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Towards a social psychology-based microscopic model of driver behavior and decision-making: modifying Lewin's Field Theory

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Abstract

Central to effective roadway design is the ability to understand how drivers behave as they traverse a segment of roadway. While simple and complex microscopic models have been used over the years to analyse driver behaviour, most models: 1.) incorporate separate car-following and lane-changing algorithms, and thus do not capture the interdependencies between lane-changing and car-following vehicle; 2.) do not capture differences in the drivers' cognitive and physical characteristics; and 3.) are constructed from observed vehicle movements and make no attempt to model the discrete differences between how each roadway element alters each driver's behaviour.
This paper employs field theory to construct a conceptual framework for a new microscopic model. In field theory, an agent (e.g. the driver) views a field (i.e. the area surrounding the vehicle) filled with stimuli and perceives forces associated with each stimuli once these stimuli are internalized. Based on this theory, the resulting model would be designed to directly incorporate drivers' perceptions to roadway stimuli along with vehicle movements for drivers of different cognitive and physical abilities. It is postulated that such a model would more effectively reflect reality, and if this model were accurately calibrated, could potentially model the effects of external stimuli such as innovative geometric configurations, lane closures, and technology applications such as variable message boards. A modified field theory could potentially capture and model "hot topics" in traffic engineering, such as the distracted drivers, road rage, the incorporation of ITS elements, and driver behaviour through a work zone.

Selection and Peer-review under responsibility of the Program Chairs.

Keywords: Microscopic model; Field Theory; Decision-making; Kurt Lewin

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1. Introduction

In psychology, there exists a social behavioral theory called Field Theory. The theory was developed by Kurt Lewin, a Gestalt psychologist, in the 1940's[1]. The theory was developed originally for use in social situations, but has made a significant contribution to the fields of social science, psychology, social psychology, organizational development, process management, and change management. Field theory is characterized as a method of analyzing causal relations and of building scientific constructs[2].

Field theory is a psychological construct used to examine patterns of interaction between the individual and the total field, or environment. It provides a framework for looking at the factors (forces) that influence an agent in a situation, originally social situations. Field theory takes into account two types of forces: those that are driving movement toward a goal (helping forces), or those that blocking movement toward a goal (hindering forces)[2]. These forces are brought about by external stimuli, experienced by the agent. Field theory shows the changes in an individual's life space depending on how an individual internalizes external stimuli[3]. The theory states that behavior must be derived from a totality of coexisting facts, and that these coexisting facts make up a dynamic field. Therefore, the state of any part of the field depends on every other part of it[1].

From field theory, a basic framework for social interaction can be constructed. Each individual, or agent, has a life space, or field, that exists around them. External stimuli exist in this life space. Each stimulus has a different set of forces associated with it, depending on how the agent internalizes the existence/presence of the stimuli. The resulting forces govern the agent and dictate a response (or a lack of a response). Forces can have an attracting or repelling quality, and there can be/are multiple forces in each life space. The cumulative effect of these forces dictates how the agent will behave, act, interact, and the choices the agent will make.

2. Field theory in traffic modeling

Even early on, some psychologists attempted to apply Lewin's research to driving models. Gibson & Crooks indicated that no attempts have been made to describe driving behavior using a psychological model[4]. Initially, Gibson attempted to construct a psychological driving model based on habits, attitudes, and response sequences; however, this approach was met with little to no success.

Gibson concluded that the driving model was predominantly a perceptual task, so he constructed a second model that would analyze driver behavior on a perceptual level. Rather than employing habitual or behavioral models, this model was based on spatial models that utilized the field of the driver, based loosely on concepts outlined by Lewin[5]. Gibson assumed similarities between driving and walking in that both tasks required locomotion through a field of space, and that the sole difference between driving and walking was the use of a tool (in this case, a vehicle) that alters a driver's abilities and capabilities to navigate the path, based on input of the environment to the driver using the driver's visual field.

