DYNAMIC TOLLING
NEXT-GENERATION TRAFFIC MANAGEMENT ALLOWING TO REDUCE TRAFFIC CONGESTION AND AIR EMISSION BY DYNAMICALLY ADAPTING TOLL TARIFFS OF ELECTRONIC TOLL COLLECTION SYSTEMS

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ABSTRACT

Due to increasing road traffic transport policy together with traffic engineers have to find new approaches and concepts for managing traffic effectively. This paper discusses a next-generation traffic management concept allowing to reduce traffic congestion and air emission by dynamically adapting toll tariffs of electronic toll collection systems. The paper provides an overview about existing systems with variable / dynamic tariffs, objectives and effects, possible use cases, pricing strategies as well as political and legal aspects of dynamic tolling.

KEYWORDS

Dynamic tolling; traffic management; variable tariffs; electronic toll collection

1. MANAGING TRAFFIC BASED ON DYNAMIC TOLL TARIFFS

Over the past decades, transport activities all over the world have increased at a sustained pace. According to a recent issued study[1], the stock of passenger cars in the EU-27 countries has gone up by around 40% since 1990 to reach a total of about 230 million in 2006 for example and motorisation level have gone up by 35% from 345 cars per 1.000 inhabitants in 1990 to 466 cars per 1.000 inhabitants in 2006!

Politicians on national and European level together with traffic experts have to define sustainable transport policies and new traffic concepts. The goal must be to ensure traffic flow, decrease traffic pollution and consequently reduce emissions which have a negative influence on our daily life. Transport policy has to move from the old 'predict demand and provide additional capacity' approach to one of demand management.

1.1. Road User Charging – an effective mean for implementing transport policies and for managing traffic

More and more federal and local governments are introducing road user charging for managing traffic demand. Road user charging is a powerful tool for road managers when forming transportation policy. It allows flexibility in pursuing a variety of public policy objectives such as congestion pricing, privately operated tollways, encourage use of environment-friendly vehicles or to reflect road damage imposed by different classes of vehicles.

Besides being a flexible mean for implementing transport policies road user charging could in addition open a new dimension in traffic management. By dynamically adapting toll tariffs of electronic toll collection systems traffic could be managed more effectively than in the past.

1.2. Traffic management on basis of dynamic toll tariffs

Most of today's traffic management concepts rely on "soft measures" and depend to some extend on the understanding and the cooperation of road users. Today traffic management on roads consists of traffic light systems, key information for the driver about the traffic conditions and systems for influencing routes and road networks. Traffic management centers in cooperation with radio and TV broadcast stations provide "collective" recommendations to all road users about estimated travel times, possible alternative routes, or alternative transport modes.

Compared to today's "soft" traffic management solutions, dynamic tolling is a more strict approach influencing the behaviour of road users by temporarily increasing toll tariffs making them rethink their route choice, departure time or preferred transport mode in case that certain roads reach their capacity limits or in case that air emissions reach critical values.

Objectives of dynamic tolling are on the one hand side traffic control / demand management for reducing traffic congestion, maximizing throughput and utilization of HOT lanes or for guaranteeing a certain level-of-service on road sections and in zones. A second objective is to improve environmental protection and quality of life by reducing air pollution and noise. The following graphic visualizes the principle mechanism and the goals of dynamic tolling.

