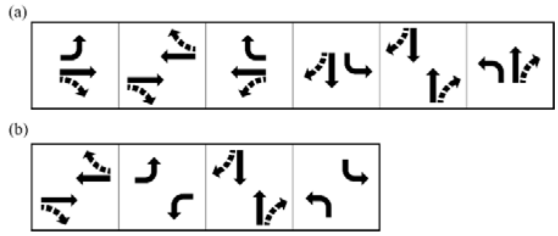

Fig. 8 (a) Simultaneous left-turn and straight crossing (b) Sequential left-turn and straight crossing

TABLE I
RELATIONS BETWEEN STEP1 AND STEP2

STEP1	STEP2	NAND
0	0	1
0	1	1
1	0	1
1	1	0

TABLE II
RELATIONS BETWEEN STEP1 AND STEP3 IN SIMULTANEOUS LEFT-TURN AND STRAIGHT CROSSING

STEP1	STEP3	NAND
0	0	1
0	1	1
1	0	1
1	1	0

TABLE III
RELATIONS BETWEEN STEP1 AND STEP3 IN SEQUENTIAL LEFT-TURN AND STRAIGHT CROSSING

STEP1	STEP3	NXOR
0	0	1
0	1	0
1	0	0
1	1	0

D.Lane Switching

Next we discuss our model when there are multiple-lanes in a road as shown in Fig. 9. In this scenario, cars can switch lanes that are adjacent to each other or if the tail of one STEP joins the head of other STEP. This switching is represented using directed arrows as shown in Fig. 10. In Fig. 10, arrows denote pointers that allows one STEP to migrate to the other STEP linked by the directed arrow. This representation can also aid in increasing the safety of lane-switching among connected cars [1]. For example, imagine a car is currently traveling at STEP5 and wishes to continue traveling by stepping onto STEP7. Also imagine another car is currently traveling at STEP4. Since both cars broadcast their current locations and its trajectory, they can negotiate who can move onto STEP7 and thus avoid possible collisions. This ability to gracefully accommodate lane-switching algorithm is one of the benefit of the proposed data structure.

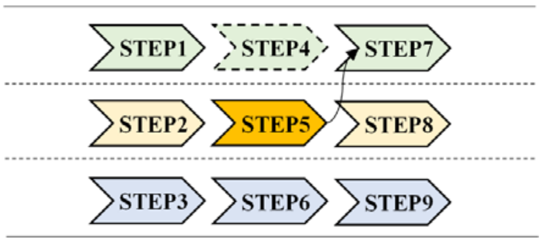

Fig. 9 Lane switching STEP

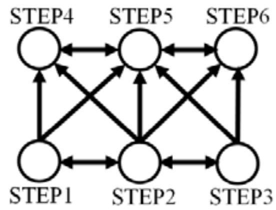

Fig. 10 STEP data structure in multi-lane

IV. OPTIMAL AND DYNAMIC ROUTE PLANNING ALGORITHM USING THE STEP DATA

The STEP information model is shared among the cars by the connected cloud system and constantly updated. Because the information is in real-time, all cars will gain instant knowledge of any sudden change in the road conditions [4], [5]. Using this information model, each participating connected can acquire the optimal route planning. This happens even when the pre-existing route plan is being followed. For example, imagine another car that is located in a location at the pre-existing route senses sudden accidents or constructions. This information will be reported immediately to the cloud system and the central processor will update the STEP information model and push the changed information to all the cars that will be effected by this change. Thus these cars that are informed will have the time to alter its course to avoid the subject site. The information flow is illustrated using a use case model in Fig. 11. We have two actors, a connected-car and the cloud system. When a connected-car joins the cloud system, the cloud system manages and groups connected cars that are in close proximity and thus can benefit by sharing the STEP data [2], [6]. Grouped connected cars can continuously download the STEP data in its route and can be always updated with the optimal and dynamic route. Also note that these connected cars sense impinging events at the STEP that they are located and immediately reports accidents to the cloud system so that their peers (other connected cars in the group) can benefit from the knowledge of the updated road conditions. The algorithm that computes the optimal routing path using the STEP information model is explained below method. The intersections are converted to nodes and the STEPs residing in the cloud joining any two intersections are summed to an edge. The weighting of the edge is determined by the summed duration in all the STEPs connecting any to nodes. Notice the duration is dependent upon the entry time.

Cars on the road will travel according to the optimal path that it calculated previously. An in any event that any STEPs in the path is changed, a new optimal path will be sought and switched to the current optimal path. The final destination does not change during the travel. However, the start point changes as the car moves. The sought optimal path is calculated using the minimum time cost criterion and this is all made possible using the dynamically changing STEP information model.

Fig. 11 Connected-car system Use-case diagram

V. Conclusion

There are many works in relation to the next generation car navigational system. Amongst them, the dynamic route planning features that can be made possible using connected-cars are receiving much attentions. In this paper, we proposed a novel data structure that can represent the dynamic motions of a car in roads. We have shown example scenarios that can utilize the data structure in real driving conditions. The STEP data we have described can unambiguously represent various road types. The STEP data is designed to be shared in a cloud system and enables connected-cars that utilize the STEP data to avoid possible collisions as well as receive information about the new road conditions. We have developed the STEP data using the Use case modeling and thoroughly investigated various processes and scenarios. Lastly, we have discussed possible algorithm that can utilized the proposed data structure for optimal route planning.

In the future, we plan to develop the optimal route planning algorithm with virtual city maps with virtual cars and demonstrate the feasibility and benefit of the proposed data structure. This work can benefit developers of the next generation connected-cars by pioneering and standardizing the data structure for connected-cars.

Acknowledgment

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