A Comprehensive Review on Managed Lanes in Europe

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ABSTRACT

The field of managed lanes encompasses a range of traffic engineering measures, including HOV lanes, special use lanes, hard shoulder usage and dynamic control signs. Many of these instruments, are also used in Europe, even though the term managed lanes is not widely used there.

To date, there has been no comprehensive evaluation for Europe of where, what type of and to what extent managed lanes are used. This paper aims at giving a comprehensive review on managed lane systems in Europe. To this end, strategies for the coordinated usage of managed lanes will be developed in the next steps.

In Europe, the main areas of application of managed lanes are metropolitan areas and Western Europe, where the previous strategy of expanding and building new roads has reached its limits. It is now replaced by attempts to increase the capacity of transport networks through traffic management measures. In inner-city areas, prioritization in favor of low-emission and public transport is already being implemented in many regions with public transport lanes and an increasing number of bicycle lanes. Outside these metropolitan areas, especially on freeways, dynamic control signs are increasingly being used. Hard shoulder usage is currently only used in a few European countries, but if so, on a relatively large scale.

HOV lanes and congestion pricing are currently rarely used in Europe.

In general, many transport authorities have recognized the potential of managed lane systems, so that a further, significant increase in projects can be expected in the next few years.

Keywords: Managed Lanes, Europe, traffic management

INTRODUCTION

Managed lanes are a well-known method in the United States to improve traffic flow, to decrease congestion emergence, and to increase traffic safety. In contrast, in Europe, the term "Managed Lanes" is rather little common up till now. Yet, there are measures to improve and control traffic flow. Though there is still no official definition of managed lanes, the classification of managed lanes is usually done as shown in Figure 1, the classification given by Collier and Goodin (*1*), evolved by Fitzpatrick et. al (*2*).

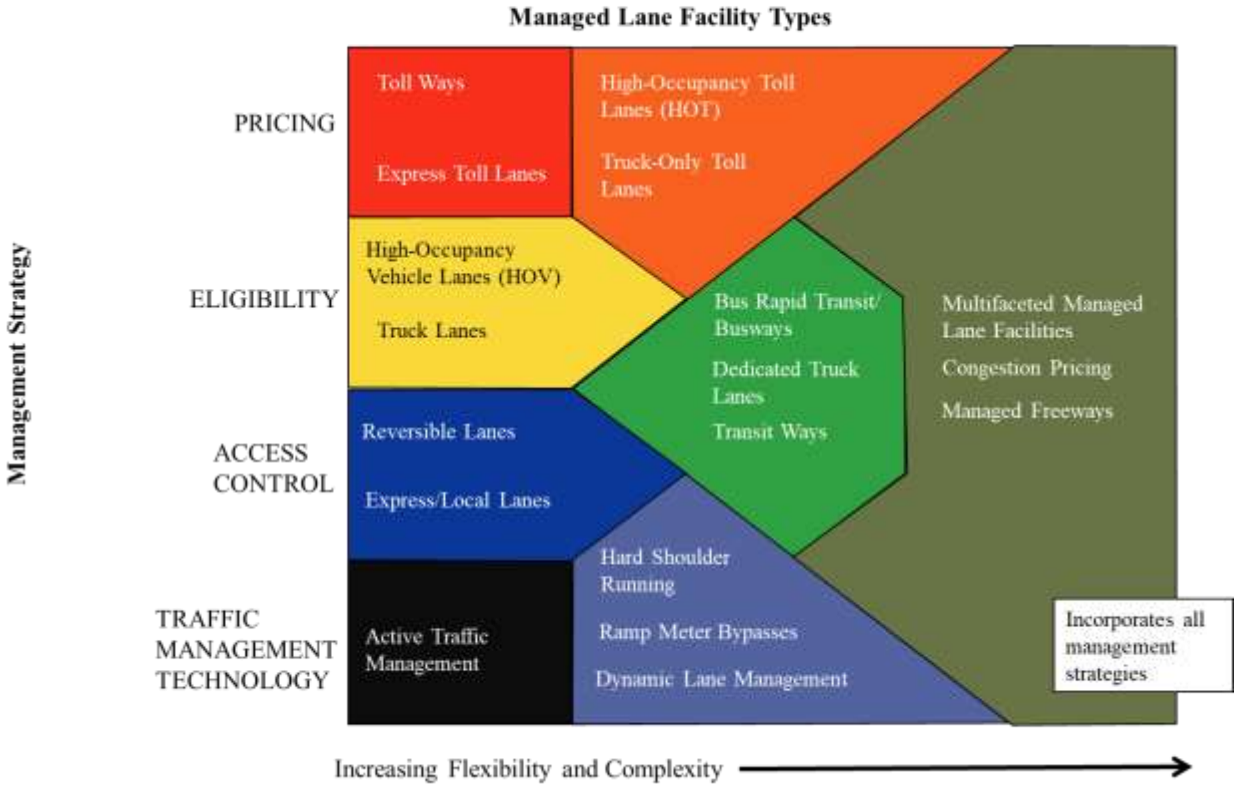

Figure 1: Managed lane facility types and management strategies *(2)*

This paper aims at giving a comprehensive overview of all managed lane systems in Europe and additionally compares in-use systems from the US. To this end, all European countries have been surveyed, if necessary by an online questionnaire, and their answers are evaluated here. We restrict ourselves to the following traffic management systems that can be encountered in the field of managed lanes:

- Hard shoulder usage
- Special use lanes, specifically bus/public transit lanes
- High-occupancy vehicle lanes (HOV lanes)
- Reversible lanes
- Ramp metering
- Dynamic message signs

As Kress et. al (*3*) showed, variable speed limits are the most common traffic management tool on European freeways.
This paper focuses on managed lane systems on freeways. In addition, the fields of application in the urban environment are also mentioned, but without going into details. Here, we define managed lanes as lanes that are withdrawn from unrestricted usage by traffic participants, taking into account specific

conditions such as speed limits or their normal usage, and are controlled instead by traffic engineering within a larger network context in order to account for concerns relating to traffic safety, performance, efficiency or user control. Depending on the type and location of the managed lane, different user groups are addressed and, as a result, others are affected. In general, however, managed lanes affect all road users, from heavy goods vehicles and private vehicles to public transport and cyclists. In urban areas, the focus is often on accelerating public transport, making it more attractive, and protecting vulnerable road users. On highways and freeways, on the other hand, efficiency improvements and general road safety often play an important role.

Increasing traffic volumes led to the decision that further traffic control measures are necessary to improve traffic flow, so there is quite an interest in implementing managed lane strategies in Europe. However, it must always be kept in mind that the European highway and expressway network cannot be compared with the American one. Although there are various European roads that span the continent, the roads are mainly in the responsibility of the nation states, so that there are considerable differences in small areas. Likewise, the countries in Europe are generally much smaller than American states, and driven distances are often significantly shorter. In addition, the local transport network in Europe is usually more developed.

This paper is structured as follows. First, we give a state of the art of research on managed lanes. Thereafter, we describe managed lane systems in Europe where we highlight every single European country. After this overview, we conduct a cost and benefit discussion, followed by an interpretation of the findings. At the end, we give a conclusion and an outlook on further research.

STATE OF THE ART

Managed lanes have been used in various ways for over 70 years. The research focus is mostly on the United States, whereas the terminology is often unusual in Europe. The current standard works for planning and implementing managed lanes include the Guidelines for Implementing managed lanes from 2016 (*2*). Goodin (*4*) and Henderson (*5*) provided an overview of the status of managed lanes in the USA. This was again clearly specified by the 2021 National Inventory of Specialty Lanes and Highways (*6*). There, a detailed overview of the different types of managed lanes in the US and their regional usage is provided. Such an overview is currently missing for Europe and is the aim of this paper.

In the literature, one can find some comparisons between European traffic control measures and those from the US, one example being the report by Kuhn (*7*). There, clear parallels between the systems become visible.

A good overview of the trunk road network is provided by the report Motorways 2018 (*8*), which was published by the European Commission and already touches on the topic of managed lanes in parts.

Further considerations on future mobility are currently coming from Great Britain. In a comprehensive report (*9*), opportunities and development possibilities for mobility were worked out and linked with new methods and technologies to form a vision of the future. Managed lanes also play an important role in this context.

The existing literature already provides a good insight into the topic of managed lanes in Europe. However, as already mentioned, what is currently missing is a precise inventory of the scope and forms of usage of managed lane facilities in Europe.

History and development

The first pilot project for temporary usage of the hard shoulder lane was put into operation in Germany in 1996 (*10*). Today, the focus of a temporary hard shoulder usage is primarily in Germany, England, the Netherlands, Belgium and France. Some other countries operate hard shoulders on a small scale or are planning at least some projects for implementation. After initial positive experiences from the end of the 1990s, further projects on a larger stretch of road for hard shoulder use were implemented in Germany in the new millennium. From 2003, the system was also successfully tested in the

Netherlands, followed by projects in Great Britain (*11*). Evaluations show that the temporary usage of hard shoulders has led to a significant reduction in travel times and an increase in traffic safety (*12*).

Reversible lanes are among the oldest traffic control devices. In the US, they have been used in urban areas since the 1920s, but have also been applied to highways since the 1960s and 1970s. In Europe, traffic planners are much more reluctant to use reversible lanes. They were first used on freeways in the 1970s in the United Kingdom, in the Birmingham area (*13*), Since then, reversible lanes have not gained widespread popularity. In France and Spain, there are a few shorter highway sections with reversible lanes, and in Tallinn and especially Istanbul, reversible lanes have been built in urban areas. An intermediate route is taken by Germany, where reversible lanes are sometimes used in narrow spaces at construction sites, but only for a temporary period.

HOV lanes have been a standard traffic control measure in the United States since the 1960s when the aim is to improve the performance of transportation networks around metropolitan areas. In Europe, this method was not used for a long time. Only since the mid-1990s have there been a few pilot projects; after an initial failed project in the Netherlands, successful projects followed in Madrid, and later in Leeds and Trondheim (*14*). The second generation of HOV lanes followed from the end of the 2000s in Europe. The number of projects implemented was again modest, with the main focus on Belgium and Norway and Portugal. The importance of HOV lanes for Europe can nevertheless be classified as low, which is also evident from the fact that no European country has reached a route length of 50 km of HOV lanes.