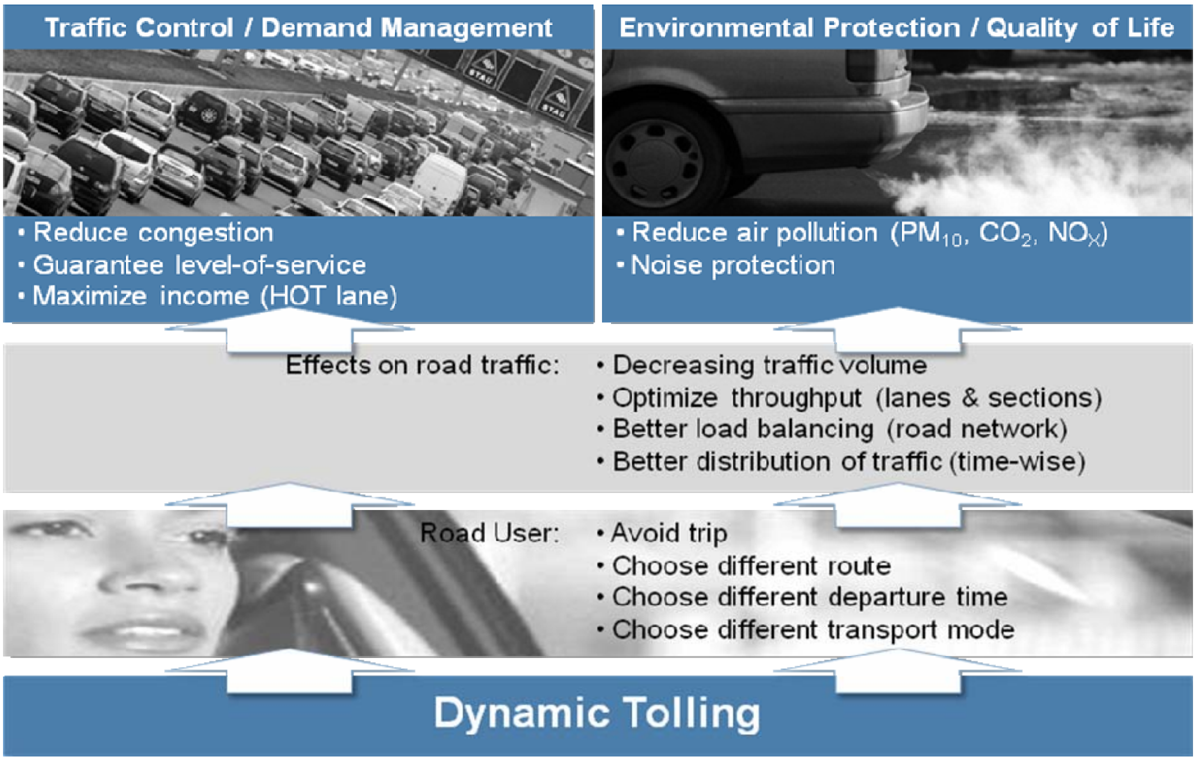

Figure 1: Mechanism and objectives of dynamic tolling

2. EXISTING ETC-SYSTEMS WITH VARIABLE AND DYNAMIC PRICING

Although first thoughts about the idea of using variable and dynamic toll tariffs for managing traffic can be traced back to the 1920s when Pigou and Knight released theoretical studies about this subject followed by studies from Vickrey in the late 1950s, there is only a little number of tolling schemes with variable and dynamic tariffs in place today. One of the main reasons for this is most likely that for a long time the technology was not ready. With electronic toll collection systems, state-of-the-art traffic management systems, as well as new media to inform road users about the traffic situation, possible detours and actual toll tariffs technologies are available today allowing implementing and operating dynamic tolling schemes efficiently.

First tolling schemes using variable toll tariffs have been implemented in Singapore and Stockholm. In both cities toll tariffs vary depending on time of day according to a predefined but fix tariff pattern. Such systems can be referred to as „variable“ or “semi-dynamic”. Some projects go even further than that. In the US, HOT (High Occupancy Tolling) lanes are tolled fully dynamically guaranteeing road users who are willing to pay for using these lanes free flow traffic and a calculable time of arrival.

	STATIC	VARIABLE	DYNAMIC
TARIF	Fixed prices – same price over time	Variable (time depending) pricing scheme	Dynamic price model
	Predictable prices	Predictable prices	Prices vary between min / max
	No price-change	Price review after a defined time	Real-time price-change
EFFECTS	Avoid trips Influence transport mode choice	Avoid trips Influence route choice Influence departure time choice Influence transport mode choice	Avoid trips Influence route choice Influence departure time choice Influence transport mode choice
OBJECTIVES	Finance (Congestion decrease)	Finance Congestion decrease Smoothing peak traffic Environment (general traffic decrease)	Finance Congestion decrease (real time) Traffic Management Environment (traffic decrease on demand)
EXAMPLES	Austria, Germany, Italy	Stockholm, Singapore	HOT Lanes (USA)

Table 1: Static, variable, and dynamic tolling schemes

2.1. Variable city tolling

One of the first projects in which toll tariffs have been used as a mean for managing traffic is Singapore ERP (Electronic Road Pricing) which has been introduced in 1998. In Singapore all road users (cars, trucks, motor cycles) have to pay for driving on certain city highways and major roads when passing one of the 65 ERP gantries installed in the city. The aim of the system is to reduce congestion within the city center and to use the existing road infrastructure more efficiently.