In his work, Gibson defines a *field of safe travel* as being compromised of elements crucial to travel in an automobile and bound by the roadway and roadway stimuli. Elements in the roadway alter and shape the field of safe travel. Ultimately, it is best to think of Gibson's field of safe travel as a field defining the possible paths which a vehicle may traverse unimpeded. There are limitations in Gibson's model from a microscopic modeling standpoint. 1.) Gibson's model was not applied or used to develop any sort of microscopic model, nor was Gibson's model ever calibrated. Gibson only proposes a theoretical model as an alternative to viewing a driver's experience. 2.) Gibson's model is only concerned with the area that the vehicle can travel forward into, and not adjacent areas and/or any stimuli behind or next to the vehicle. For this reason, even if Gibson's model were calibrated and adopted to construct a microscopic model, it could not model lane-change behavior, nor would it show the influence of stimuli on the driver, visible to the driver but located outside the field of safe travel. For this reason, Gibson's theoretical model is only applicable when predicting how a vehicle might react to stimuli that appear directly in the trajectory of the vehicle.

3. Current microscopic models are incomplete

Microscopic models are designed to capture and model the discrete choices and movements made by individual vehicles in a traffic stream. Unfortunately, there are gaps in the underlying structure of these models that may limit their potential to accurately model driver behavior:

- *Current microscopic models do not simultaneously predict lateral and horizontal vehicle movements/driver reactions because current models employ separate car-following and lane changing algorithms* [6,7]. This creates potentially inaccurate situations. For instance, factors of safety are sometimes generated independently for lateral and horizontal vehicle movements, creating vehicles that leave ample headway when following another vehicle but will cut-off a neighboring vehicle in the adjacent lane, accepting a minimal gap.
- *Algorithms are stochastic and deterministic in nature, rather than explanatory; the driver decision-making process is not captured in the model.* Microscopic models do not consider how a driver scans the roadway, identifies stimuli, and formulates a reaction based on the roadway environment [8,9].
- *Current microscopic models lack the ability/flexibility to incorporate new elements without complete model recalibration* [10,11].
- *Current models attempt to describe the entire driving population using the same algorithm, rather than dividing the driving population into sub-populations that exhibit similar driving habits. Published research indicates the driving behavior of older drivers differs from other drivers and drivers familiar with a roadway behave differently than unfamiliar drivers* [12,13,14,15,16]. Different populations of driver exhibit different driver behaviors; therefore, different models should be established to reflect the decision-making behaviors of different driving populations.

4. Purpose

The purpose of this paper is to introduce the framework for a new microscopic model that incorporates some of the seminal theories established in psychology, specifically Kurt Lewin's Field Theory while addressing those limitations listed above. The basic structure for this new microscopic model, Modified Field Theory, will be outlined. This paper will provide examples of how Modified Field Theory could possibly be applied to create a more accurate microscopic traffic flow model, incorporate the effects of roadway stimuli on each driver, and capture how various roadway conditions impact driver behavior. Possible applications of how Modified Field Theory could address and model current issues in traffic will be postulated.

5. Modified Field Theory

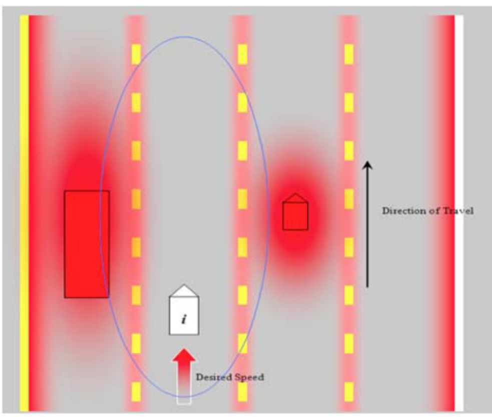

Fig 1. Example freeway segment demonstrating the forces in Modified Field Theory

Modified Field Theory (a modified version of Lewin's Field Theory) is based off the idea that each driver reacts to stimulants they perceive on and off the roadway. Stimulants include: other vehicles, lane markings, signage, and desired speed. Each stimulant has a perceived force associated with it, which may vary from driver to driver. Some stimulants can alter aspects of driver behavior, such as pedestrian crossing signs that could alter a driver's roadway scanning frequently or locations. Each driver reacts to the forces they perceive, influencing travel speed, lane choice/lane change, and driver behavior. Even route choice can be modeled in Modified Field Theory.

Each driver perceives stimulants around them. For roadway elements, a perception bubble will be employed to show which forces the vehicle perceives. Figure 1 shows this perception bubble (represented by a blue oval) for vehicle, *i*.

