Time-dimensional Transport Demand Management Aiming Traffic Safety

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論 文 内 容 要 旨

In this thesis we propose a time-dimensional transport demand management (TDM) methodology and prove the importance and viability of the temporal management for a safer traffic. Modifications in the time dimension will generate social costs, while traffic changing elements are control variables. Our objective was to apply a time dimension TDM strategy to mitigate the accident risk effects of traffic mixture. We achieve this by minimizing the formulated social costs. Since the time choice remained completely in the hands of the commuter then we incorporated the Equilibrium Conditions to our model. These conditions result in a mathematical programming with equilibrium conditions problem or MPEC problem. The theoretical contribution to the TDM field was supported by a direct application during an urban development construction process. The setting we used was Tohoku University Aobayama Campus where conflicting traffic conditions were present.

In chapter one, we presented why a temporal dimensional traffic demand management is a solution to the mixture of different type of vehicles in a congestion setting. Also, this type of solution and its implementation is a novel approach that can be easily implanted. On the other hand the solution attracts some drawbacks. In that sense, we construct the social costs, from which we determine how to minimize these social costs when modifying the heavy vehicle schedule. These heavy vehicles are the heavy construction vehicles and bus transit. Bus transit schedule modification affects indirectly the commuter which was reflected in the commuter modal decision. Furthermore, commuter's time decision was time decision was taken into consideration and modeled. Our formulation problem incorporating these conditions was a mathematical programming with equilibrium conditions problem. The theoretical framework of this model was used with regards to a practical problem regarding the construction works on a university

campus, specifically, at Tohoku University on Aobayama Campus.

In chapter 2, we explain university traffic conditions and its relevance to the traffic safety context. Also, we summarize the traffic conditions on Tohoku University's Aobayama Campus and describe the student commuter behavior during weekdays to the campus to attain lectures and other activities. Also, we found that the most preferred way for students commuting to Aobayama Campus is the use of mopeds. On their commute to the university campus, the students do it during the day, most frequently near the starting time of classes. This phenomenon creates congestion among the day, therefore the presence of various congestion peaks during the day. Construction phases imply a wide range of activities, such as the utilization of heavy construction vehicles; and there is also the presence of bus transit vehicles. The mixture of mopeds and heavy vehicles bears a potential traffic accident risk. In this setting we considered the potential use of the time dimensional transportation demand management methodology for solving the safety problem at Aobayama Campus.

In chapter 3, based on the literature review, the young and inexperienced moped driver who faces an increase of heavy vehicle flow during moderate and heavy traffic hours and consequently an increase of the probability of a fatal accident. In other words, this mixture of motor vehicle types can change both the result and the occurrence in terms of fatalities and number of accidents. We showed that the young moped driver, such as the student commuter lacks the experience of maneuvering in a complex situation such as heavy traffic conditions with heavy vehicles. Therefore, the student commuter driver faces a latent accident risk when when he uses a moped as his choice of travel for commuting to the university campus. Moreover, the probability of a fatality is greater than the probability of an injury since the dissipation of energy is mostly on the light vehicle and the moped does not provide sufficient protection to the driver. Traffic safety science addresses the accident risk from its factors, like the vehicle, driver and geometric conditions. These conditions are already reviewed and the proper laws involving them are enforced by the respective agencies such as the Bureau of Transportation or the Police Enforcement Agencies. We also found that some accident factors cannot be changed due to physical, spatial or geographical limitations. And, mixture of heavy traffic conditions with heavy vehicles will not be a permanent problem. Consequently, the changes in a permanent scale such as geometric or spatial changes cannot be justified, or in our case possible to attain. Young drivers (between 18 and 24 years old) can obtain easily obtain the license for moped. Being a commuter with no previous riding experience, the student faces the changes of heavy vehicle traffic during peak hours. Completely separation of the vehicle flow is not possible given the geographic conditions of the road to Aobayama Campus. Therefore, a solution based on time dimension transportation demand management fits the Aobayama Campus altered traffic situation.