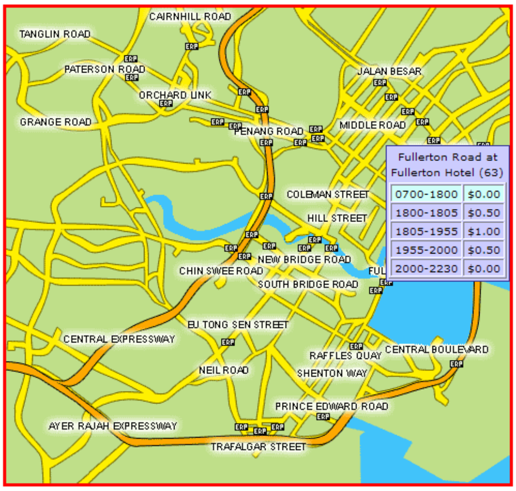

Figure 2: Singapore rates of one ERP gantry

In order to manage traffic toll tariffs in Singapore vary between \$0.25 and \$7.00 per ERP gantry based vehicle class and time.

The entire tariff scheme is worked out based on traffic statistics and can be adapted in certain assessment periods to reflect possible changes in the traffic patterns of the city over time. The goal is to guarantee an average speed of 45 to 65km/h on expressways and of 20 to 30km/h on arterial roads.

In Stockholm variable toll tariffs are also used to control traffic in the city. The system has been set in operation in 2007 after citizens have voted in a referendum in favor of the system after a trial phase. Main objectives of the system are to reduce the number of road congestion situations as well as to cut air pollution caused by road traffic by reducing the traffic volume and by smoothening traffic peaks.

For smoothening traffic peaks a variable tariff scheme has been implemented. The following graphic shows the tariff table and a diagram with traffic passing in and out of the inner city on an average day in spring 2005 compared with spring 2006.

The peaks hours have been smoothed (less vehicles) and widened (departure time has changed). The areas below the curve that are shaded green mark the charge-free period. The yellow, orange and red bars show the periods during which a charge of SEK 10, SEK 15 and SEK 20 respectively is levied.

Time	Charge
06.30-06.59	SEK 10
07.00-07.29	SEK 15
07.30-08.29	SEK 20
08.30-08.59	SEK 15
09.00-15.29	SEK 10
15.30-15.59	SEK 15
16.00-17.29	SEK 20
17.30-17.59	SEK 15
18.00-18.29	SEK 10
18.30-06.29	SEK 0
Maximum charge SEK 60 per day and vehicle	

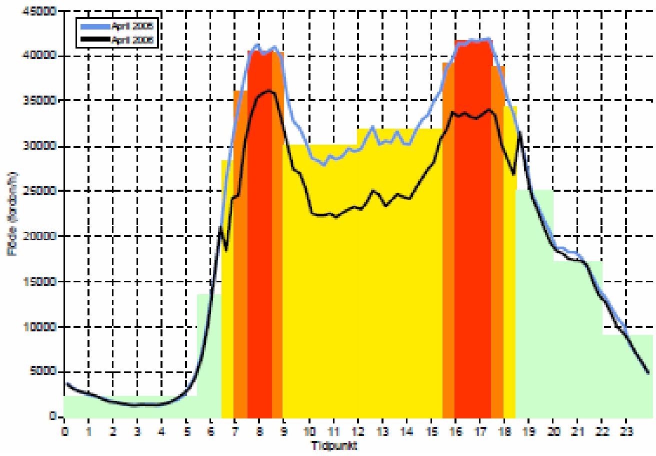

Figure 3: Tariff table and traffic statistics from the Stockholm City Tolling system

2.2. Dynamically tolled HOT Lanes

First projects in which truly dynamic tariff schemes have been implemented are several HOT lane (high occupancy toll) systems in the US. There, HOV lanes (high occupancy vehicle) have been a solution for several decades. Carpools are allowed to use these lanes in order to ensure that they can carry more people than general purpose lanes. In order to better utilize the capacity of HOV lanes single occupancy vehicles are allowed to access them by paying a toll. In some HOT lane systems tolls are being adjusted in response to real traffic conditions for optimizing system performance. Here the toll rates can change based on congestion factors, time of day, traffic volumes, and traffic flow. Sample projects with dynamic pricing are I-15 San Diego, I-394 Minneapolis, or SR 167 Washington State.

On SR 167 HOT lanes, for example, the toll rates vary between $0.50 and $9.00 currently. Traffic counters beneath the pavement collect traffic data (traffic volume and traffic speed). This data is processed WSDOT's Traffic Management Center. Based on the real-time traffic data, the computer automatically adjusts the price on the toll rate signs to manage the number of vehicles entering the HOT lanes. The objective is to allow traffic volumes to be as high as possible, without allowing the HOT lane to become congested. The computer is set to maintain speeds of at least 45 mph 90% of the time during rush hour. As more vehicles enter, space in the HOT lanes becomes limited, and the price goes up. When the HOT lanes have lots of space available the price drops. [2]

Figure 4: Dynamically tolled HOT lane SR 167

3. DYNAMIC TOLLING CONCEPTS

The above listed examples show that controlling road traffic based on variable / dynamic toll tariffs have already been implemented successfully in city environments and on HOT lanes. With the technologies available today further fields of applications for dynamic tolling would be possible.