Special use lanes, especially bus or public transport lanes have been standard in many European cities since the 1970s. For some years now, the network of public transport lanes has been significantly expanded. In addition, in many larger cities there are also bicycle lanes on a larger scale. Only a few special use lanes are used on highways in Europe. Here, too, the developments tend to be more recent; they are mostly bus lanes in urban areas and much less frequently transit lanes, which carry traffic flows past cities. This system has not yet been able to gain widespread acceptance.

Ramp metering was developed in the USA in the 1960s and has been used ever since. In Europe, this development was not taken up until the 1980s. Here, ramp metering was first used in England in 1986. After the technology had proven itself, a number of other projects followed from the end of the 1990s. Today, ramp metering is one of the standard tools for traffic control in Europe, especially in the vicinity of metropolitan regions in Western Europe. For example, the freeway ring in Paris as well as the freeways of the Ruhr area in North Rhine-Westphalia, in Germany, are controlled in this way and protected against congestion. The technology has evolved over the years from uncontrolled throttle systems, which signal vehicles to enter the freeway at regular intervals regardless of the traffic load in the system, to intelligent, automated systems that adjust the inflow volume onto the freeway to the traffic load in the ramps as well as the continuous section.

SITUATION IN EUROPE

In 2010, the EU issued the Intelligent Transport Systems Directive (ITS), a binding set of regulations for optimizing transport in Europe. The exact implementation is left to the individual member states, but they must report the current status in a regular report to the European Commission. The directive identifies the following four important fields of action, optimal use of road, traffic and travel data, continuity of ITS services in the areas of traffic and freight management, ITS applications for road safety, connection between vehicle and transport infrastructure.

In Europe, measures from the field of managed lanes are used in inner-city areas in various countries, even if the term itself is not used here. Their main purpose is to speed up public transport, protect cyclists and harmonize traffic flows. Table 1 shows, based on data by Eurostat (*15*), the length of freeways and expressways in 2020 in different countries. The respective countries are discussed in detail below. To this end, a survey was launched among the transport and traffic ministries to find out what types and to what extent managed lanes and other traffic control systems are used in the respective countries. The data were generally provided by telephone, mail, or videoconference. In comparison to the European data, data from three selected U.S. states and a total number of managed lanes in the U.S. were added at the end of Table 1. These data do not come from the survey conducted, but were taken from the FHA publication (*6*) (*16*). A detailed evaluation of the managed lanes is not provided here, but can be found in the FHA publication (*6*).

Table 1: Motorways in Europe and the US 2020 ***(6) (15)*** **(*16*)**

Country	Length of motorways [km]	Proportion of Managed Lanes [km / %]	Country	Length of motorways [km]	Proportion of Managed Lanes [km / %]
Belgium	1.763	>17 km* / > 1%*	**Netherlands**	2.790	533 km / 19 %
Bulgaria	790	0 km / 0%	**Austria**	1.749	23 km / 1 %
Czech Republic	1.276	0 km / 0 %	**Poland**	1.676	0 km / 0 %
Denmark	1.329	2 km / 0 %	**Portugal**	3.065	0 km / 0 %
Germany	13.183	414 km / 3 %	**Romania**	866	0 km / 0 %
Estonia	161	0 km / 0 %	**Slovenia**	623	0 km / 0 %
Ireland	995	0 km / 0 %	**Slovakia**	495	0 km / 0 %
Greece	2.320	0 km / 0 %	**Finland**	923	0 km / 0 %
Spain	15.585	20 km / 1 %	**Sweden**	2.133	27 km / 1 %
France	11.671	67 km / 1 /	**Iceland**	0	0 km / 0 %
Croatia	1.310	0 km / 0 %	**Liechtenstein**	0	0 km / 0 %
Italy	6.966	0 km / 0 %	**Norway**	1.008	7 km / 1 %
Cyprus	257	0 km / 0 %	**Switzerland**	1.462	22 km / 2 %
Latvia	0	0 km / 0 %	**United Kingdom**	3.838	105 km / 3 %
Lithuania	403	57 km / 14 %	**North Macedonia**	335	0 km / 0 %
Luxembourg	165	7 km / 4 %	**Serbia**	963	0 km / 0 %
Hungary	2.076	0 km / 0 %	**Turkey**	3.060	50 km / 2 %
Malta	0	0 km / 0 %	**Kosovo**	137	0 km / 0 %
USA	501.554**	49.603 km / 9 %	**Texas**	39.139	4.686 km / 12 %
Florida	19.864	5.544 km / 28 %	**New York**	20.297	4.188 km / 21 %

**Overall lengths are not recorded, ** Data from 2019*

Belgium

In Belgium, there are two independent transport agencies for Flanders and Wallonia, with different operational procedures, so that no common statistics exist. In general, there is a temporary hard shoulder use on some Belgian freeways, especially in the area of larger cities. In Wallonia, exists a 17 km HOV lane. In addition, there are a number of bus lanes on freeways that are used by all public transport agencies. No other measures are currently being taken on freeways. In inner-city areas, there are small-scale bicycle lanes and bus lanes. Overall, the lengths of the special lanes in Belgium are not recorded.

