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Abstract

Current land transport is not optimal. Road transport is congested and rail transport is under-utilised and unprofitable. Land transport is based on the burning of fossil fuels and contributes to climate change. Hence the EU’s desire to push for electric propulsion on the road and to make rail the backbone of Europe’s transport system. Developments in transport are solving some problems but creating others. The ComplexTrans project addresses private and public transport of people and freight in and between cities and removes current and upcoming transport problems in a natural way (without restrictions and subsidies), based on the mutual adaptation of electric road and rail vehicles and their deep intermodal and multimodal cooperation and using fast mixed passenger/freight trains. The solution for land transport is not competition but cooperation between road and rail.

Keywords: transport, road, rail, intermodal, multimodal, e-mobility, battery exchange, recharging infrastructure, city transport, renewable energy

1. Introduction

1.1 The current state of transport

The main current modes of transport are

• land (road and rail) transport, which provides transport of passengers and goods mainly over short and medium distances (up to about 1000 km), with road transport dominating over rail transport

• air transport, which mainly carries passengers over medium and long distances (from about 500 km)

• and shipping, which mainly transports goods over medium distances (river transport) and long distances (maritime transport).
All these modes of transport have their advantages and disadvantages. A common problem with all modes of transport (except electrified rail transport) is their dependence on fossil fuels and the production of greenhouse gases that contribute to climate change.

1.2 Current state of transport development

The current state of transport development can be characterised by these main objectives.

1.2.1 In the field of emissions

Switch the majority of continental passenger and freight transport from road to rail in order to reduce the energy intensity of transport and emissions, both as a result of the lower energy intensity of rail and the increasing possibility of powering electric rail with renewable sources of electricity.

Replace continental passenger air transport over medium distances by high-speed rail, which can offer shorter or comparable overall travel times over distances of up to about 1000 km.

Use more river and sea transport for freight. However, this mode of transport is linked to waterways and sufficient water in rivers.

Replace combustion engines in cars with emission-free powertrains. At present, the development of emission-free drives is mainly focused on the following directions

a. development of synthetic fuel for internal combustion engines,

b. battery-powered independent electric motor propulsion,

c. independent electric propulsion powered by a fuel cell drawing energy from hydrogen and

d. dependent electric propulsion powered by trolley or non-contact (inductive).

All these methods of eliminating emissions can only be successful if the electricity is generated by emission-free sources.

1.2.2 In the field of transport

Reduce the number of private cars by (autonomous) car-sharing.

Replace human driving with autonomous driving. And autonomous driving means also need for connectivity and 5G networks.

By creating and extending MaaS.

So, the aim of the development in land transport is to shift the transport of goods and passengers from road to rail, to shift continental air transport up to 1000 km to rail and to reduce air transport, to strengthen water transport and to have full battery or hydrogen electromobility in road transport, probably also associated with a reduction in the number of cars, which will be replaced by autonomous car sharing. The use of public transport should be made as easy as possible by the introduction of
the IT platform MaaS. Developments in land transport, in conjunction with renewable energy sources, are heading towards zero emissions, but also to a restriction of freedom of movement, unless much more suitable traction batteries are available.

Could transport development be organised in such a way that transport emissions are reduced to zero, whilst at the same time individual freedom of movement is not restricted, parking problems are eliminated and traffic density is reduced, the switch from road to rail is voluntary, more air transport can be transferred to rail and rail becomes self-financing? Is there such a transport solution?

Yes—it exists, it is based on a deep cooperation between road and rail and is described in next chapters.

2. Methodology and results

There is one transport solution that can cope with the demands placed on land transport much cheaper and better than the above set of transport solutions currently being developed and implemented. It shifts most passenger and freight traffic from road to rail without any restrictions, effectively replaces continental air transport with rail transport up to a distance of about 3000 km, removes the problems of parking and congestion in and between cities, makes rail self-financing, increases speed, comfort and safety, makes land transport independent of fossil fuels and, in cooperation with renewable sources of electricity, makes it carbon-free. And brings many other benefits.