The perception bubble represents the visual field of each driver. When a roadway stimulant enters the perception bubble, the forces associated with the stimulant are perceived by the driver. Portions of the perception bubble update, to include presence and location of observed stimuli, depending on the locations and frequencies within the bubble that each driver scans (i.e. a driver that checks their blind spot twice every 10 seconds will have a 'refresh rate' of once every 5 seconds for that location). As the driver continues, his or her perception bubble is dynamically updated as new stimulants enter and active ones exit. The perception bubble can change size and shape. Elements that might affect the size and shape of a perception bubble include: driver speed (may scan further down a roadway when traveling at higher speeds), vehicle type (i.e. blind spots), driver characteristics (i.e. older drivers have different scanning patterns and frequencies in intersections [14,16,17]), and elements present in the driving environment (i.e. zebra stripped crosswalks or pedestrian crossing signage might cause a driver to slow down and scan the side of a roadway more frequently for pedestrians).

Multiple forces can be experienced by a vehicle; the cumulative effects of these forces govern the reactions and alterations in driver behavior of vehicle *i*, assuming that these forces are strong enough to elicit a reaction in driver *i*. Each driver *i* has an initial internal force tolerance that must be overcome to elicit a reaction (this will be used to model a driver's stubbornness or unwillingness to yield) which will vary from driver to driver. If roadway forces overcome the driver's force tolerance, the driver will react. Figure 1 depicts a sample stretch of freeway. Lane markings and other vehicles are the stimuli in this example, and the force field around each stimulus is experienced by vehicle *i* once the stimulus enters the perception bubble. When other forces overwhelm the lane marking and stubbornness forces, a vehicle may choose to change lanes. Defining stubbornness as a force enables the model to incorporate drivers who are unwilling to yield to certain stimuli. For instance, some drivers traveling in a left hand lane on a freeway will move over when another vehicle tailgates them, whereas other drivers do not. Microscopic models are designed to predict each individual driver's behavior and vehicular movements in a traffic stream. Current models predict vehicle movements by employing empirically derived algorithms based on observations of "how each vehicle behaves in situation X with elements a, b, and c." By predicting vehicular movements and driver behaviors using sound psychological theories that can describe how a driver internalizes, evaluates, and responds to their driving environment, Modified Field Theory's model infrastructure better represents the decision making processes that occur on roadways.

By including all stimuli affecting the driver, Modified Field Theory can show a driver's cumulative response to roadway stimuli, whereas other models describe individual aspects of how a driver behaves. Complex situations with multiple roadway stimuli could be modeled and analyzed because the force fields allow for an "apples to apples" comparison regarding the impacts of each stimulus on the driver. Additional stimuli can be added to the model by simply calibrating the forces associated with them, making Modified Field Theory expandable and easily "updateable" as we learn more about agent-based vehicle movements and develop new innovative geometric design and roadway elements.

6. Applications of Modified Field Theory

Modified Field Theory could be applied to model and address numerous current issues in traffic. Because the model structure is rooted in sound psychological theories, applying the model to various driver types, driving scenarios, and even capturing additional stimuli would require a simple calibration of additional stimuli (and any behaviors these stimuli might provoke).

6.1. Incorporation of Roadway Elements such as ITS Solutions

An optimal microscopic model should be capable of modeling ITS technologies and corridor and network management strategies with little to no changes in the actual model structure. Calibrating, assessing, and adding the impacts of new technologies (ITS), design elements (such as adjusting taper length or modifying signage), and other traffic management strategies can be achieved in Modified Field Theory without changing the underlying model structure by calibrating the effects of each element on drivers (such as a perceived force or adjustments to scanning patterns) and adding the element to the model. The model structure of field theory has a driver perceiving a stimulant and then reacting to the perceived force, which makes adding new stimulants (such as a different pavement marking, or new ITS technology) to the model simple.