Bulgaria

Bulgaria has invested heavily in its highway network in recent years. Steadily growing traffic figures and burdens from an ever-increasing (freight) transit had made this expenditure necessary. Most of the investment went into structural improvements to the highways to increase traffic safety and expand capacity, for example by adding lanes or hard shoulders, and less into traffic engineering equipment. Some freeways have lanes for vans and trucks; the designation of such a special purpose lane is based on traffic figures and regularly updated, so the length of special purpose lanes changes regularly but has tended to grow in recent years.

In the larger cities of the country, there are a number of bus lanes to accelerate public transport.

Czech Republic

The Czech Republic does not use managed lane systems on highways. There are a number of bus lanes to accelerate public transport in larger cities and in the approach to them, as well as some bike lanes in urban areas.

Denmark

Since 2005, heavy trucks, buses and vehicles towing trailers have been prohibited from passing on certain stretches of the Danish motorways. Temporary hard shoulder use is currently being used on 2 km. No further traffic control measures attributable to managed lanes are applied on Danish highways. Around larger cities, there are a number of bus lanes to accelerate public transport. In many cities, bicycles are strongly promoted and preferred as a mode of transport. This is expressed in a large number of bicycle lanes and other infrastructure for bicycles, mostly at the expense of private transport.

Germany

In many cases, the German highways have reached their capacity limits. Since expansion is proving difficult due to high financial, ecological and social obstacles, the focus is currently on increasing efficiency. Temporary hard shoulder use is currently being used on 414 km. Reversible lanes are increasingly being tested in construction zones, but they are not yet being used on the open road. At more than 100 interchanges, mainly in North Rhine-Westphalia, ramp metering takes place at times of high road occupancy. In addition, various measures are being investigated for automating traffic, which are seen as having high potential in the future.

Various managed lane systems are used in urban areas, but each is an individual project, so that the name, design and objectives differ greatly. Public transport lanes to accelerate public transport are now standard in many larger cities. Similarly, bike lanes are often installed to protect and prioritize these road users. In some cities, trials of HOV lanes are currently underway to increase vehicle occupancy rates. Some cities are trying to promote public transport, electric mobility and high occupancy vehicles by establishing so-called "environmental lanes".

Estonia

In Estonia, no managed lane systems are used on freeways apart from the variable message signs mentioned at the beginning. In the urban area, public transport enjoys a high priority, which is reflected in a number of public transport lanes. In recent years, the share of bicycle traffic has also increased, which is reflected in current traffic planning. In Tallinn there is a 1,6 km long reversible lane, leading from the inner city area to the biggest suburb.

Ireland

Around one-third of Ireland's highways are operated under public-private-partnership (PPP) projects. This leads to a certain degree of competition between operators to ensure that traffic flows are as comfortable as possible.

On some stretches, certain lanes are closed to heavy traffic to improve traffic flow. Beyond that, there are no other traffic control measures. In the cities, there are a number of bus lanes and a few bicycle lanes.

Greece

The highways in Greece, in addition to state-owned sections, are operated by various private companies under PPP projects. Work is currently underway to harmonize the conditions of use on the different sections of the highway. This also includes a uniform toll system. In addition, there are no managed lane measures on highways. In the greater Athens area, there is a network of bus lanes approximately 50 km long, which was set up in the run-up to the Olympic Games.

Spain

In Spain, the traffic system, including highways, is testing many innovative traffic control measures, including a number of managed lane systems. In the Madrid area, there is an HOV lane around 20 km long. In the Barcelona area, ramp metering is being tested at highway interchanges. In addition, hard shoulder uses are in preparation at several locations. Outside the freeways, there are several trials with alternating traffic lanes on the main access routes of larger cities. In addition, there is a network of public transport lanes.

France

France has implemented a large number of innovative projects on its highways and is constantly expanding this network of modern traffic control measures. The aim is always to create a modern roadway network to increase the safety and ease of traffic while taking ecological concerns into account. In a total of 3 projects, HOV lanes were created over a length of approximately 16.5 km. Another 6 projects with carpool lanes were implemented in the subordinate, interurban roadway network. There are public transport lanes on 19 sections of the freeways, that have a total length of around 48 km. In addition, there is a double-digit number of public transport lanes outside the freeways, with a constantly growing length. In the vicinity of 8 French metropolitan regions, there is a ramp metering onto the freeways. The linking of the A4 and A86 freeways is a special feature. Here, the approximately 2.2 km long interlinking area of the two highways is extended by a reversible lane during peak hours. In addition to these innovative approaches, the hard shoulder of a number of freeways will be released for use during peak hours.

In France, modern managed lane approaches are not only used on freeways and interurban roads, but are also applied in inner-city areas. Bus lanes and bicycle lanes are a natural part of the public traffic environment in many cities.

Croatia

In Croatia, no managed lane systems are currently in use, either in urban areas or on highways. Within the framework of the ITS program, traffic management systems are to be implemented in the next few years. Bus lanes on highways and in cities, for example, are under discussion.