This solution is called ComplexTrans [1–4] and is based on the mutual adaptation of road and rail vehicles and their deep cooperation with each other and with renewable electricity and on exploiting the synergy of all systems working together (Figure 1).

ComplexTrans deals with private and public door-to-door transport of people and goods within and between cities, using almost exclusively electricity for propulsion. Whilst local transport is carried out by road, long-distance transport is mainly carried out by rail. A variant of long-distance transport is the use of the road, with electricity supplied to the vehicles by interchangeable range-extenders powered by hydrogen, synthetic fuel or, temporarily, fossil fuels.

Figure 1. ComplexTrans "takes everything"—people, cars, transport modules, wagons—like an 'overland ferry'.
3. Results

3.1 ComplexTrans rail vehicles

The ComplexTrans system has basically two types of rail vehicles (Figure 2).

3.1.1 Fast train units for mixed passenger and goods transport

are made up of end and inserted double-deck carriages with Jacobs bogies (Figure 3), whereby the lower deck is used for the transport of adapted passenger vehicles (so-called coupemobiles) including their crew and/or freight transport modules; and the upper deck is used for the transport of passengers and/or delivery boxes which are carried in the places not occupied by passengers. Small variable compartments of two sizes for 2(1) or 4(2) seated (lying) persons are used for transportation, providing sufficient privacy and comfort for passengers.

The 400 m train unit consists of either two nine-carriages units with integrated service carriage or four four-car units with two separate service carriages. From the rear the fast freight waggons are attached to the train units (Figure 4).

The units are equipped with automatic couplers and allow easy splitting of trains. The front carriages allow passage to the adjacent unit. Propulsion is electric and distributed.

Figure 2.
ComplexTrans train consists from fast units with double deck mixed carriages.

Figure 3.
ComplexTrans double-deck rail carriage for mixed passenger and freight transport. The upper deck carries passengers or delivery boxes in small compartments (left), while the lower deck carries adapted passenger and freight vehicles. Sanitary facilities are available on both floors.

Figure 4.
The mixed train ComplexTrans consists of two or four fast train units for mixed transport of passengers and goods with a length of 400 m (left) and fast freight cars (right).
The carriages are compatible with the European GA, GB outline for electrified lines and can stop at ComplexTrans double-deck platforms as well as at all common European platforms of all heights (550, 750 and 950 mm). The operating speed is 230 km/h and the maximum axle load is 17 t. With a distance of terminals approximately 50 km and a stopping time of 3 minutes, the average speed of ComplexTrans fast trains is 150 km/h.

Thanks to the flexible interior of the trains as well as the passenger and freight transport modules, the entire capacity can be flexibly changed from 100% passenger to 100% freight (Figure 5).

3.1.2 Fast rail freight wagons

are attached individually or in small groups to the ends of ComplexTrans trains and are used to transport larger or heavier loads between sidings. These are covered flat wagons with an integrated pocket/basket for transporting vertically manipulable and non-manipulable freight trailers.

The drive of the car can be controlled by the train bus, remotely or by its own control unit autonomously, with the control unit also carrying all information about the load. An automatic coupling allows quick coupling and uncoupling and an electrically operated brake allows a quick two-phase brake test (Figure 6).

Figure 5.
ComplexTrans double-deck rail carriages can be operated on all European electrified rail networks with outline GA, GB, G2 and larger.

Figure 6.
The ComplexTrans fast rail freight wagon has an automatic coupling, self-propulsion - 500 kW with energy storage and is equipped with a hinged cover. Operating speed 230 km/h and axle load max. 20 t. It can transport sea containers, cargo trailers, transport modules and other large goods.
3.1.3 Fast direct trains

connect the main stations or terminals of the main and major cities, do not stop at intermediate passenger-cargo terminals and stop only every approximately 250–300 km. At the same operating speed of 230 km/h they reach a cruising speed of over 200 km/h. They may or may not be of the ComplexTrans type.

3.2 ComplexTrans road vehicles

The road transport in the ComplexTrans system is mainly provided by adapted electric cars.