6.2. Ability to Model Compromised Driving

Recent studies indicate that distracted and compromised drivers negatively impact traffic flow, creating delays and adding to congestion [18]. Distracted and intoxicated drivers can be modeled by altering the perception bubble of these drivers based on roadway scanning habits and frequencies. Distracted drivers don't observe roadway hazards as often as they should because of their distraction, causing a delay in reaction time. By slowing down how often the perception bubble updates, you could create a situation where the distracted driver might react to a stimuli when it's very close, causing the driver to make an evasive maneuver (such as slamming on the brakes or veering into another lane), much like we can observe in the field. The impacts of distractions can be calibrated and added in to Modified Field Theory, and the impacts of distracted drivers on traffic flow could be predicted.

A driver's frustration, or road rage, can be predicted and modeled in Modified Field Theory. A driver surrounded by stimuli and forces who cannot remove himself from the situation will experience "pressure" from these forces, exerted over a prolonged period of time. If properly calibrated, this pressure felt over time could help predict locations or areas where drivers feel uncomfortable or may succumb to road rage. In this way, Modified Field Theory can predict instances where road rage can be provoked, and if certain work zone set-ups will create areas, either in the merge or the queue, where road rage could occur. This, theoretically, could allow engineers to avoid creating set-ups that create excessive instances of road rage.

6.3. Modeling the Impacts of a Work Zone

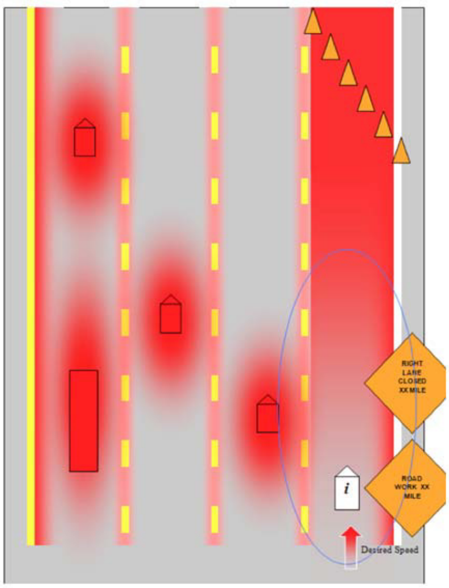

Fig 2. Modified Field Theory with added work zone forces

Some freeway work zones close one lane at a time. The lane closure forces vehicles traveling in the closed lane to merge onto an available lane prior to the start of the taper zone. Some vehicles merge immediately, whereas others wait until they cannot travel any further without merging. To model the lane closure, a work zone force will be added in the lane that is closing, forcing vehicles traveling in the closing lane to merge to another lane.

The portions of the traffic control zone that affect a merging vehicle are the Advanced Warning Area and the Taper Area, therefore, they will be included in this model. Figure 2 illustrates how this work zone force will be added to Modified Field Theory. Signage begins in the Advanced Warning Area, alerting the driver that the Taper Area will begin in "XX" miles. A force begins to develop in the closing lane, growing with intensity as the driver approaches the Taper Area. Other forces, such as the desire to stay in one's lane or the presence of other vehicles, might overpower the work zone force initially; however the growing intensity of the work zone force will eventually cause the vehicle to merge.

Previous studies have shown that a vehicle over time will accept a gap that it has previously rejected [19]. Consider the example of a vehicle approaching a construction zone in a lane that will close some distance downstream (taper area) with two vehicles following closely together in the neighboring lane. An ambient force, caused by the presence of the other two vehicles, would be felt by the driver in the gap between them. Under normal circumstances, such an ambient force might dissuade a driver from accepting that gap. However, if the driver is near the taper area, then he may accept the gap and change lanes. If the taper area is still relatively far away, the driver might instead choose another strategy to avoid the tight gap. Rather, the driver may choose to slow down, allowing both cars to pass, and seek out a safer gap.

7. Conclusions

Current standards in microscopic modeling lack the ability to address certain traffic scenarios, the ability to capture discrete differences in driver behavior that exist between various driving populations, and are structured in such a fashion that various vehicle movements are predicted and modeled separately. By incorporating structure established in sound psychological theories, a new model could be created that more accurately represents the effects of roadway and driving stimuli on each driver. Kurt Lewin's Field Theory and Force Field Analysis could possibly be modified and applied to traffic flow theory, and a new microscopic model could be created that predicts driver behavior by mapping the influence each roadway stimuli has on each driver. A microscopic model structured in such a fashion could potentially find application addressing prominent issues in driver behavior and behavioral analysis. The incorporation of a psychological model also grants the model the capability of predicting driver frustrations. Before any such model is established, in-depth analysis and calibrations must be performed, as well as model verification and validation.