Italy

In Italy, managed lane systems have not yet been deployed on highways. However, a number of smart road projects are in preparation. The aim here is to network infrastructure and vehicles and to automate monitoring of routes throughout the country in order to be able to react quickly and appropriately to current conditions. This includes, for example, route suggestions in the event of obstructions, automated speed adjustments to the traffic density or the detection of accidents on the route. Another project that has already been introduced is Dynamic Acoustic Mapping, which determines the noise pollution emanating from the route in real time and attempts to optimize the burden on residents by means of traffic control measures.

In larger cities, special use lanes are occasionally used, partly in the form of public transport lanes, but also for freight or transit connections.

Cyprus

Cyprus does not yet have any managed lane systems in operation on highways, but plans are underway for several projects, which are also to be implemented in the near future.

There are already some special use lanes in urban areas. In the Nicosia area, there is a public transport lane that is also used by emergency vehicles, as well as other bus lanes. In addition, a reversible lane / contra flow lane is currently being built, which will serve in particular to accelerate public transport.

Latvia

Latvia does not have an independent highway network. There are a number of expressways, but they do not reach freeway level. There are a number of bus lanes in Riga, otherwise there are no managed lane systems.

Lithuania

Lithuania has a generally well-developed and by far the largest highway network of the Baltic States. Elements of managed lanes are not used there.

In larger cities, there are bus lanes, HOV lanes (4+) and bicycle lanes. In some cases, bus lanes are also expanded into public transport lanes or environmental lanes and opened for cabs, high occupancy vehicles or electric vehicles.

In total, the (extended) bus lanes cover about 45 km, the HOV lanes about 12 km and the bike lanes about 20 km.

Luxembourg

There are around 7 km of bus lanes on Luxembourg's highways to accelerate public transport. These partly continue in the inner-city area. Cycling is a major focus of attention in Luxembourg and is given high priority, including dedicated bike lanes and priority at intersections.

Hungary

To date, Hungary does not use managed lane systems on its highways. In the inner-city area, there are some public transport lanes as well as bike lanes in the metropolitan areas.

Malta

No elements of managed lanes are used on freeways in Malta. In the inner-city area, there is a small number of bus lanes. Further traffic-steering measures are controversially discussed, but have not yet been implemented.

Netherlands

The Netherlands has one of the densest and best developed road networks in the world. Europe's first HOV lane was built here back in 1993 (*17*). The test failed after a short time for legal reasons, among others, but innovative elements are regularly implemented in traffic control.

In the urban environment, bicycle traffic is strongly prioritized. In particular, dedicated bike lanes and structurally separated bike paths ensure that bicycles are one of the strongest modes of transport for short and medium distances in urban areas. In addition, public transport is also preferred at the expense of private transport.

On highways, various measures from the field of managed lanes are used. Bus lanes are used on a length of 324 km. At least a temporary truck overtaking ban is in place on 2,099 km of road. Around 161 km of temporary lanes are in place for peak hours during rush hour. Around 48 km of interlinking lanes are used to harmonize traffic. Around bigger cities like Amsterdam or Rotterdam, ramp metering is used to harmonize traffic flow on highways. Further measures, such as a resumption of HOV lanes, are under discussion.

Austria

Austria has been testing innovative projects on its road network for many years, both locally and on interurban roads. On the A7 highway, there is currently an 8 km bus lane to accelerate public transport. In 2018, a temporary hard shoulder use was installed on just under 4 km of the A4. In the next few years, further sections are to follow on the A1 and the A12 with a total length of 11 km in each direction. At present, the use of HOV lanes on freeways is being intensively tested; in Austria, these are currently only available on one country road in the Linz area. The use of section control to monitor speed is noteworthy. The number of speeding violations is significantly lower than with stationary speed measurement.

In the inner-city area, public transport and cycling have priority in Austria. This is reflected in a large number of public transport lanes and bicycle lanes, which have priority over private vehicles.

Poland

The Polish highway network has grown significantly in recent years and there are further extensive expansion plans. So far, bottlenecks have been solved in this way, so that the use of managed lanes has not been necessary.

In the inner-city area, a number of public transport lanes are used.

Portugal

Portugal does not use managed lane systems on its highways. Due to steadily increasing traffic volumes, various measures are currently being discussed to improve traffic management. For example, the introduction of HOV lanes with a length of around 20 km is being planned on two freeways, although implementation has not yet been secured or even scheduled.

To speed up public transport in Lisbon, an intermittent bus lane system was introduced there in the early 2000s, which dynamically designates individual lanes as bus lanes and then reopens them for general traffic.

Romania

Romania does not use managed lane systems on its highways. In the urban environment, too, there are only small-scale solutions and no area-wide traffic control.

Slovenia

Slovenia does not use managed lane systems on its highways. Due to steadily increasing traffic volumes, various measures are currently being discussed to improve traffic management. The centerpiece is to be the new National Traffic Management Center, from which the traffic flows of the entire country are to be controlled.

To speed up public transport, there are bus lanes in larger cities, as well as occasional bicycle lanes.

Slovakia

Slovakia does not use managed lane systems on its highways. Due to steadily increasing traffic volumes, various projects are currently being pursued to optimize traffic. However, concrete dates have not yet been set.