In chapter 4, student commuters using a moped clearly reflect the preferred arrival times near the starting times of classes, since they are less restricted by road capacity. Still, they also come across the congestion problem at the parking lot in the most preferable time. Student commuters, therefore, may decide their arrival time as the trade off between a convenient schedule and congestion trouble. We proposed a model that describes the moped flow when there are specific target points in time. Early arrivals are described in terms of disutility and equilibrium conditions. Road traffic data were collected and used to validate these models. The proposed validation procedure suggests stability of the model when finding the parameter estimates and a good reproduction performance. The validation assures that the model performs well in similar context and can be used for forecasting or reproducing the moped flow. Also, the reproduction of the early arrivals for the first class and particularly on Monday was reproduced and validated. However, the parameters for all weekdays have been obtained and the same procedure will reproduce similar results.

In chapter 5, we proposed a time choice model that describes the bus usage considering congestion cost, when aiming a specific target arrival time, in this case, the first morning class held at Aobayama Campus. The statistical parameter fitting could determine the impact of the bus usage in terms of selecting the bus according to the route and arrival time. The intra-day analysis conducted in this chapter helps to understand commuting as an activity subject time and congestion. This factors influence the bus usage. We obtained the model to predict congestion level of each bus by the congestion function when the most preferred arrival time is given by weekday. In our analysis we presented the Monday curves and is feasible to expand the results to other weekdays. From these results we can determine when the congestion starts an also know the maximum congestion value by the end of the considered time line in our case the beginning time of the first class held at campus.

In chapter 6, In this chapter we proposed a planning model using bus transit and heavy construction vehicles as control variables. This model calculates the social cost composed of the bus transit operation, the heavy construction vehicle operation, the accident risk and the students' disutility for either commuting mode (bus transit or moped). Equilibrium conditions between modes and within modes were incorporated and the model was solved. From this solution we could observe that the social cost will decrease if the heavy construction vehicles can operate during early hours combined with a more concentrated bus schedule around a convenient hour, which allows. The qualitative information gathered from an real number solution is similar to the information from an integer solution. Therefore, the real number limitation does not impose a drawback in the proposed model. Other scenarios were analyzed when the given parameters and constants are changed. These scenarios produced different results with regards to the first obtained solution. When the bus operation cost constant was increased, the concentration of buses around the most preferable peak started to flatten and this peak was shifted to a later time. Increasing the supply of the bus transit result in a more constant use of bus transit vehicles. Meanwhile, the increase in the heavy construction vehicle cost resulted in lengthening the usage of them, or in the case of the supply, shortens the usage. Regarding the accident risk constant, the concentration of bus transit units around a convenient arrival time varies whereas the avoidance of construction vehicles is more pronounced. Finally, the sensitivity analysis gives the following insight: If proportion between the costs does not exist, then the dominant price handles the cost. For example: If the bus operation cost is the high enough, the operator's usage is significant instead of the disutility or the accident risk cost. If the accident risk cost is the high enough, both bus transit vehicles and construction heavy vehicles will operate only on early times. If all costs are high enough, the cheapest solution will satisfy the model regardless of the constraints. In other words, if there is no balance in the elements between the decision makers and the solution is focused in a single major element, then our planning model cannot provide a satisfactory solution to all parties.

In chapter 7, we show that when both models are in modal equilibrium, we can obtain an insight into the potential gain if time dimension transportation demand management was implemented. We considered possible modifications to the schedules of the bus transit and construction vehicles as part of the elements that composed of social cost. In the concurrent empirical analyses on bus use and mopeds flow to Aobayama Campus, we determined several parameter values in the proposed models. In our formulation we consider not only the cost regarding a new kind of operation for construction vehicles and the accident risk, but also the disutility in using either kind of commute modes for transportation. The solution of the model shows that the earlier operation of construction vehicles and a more strategic concentrated bus operation provide a safer and more efficient traffic situation en route to the university campus. These study policies can be designed in qualitative terms. The general model suggests that heavy construction vehicles should realize their operations when the moped traffic is light in order to avoid a potential accident. Meanwhile, bus transit service should be provided at a more comfortable time just before the start of moped arrivals.