3.1. Possible use cases of dynamic tolling

Dynamically adapting toll tariffs for traffic/demand management purposes and for protecting the environment is conceivable in virtually all fields of application in which electronic toll collection systems can be used. Dynamic tolling could be applied on highways and rural roads, in cities, on single lanes, in environmental zones as well as in tunnels and on bridges. The following table gives an overview about possible use cases:

OBJECTIVE	Highway	Area	City	HOT lane	Bridge/tunnel	Environ-mental zone
Traffic / demand management	☑ Load balancing of alternative routes (possible detours on lower network)	☑ Load balancing of alternative routes	☑ Controlling access (volume and peak-times) into/out of city zones	☑ Controlling throughput on HOT lanes	☑ Controlling throughput (volume and peak-times) over/through bridges & tunnels	
Environmental protection / improving quality of life	☑ Reducing traffic on sensible routes (e.g. noise reduction at night time) (possible detours on lower network)	☑ Reducing traffic on sensible routes / sections (e.g. noise reduction at night time)	☑ Reducing traffic in sensitive zones			☑ Reducing traffic in sensitive zones
Status / existing systems	Not yet implemented	Not yet implemented	Already implemented for inner city zones; only based on historical traffic data, no real-time traffic or environmental data Examples: Singapore, Stockholm	Already implemented on short highway sections (max. 20 miles) Examples: SR-167 Washington State, I-15 San Diego	Already implemented (variable scheme) Examples: Cape Coral Bridge, Midpoint Memorial Bridge (both Lee County, US)	Not yet implemented

Table 2: Possible use cases of dynamic tolling in various schemes

4. REQUIRED LEGAL AND POLITICAL FRAMEWORK

A pre-requisite for successfully introducing dynamic tolling is a high percentage of vehicles which are subject to toll. Only when variable tariffs have an impact on the majority of road users (heavy goods vehicles, passenger cars etc.) traffic can be managed using this concept.

Politicians should therefore think of changing their national transport costs models from the old “all in approach” where costs related to traffic are covered by fixed taxes (e.g. car tax) towards a pay-per-use model where road users pay for using the road infrastructure rather than for owning a car.

On European level politicians are currently discussing the Eurovignette Directive allowing the integration of external costs like air pollution and noise caused by traffic into tariffs levied on heavy goods vehicles. This Directive – even if not yet finalized – would be an important step towards a legal framework allowing on the one hand to better reflecting external costs by road user charges in general. In addition the Directive could be a starting point for a legislation allowing utilization of electronic toll collection systems as a mean for real-time traffic management by dynamically adapting tariffs.

CONCLUSION AND OUTLOOK

Today, toll collection and traffic management are mostly being treated separately by transport authorities. Projects like City Tolling Stockholm or HOT lane projects in the US proofed that dynamic road pricing can be used as an effective mean for managing demand on single lanes as well as controlling predictable recurring traffic situations like peak traffic in the morning or in the evening. In addition the concept of dynamic tolling could be used to manage ad-hoc traffic situations like incidents, balance load on alternative routes, optimize throughput on bridges or tunnels, or restrict access to environmental zones.

Unlike today's "soft" traffic management solutions dynamic tolling has a much higher impact on the driver's choice of routes, trip start times, and transport modes and offers great flexibility through the differentiation of tariffs by vehicle type, route, time of day, environmental pollution, traffic situation, etc. Dynamic tolling can therefore be an important measure helping road managers to cope with increasing traffic and the problems which are connected to it. It could be a core piece of future traffic management concepts ensuring traffic flow and reduced emissions helping to sustain our mobility and to protect the environment.

For successfully introducing dynamic tolling a couple of aspects have to be considered: A legal basis is needed allowing charging road users dynamically based on external factors like traffic or environmental situations. In order to be effective a high percentage of vehicles have to be subject to toll. As a basis, transport costs models for the majority of road users should change from a flat tax-based model to pay-per-use schemes. Probably the most important point however is that road users can easily understand dynamic road pricing meaning that tariff schemes have to be simple and easy-to-understand. Moreover, additional information about the current traffic situation, alternative routes, or other transport modes have to be easily accessible.

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