In inner-city areas, public transport and bicycle traffic often enjoy preferential treatment. Bus lanes and bike lanes have been installed for this purpose.

Finland

Finland does not currently use managed lane systems on its highways. However, due to increasing traffic volumes, various traffic control measures are currently being investigated. The main focus is on the automation and digitalization of traffic.

In larger cities, especially Helsinki, cycling and public transport play an important role. In particular, bicycle traffic is prioritized and protected via dedicated lanes. As a rule, public transport moves in the general purpose lanes.

Sweden

Sweden uses congestion charges to manage traffic in metropolitan areas. This applies both to the freeways and to the secondary road network. In addition, there are a number of innovative approaches to optimize traffic flows, capacity utilization and emissions.

In larger cities, the focus is on public transport and cycling. Dynamic as well as static public transport lanes and bicycle lanes give priority to and accelerate the traffic flow for these user groups and contribute to a high level of safety.

Iceland

With the exception of some areas in the Reykjavík area and a few other areas in the urban environment, for example Akureyri, traffic density in Iceland is rather low. Accordingly, traffic control measures are not very pronounced. However, instead of congestion due to overloading, roads in Iceland occasionally have to be closed due to weather conditions, especially in the highlands. Where necessary, modern systems are used, for example with automatic license plate recognition. In urban areas, there are a few bus lanes as well as bike lanes.

Liechtenstein

The transport network in Liechtenstein is manageable due to the size of the country and does not contain any highways. In the inner-city area, Liechtenstein has two bus lanes; further traffic-steering measures are controversially discussed, but have not yet been implemented.

Norway

There are three HOV lanes in Norway around the major cities of Oslo, Kristiansand and Trondheim with an overall length of 7 km. Tolls are currently levied at certain points on the highways to finance specific projects, but congestion pricing is also under review. In addition, there are initiatives to electrify traffic as quickly as possible.

Bus lanes have been installed in most cities in Norway to speed up public transport. In addition, bicycle traffic plays an important role and is often handled on dedicated lanes.

Switzerland

Switzerland is currently investing heavily in hard shoulder use. To date, around 22 km of hard shoulder clearance are under traffic; in the next few years, this figure is expected to grow to around 250 km. In addition, mobility pricing is currently being prepared. On selected routes, overtaking bans for trucks have been imposed in order to harmonize traffic flow. Studies on automated traffic are also currently underway.

In urban areas, priority is given to public transport, which is handled by dedicated bus lanes, for example.

United Kingdom

The UK leads the way in Europe when it comes to managed lanes. Under the name smart freeway, various active traffic management features are applied on a number of freeways. On 6 highway sections with a total length of over 100 km, the hard shoulder is temporarily released for use. At times of heavy traffic, ramp metering is activated at 88 interchanges. In the Leeds area, an HOV lane of around 1.5 km has also been installed.

There are public transport lanes in the approach to some towns and in the inner-city areas of many towns. Some of these are also used as contraflow lanes.

North Macedonia

The highway network of Northern Macedonia has been massively expanded in recent years and adapted to the changing needs of local and transit traffic. No elements of managed lanes were used in the process.

In Skopje, there is a modern network of bus express lanes, but otherwise no managed lanes are used in urban areas.

Serbia

Serbia does not currently use managed lane systems on its highways. The network has been noticeably expanded in recent years, so that demand can currently be met by existing capacity without special traffic control measures.

Also, no special lanes or similar are currently used in the urban environment.

Turkey

In Turkey, managed lane systems tend to be concentrated in the metropolitan regions in the west of the country. In the Istanbul area, for example, there is a bus lane on the highway that is about 50 km long and a centerpiece of the public transport system. In Istanbul, there are also four reversible lanes, which release additional lanes in the respective direction depending on the daily traffic flow. Trucks are banned from selected routes in the metropolitan regions during peak hours.

In some larger cities, there are bus lanes to accelerate public transport.

Kosovo

The highway and trunk road network of Kosovo is still under construction and is currently undergoing a strong transformation. Currently, no managed lane systems are used on Kosovo's roads.

Summary of the situation in Europe

Figure 1 shows how intensively managed lane systems are currently used in the respective European countries. The darker the color, the more usage there is. The main focus is clearly on Western Europe. The example of Turkey shows how difficult such generalized illustrations are, since the Istanbul area plays a leading role in managed lanes, but no traffic control elements are used in large parts of the country.