We also point out that, although we consider the equilibrium conditions to reflect the behavior of the bus user and the moped driver, we proposed some assumptions with regards to the general model. In this sense, the primary aim of this study was realized but there is room for improvement. Our models regarding moped disutility can incorporate a more realistic parking queuing system that manages the arrivals and departures simultaneously as a system of equations or incorporate elements such as multiple parking lots and walking from the parking lot to the lecture building. The bus commuting time choice model be improved incorporating the delays from congestion outside the vehicle. As for the general social cost model, the bus transit cost and supply is subject to a more complex analysis in order to determine a better fitness of their parameters and constants. The same applies to the heavy construction vehicle cost and supply. Meanwhile, the accident cost can be estimated if the actual cost of an accident is known. But the type of accident, magnitude and sequels vary too much to determine only one cost. We suggested handling the accident cost in terms of best case and worst case scenarios.

We summarize that this analysis shows the importance and viability of the temporal management for safer traffic conditions. The proposed model provides a good starting point for safer commuting using time dimensional transportation demand management.

論文審査結果の要旨

本論文は、大学生の通学に多く用いられている自動二輪車と、バス・トラックなどの大型自動車の錯綜が交通事故の発生につながっていることを踏まえ、道路線形改良などの交通工学的政策の適用が困難な大学キャンパスにおいて、交通事故リスクの削減のための大型車運行の計画方法論を研究したもので、序論、結論を含め７章からなる。

第１章は序論であり、交通事故問題に対する道路工学的政策と交通需要管理政策の概要を論じている。交通工学的な政策は地理的、財政的制約を受けやすく適用性が限られる。建設工事などに起因する交通事故への対策として、時間的交通需要管理政策の活用が望まれ，利用者の行動変化を踏まえた計画の立案には、均衡制約付数理計画問題の活用が適していることを論じている。

第２章は実証研究の対象である、東北大学青葉山キャンパスの交通問題を整理している。このキャンパスは、居住地からの主要道路に急勾配の曲線区間が存在し、授業開始時刻直前のピーク時間帯を中心に各種の車両が錯綜して、自動二輪車の交通事故の多発が問題となっている。また、地下鉄建設工事の大型車両の増加による自動二輪車との交通事故の増加が懸念され、短期的な効果が期待できる時間的交通管理施策の必要性を述べている。

第３章は自動二輪車の交通事故に関する既存研究の整理と、事故リスクに関する統計分析を行っている。自動二輪車は経験の少ない若年男性が攻撃的な運転操作を行うことが多く、事故発生確率が大きい。また車体による身体の保護がないため、事故が重傷や死亡につながる確率が大きい。さらに、これらの傾向は相手が大型自動車であるときに特に顕著であり、自動二輪車と大型車の錯綜をコントロールすることの重要性が明らかにされている。

第４章は自動二輪車により通学する学生の出発時刻選択モデルの作成を行っている。すなわち出発時刻のスケジュールコスト、目的地到着後授業開始時刻までの待ち時間、および既駐輪車両に基づく通行の困難さを考慮した不効用関数を定義し、その均衡条件から出発時刻ごとの二輪車交通量に関する微分方程式を誘導している。さらにトラフィックカウンターによる計測交通量に基づきモデルのパラメータの推定を行い、良好な再現性を得ている。

第５章はバスにより通学する学生の出発時刻選択モデルの作成を行っている。すなわち出発時刻のスケジュールコスト、目的地到着後授業開始時刻までの待ち時間、およびバス車内の混雑度を考慮した不効用関数を定義し、その均衡条件から混雑関数を誘導している。また、仙台市交通局提供の乗客数データに基づき、モデルパラメータの推定を行って良好な再現性を得ている。

第６章は、以上で作成したモデルを前提に、学生の出発時刻選択と二輪車・バス間の自由な選択が均衡状態にあると仮定した上で、二輪車と大型車の錯綜を最小化する大型車の運行計画の計算方法を論じている。運行計画の変更による運行費用の増加や混雑増加による利用者不効用の増加を同時に考慮した多目的数理計画問題を提案した。青葉山キャンパスに第一校時以前に到着する交通を対象に最適化計算を行った結果、授業開始時刻直前の二輪車の集中を避けるように，その直前にバスを集中運行し、建設車両はその前に運行を終えるように計画することが望ましいことを示した。またこの結果はパラメータの変動に対しても安定的であることを確認している。

第７章は結論であり、本研究の交通計画上の意義と今後の課題を取りまとめている。

以上要するに、本論文は交通事故削減のための時間的交通需要管理政策の実用的な計画手法の提案に成功しており、交通計画分野の学術の進展に寄与するものである。

よって、本論文は博士(工学)の学位論文として合格と認める。