References

1. Sundberg, N. (2001). Clinical Psychology: Evolving Theory, Practice, and Research. *Englewood Cliffs: Prentice Hall*

2. Lewin, K. (1997). Defining the "Field at a Given Time." *Psychological Review;* 1943; 50: 292-310. Republished in *Resolving Social Conflicts & Field Theory in Social Science,* Washington, D.C.: American Psychological Association, 1997.

3. Cartwright, D. (1951). Foreword to the 1951 Edition. *Field Theory in Social Science and Selected Theoretical Papers-Kurt Lewin*. Washington, D.C.: American Psychological Association, 1997. Originally published by Harper & Row.

4. Gibson, J.J., Crooks, L.E. (1938) A theoretical field-analysis of automobile-driving. *American Journal of Psychology* 51, 453-471.

5. Lewin, K. (1936) *Principles of topological psychology.* New York: McGraw-Hill.

6. Toledo, T, Koutsopoulos, HN, Ben-Akiva, M. (2007a). Modeling Integrated Lane-Changing Behavior. *Transportation Research Record: Journal of the Transportation Research Board, 1857/2003,* 30-38.

7. Toledo, T, Koutsopoulos, HN, Ben-Akiva, M. (2007b). Integrated driving behavior modeling. *Transportation Research Part C-Emerging Technologies, 15*(2), 96-112.

8. Ahmed, K, Ben-Akiva, M, Koutsopoulos, H, Mishalani,R.(1996). Models for freeway lane changing and gap acceptance behavior. *In Proceedings of 13th International Symposium on Transportation and Traffic Theory*, Lyon France; 1996

9. Weng, J. & Meng. Q. (2011a). "Decision tree-based model for estimation of work zone capacity." *Transportation Research Record, 2257*, 40-50.

10. Chu, L., Kim, H.K., Chung, Y. & Recker, W. (2005). Evaluation of Effectiveness of Automated Workzone Information Systems, *Transportation Research Record 1911,* 73-81.

11. Yali Chen (2008). A Highway Work Zone Design and Traffic Management Decision System *Ph. D. Dissertation, University of Wisconsin-Madison*

12. Heaslip, K, Collura, J, Knodler, M. (2011). Evaluation of Work Zone Design Features to Aid Older Drivers. *Institute of Transportation Engineers. ITE Journal* 81.3, 36-40.

13. Heaslip, K., Louisell, W., & Collura, J. (2008). Driver Population Adjustment Factors for the Highway Capacity Manual Work Zone Capacity Equation. *In the Proceedings of the 2008 Transportation Research Board Annual Meeting,* Washington, DC, January 2008.

14. Romoser, M. & Fisher, D.L., (2009). Effects of cognitive and physical decline on older drivers' side-to-side scanning for hazards while executing turns. *In: Proceedings of the Fifth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design.*

15. Pollatsek, A., Romoser, M. R. E., & Fisher, D. L. (2012). Identifying and Remediating Failures of Selective Attention in Older Drivers. *Current Directions in Psychological Science, 21*(1), 3-7.

16. Romoser, M. R. E., Pollatsek, A., Fisher, D. L., & Williams, C.C. (2013). Comparing the glance patterns of older versus younger experienced drivers: Scanning for hazards while approaching and entering the intersection. *Transportation Research Part F: Traffic Psychology and Behaviour,* 16, 104-116.

17. Bao, S, Boyle, L. N. Age-related differences in visual scanning at median-divided highway intersections in rural areas. *Accident Analysis and Prevention,* 2009; 41*,* 146-152.

18. Vladisavljevic, I., Cooper, J.M., Martin, P.T., & Strayer, D.L., (2009). Importance of Integrating Driving and Traffic Simulations: Case Study of Impact of Cell Phone Drivers on Traffic Flow. *Transportation Research Board 88th Annual Meeting, 2009.* Washington D.C.

19. Mahmassani, H., & Sheffi, Y., (1981). Using gap sequences to estimate gap acceptance functions, *Transportation Research Part B: Methodological*, 15(3), 143-148.