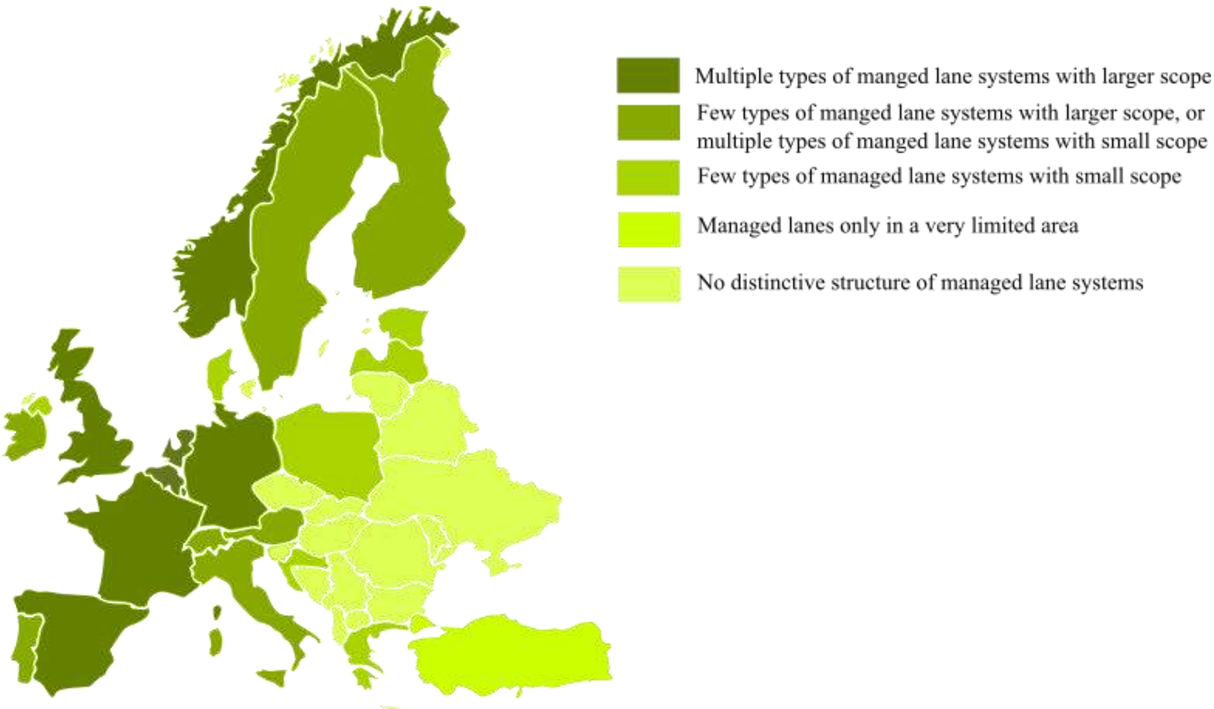

Figure 1: Degree of application of managed lanes in Europe (own findings on the basis of private communication)

COSTS AND BENEFITS

The costs of different managed lane systems vary significantly, not only in terms of initial production, but also in terms of ongoing operation and maintenance. If, for example, an existing lane is dedicated to a static bus lane, the initial construction costs are only in the 5-digit € range per km, and no further costs are incurred in ongoing operation. In contrast, the cost of dynamic traffic control systems can be in the mid 6-digit € range for the construction of a gantry with dynamic displays alone. This requires additional detectors and cameras in the roadway in order to have a sufficient data status for the decision of the respective programs. In addition to the running costs for energy, there are above all the necessary software, a traffic control center and personnel costs for the necessary operators in the control center.

At the same time, the requirements for traffic control systems fluctuate. In inner cities, public transport and occasionally bicycle traffic usually play the central role. The goal here is to create the most attractive public transport offer possible, which allows its users a noticeable gain in travel time compared to their own cars, while at the same time protecting the vulnerable traffic participants. Public transport continues to play an important role in interurban and long-distance traffic, although it is no longer as dominant as in the inner-city area. Central elements here are the safety and ease of traffic. Particularly in the vicinity of metropolitan areas, attempts continue to be made to accelerate public transport compared to private transport, but the general aim is to stabilize and accelerate the flow of traffic, while at the same time announcing risks, for example due to accidents or bottlenecks, at an early stage and adjusting the flow of traffic accordingly.

Municipalities prefer to use static and less complex systems, which require a much smaller superstructure and have lower maintenance costs. In doing so, they accept losses in the performance of the systems, which, however, can usually be well tolerated due to the generally limited system length. This significantly reduces costs, which are difficult to bear, especially for smaller organizational units. Therefore, many cities prefer to use static public transport lanes or bicycle lanes, which lead to an improved flow of public transport and, together with bicycle traffic, create the often politically desired preference for public transport and emission-free traffic. The larger the cities or organizational units become, the more worthwhile it is to invest in dynamic and thus more costly, but also more efficient managed lane systems. Synergy effects reduce the costs per km for traffic control centers, for example, if a larger number of route kilometers are managed there. In addition, static systems reach the limits of their performance over longer distances.

There are three types of benefits that can be distinguished among the benefits of managed lanes. These are capacity-enhancing measures or measures to increase performance, measures to improve traffic safety and measures to prioritize or give preference to selected user groups. A project may include a variety of benefits, but may also include only one of the above. The impact of a managed lane measure on road users depends on the type of measure and varies by project.

If hard shoulder use is used in a project, an increase in the capacity and performance of the road can generally be expected, especially during peak hours. Experience from projects that have already been implemented shows that road users accept the additional lane well and that no losses in traffic safety are observed. The situation is very similar for reversible lanes. Here, too, capacity increases are achieved for the dominant traffic flows in the peak hours, which leads to an increase in the performance of the overall system. For reasons of traffic safety, dangerous points are the start and end points of reversible lanes, especially when the direction of travel changes. As a rule, however, such lanes are used in areas dominated by commuters who know the route well, so that the overall traffic safety corresponds to that of a general purpose lane.
The benefits of a special use lane depend on which user groups it is focused on. Public transport lanes or bike lanes prioritize their respective users over other road users. In doing so, they contribute to an increase in road safety for vulnerable road users and improve the quality of public transport by shortening travel times and reducing delays. Users of general purpose lanes, however, must expect delays due to denser traffic. Transit lanes or truck lanes, on the other hand, try to homogenize the traffic flow by separating certain user groups and thus improve the traffic quality for all road users.
The effects of HOV lanes are similar to those of public transport lanes. By giving preference to highly occupied vehicles on certain sections of the route, the aim is to create an incentive for travelers to use

carpools. On the other hand, solo travelers have to reckon with travel time losses and higher traffic densities.
Ramp metering on highways aims to increase traffic safety and homogenize traffic flow. The inflow control moderates overloads and reduces risky interweaving processes into the traffic of the freeway. As a result, delays occur in the approach area of the freeway.

Dynamic control devices, which also include variable speed limits, make a significant contribution to improving traffic safety. By warning road users of accidents, dangerous spots or weather-related risks, speeds and driving behavior can be adjusted accordingly. Homogenization of the traffic flow also leads to an increase in performance. This is partly at the expense of individual travel times.

INTERPRETATION

In terms of the length of the European highway network and the secondary road network, the importance of managed lanes in Europe is still rather low. However, there has been considerable investment in recent years, particularly in dynamic control signs on freeways.

In general, there is a clear separation between urban and rural areas. In the inner cities and around the metropolitan areas, public transport lanes and, in some cases, bike lanes are now part of everyday life in many European countries. Most of these are static systems that are cost-effective to install and operate.

On highways, only dynamic control signs have become established in large parts of Europe. All other managed lane systems focus on specific countries, depending on the local strategies of the traffic authorities and their technical and financial resources. In contrast to the predominantly static local systems, the systems on freeways and trunk roads are mainly dynamic managed lane systems, which incur higher costs for investment and operation.

In general, it can be seen that many managed lane systems, especially cost-intensive ones, are concentrated in the western part of Europe, with a particular focus on metropolitan areas. The reasons are likely to be a generally higher degree of motorization and a nodal function and effect for traffic flows, since many highways are oriented toward the larger cities. In addition, such centers harbor a number of pull factors for traffic, such as workplaces, special facilities for non-daily needs, cultural facilities, as well as trading centers and goods transshipment points. Since, as explained, in the metropolitan area it is often almost impossible to expand or build new transport routes, the transport authorities try to maintain an efficient transport system by means of traffic control measures.

The experience of recent years shows that a further expansion of managed lane systems can be expected in the coming years. It has recently become apparent that measures are also taken in many countries that have not yet been used there, but have already proven their worthiness in other countries. The EU's efforts to standardize and harmonize managed lane systems already have a clear impact in the field of dynamic control signs in recent years and show promising approaches in other thematic areas.

CONCLUSION

In transport planning in Europe to date, attempts have always been made to counter bottlenecks and obstacles by expanding and building new roads. This development is now coming to an end, especially in Western Europe and in metropolitan areas. The development in Europe is divided into two parts. In many Eastern European countries, the construction of trunk road networks has not yet been completed, and in rural areas in particular, bottlenecks are being tackled using the familiar methods. Among other things, EU subsidies are being used to try to create a uniform network of traffic routes throughout Europe and to equalize living conditions. In addition, the level of motorization of the population is still below the European average, although steady growth rates have been recorded here for years. This contrasts with many countries in Western Europe and the regions around Europe's metropolises. Here, there is usually a network of routes that has grown over decades and to which the settlement structure has responded. New buildings and expansions are hardly possible due to the constricted space conditions and space utilization conflicts, while traffic volumes continue to rise. Those responsible are

reacting to this problem with innovative approaches to increase the performance and efficiency of the transport networks.
Selected concepts are being promoted by the European Union and advanced in projects throughout Europe. A lighthouse project in recent years has been the ITS project mentioned at the beginning of this article, which aims to increase safety on the roads while at the same time enabling networking between vehicles and infrastructure and optimizing traffic flow. In addition, there are a large number of national and even regional projects. However, most of these are not coordinated at European level, so that the same measure may be named and/or implemented differently in different countries. A similar situation can already be observed in the USA, where HOV lanes run under different names, such as diamond lane or community lane. In general, the topic of managed lanes has gained massive importance in Europe in recent years and will probably continue to do so in the coming years. A high level of innovative spirit can be observed in the individual projects, which can be attributed not only to financial reasons and spatial conditions but also to a change in public perception and attitude. Based on this, the potential of managed lanes in Europe will be investigated in the next steps by means of simulations, calculations and further investigations. The aim is to develop a tool that is as intuitive as possible in order to predict whether, and if so, which type of managed lane system can lead to added value on a particular stretch of road.

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The authors confirm contribution to the paper as follows: study conception and design: Th. Schoenhofer, K. Bogenberger; data collection, analysis and interpretation of results: Th. Schoenhofer; draft manuscript preparation: Th. Schoenhofer, K. Bogenberger. All authors reviewed the results and approved the final version of the manuscript.

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