3.2.1 Coupemobiles

are four-wheeled passenger cars adapted for fast loading, unloading and transport on ComplexTrans trains. Their main features are a spacious cabin, approximately in the shape of a cube with rounded edges, with a variable interior for 5 adults and their luggage, forward and reverse retractable axles with adjustable ground clearance and impact protection function, and an electrically driven rear axle from the back replaceable traction battery. The variable interior can be easily adapted for on-road driving, for work, play or rest for up to five people, or for two people to sleep comfortably (Figure 7).

3.2.2 Road freight transport modules

are enclosed four-wheel “vans without driver’s cab” and are used for the transport of piece goods, Euro pallets or air containers. They are propelled by a battery-powered electric motor with a capacity sufficient for a range of 50–100 km (Figure 8).

Similar to the coupemobile, the freight transport module has forward and reverse extendable axles with height adjustability and crash protection. Both axles are retractable and equipped with a coupling and at least one wheel of each axle is driven.

Figure 7.
Coupemobile, a passenger e-car of the ComplexTrans system for the comfortable transport of five adults and their luggage. Retractable axles, from the back swappable battery, roof grip points and couplers give these cars a whole new range of possibilities, an “unlimited” range and a widely acceptable price.

Figure 8.
Long and short freight transport module for transporting goods in ComplexTrans mixed trains. It has its own electric drive, is transported to the end users by road platoons with a guiding vehicle, and can be remotely controlled for local manipulation.
by an electric motor (cross-placed). All wheels of the long transport module can be swivelled 90° when loading into the train.

The maximum weight of the loaded transport module is 3.5 t, the maximum speed in a platoon is approx. 90 km/h and in a solo journey approx. 25 km/h.

3.3 Terminals: interfaces between road and rail for the transfer of people and goods

In order for road and rail vehicles to work together, road-rail interchange terminals need to be built. In the ComplexTrans system, terminals are shared for passenger and freight transport, but passenger and freight transport are separated for safety and traffic reasons. Two-storey platforms are used for passenger boarding and alighting and loading and unloading of parcel delivery boxes takes place on the upper platform floor, whilst loading and unloading of passenger and freight vehicles takes place on the lower platform floor (Figure 9).

The terminals are located on the outskirts of towns so that the road vehicles carried on the trains do not clog up the town centres. In accordance with the different sizes of cities, there are two types of terminals—terminals and semi-terminals (Figure 10).

The terminals will also include preparatory and staging car parks for the vehicles being transported.

Figure 9. Two main and two additional double-deck platforms for passenger-freight exchange. The train stopping time in the terminal can be reduced to about 3 min.

Figure 10. ComplexTrans (semi-)terminals on the outskirts of cities are used for passenger boarding and alighting as well as cargo loading and unloading; central stations can be used for passengers only.
The terminals will also include freight tracks where fast freight wagons will wait to connect to and depart from ComplexTrans trains and will be loaded and unloaded at the terminal if they will be carrying shipping containers or car trailers, or will be transported on regional tracks and sidings to their consignees (Figure 11).

4. Main contributions

The main benefit of the ComplexTrans system is the fact that, thanks to the synergistic cooperation of road and rail door-to-door transport, it solves virtually all the problems of interurban and urban transport of passengers and goods, converts a significant part of continental air transport to rail transport and electrifies the entire land transport. In addition, they are strong supported renewable sources of electricity and reduced the energy consumption.

4.1 Rail: door-to-door mixed transport of ComplexTrans system makes the rail a backbone of ground transport

The double-deck ComplexTrans trains operate at 230 km/h between terminals about 50 km apart at short intervals (3–15 min) and carry passengers, coupemobiles and freight in mobile transport modules, enabling door-to-door transport of passengers and freight (Figure 12).

The mixed transport of passengers and freight and the high frequency of trains will create a self-financing [5]. European backbone transport system similar in nature to ferry shipping (Figure 13). If about 10% of the European rail network (TEN-T corridors, approx. 20,000 km) is adapted to the ComplexTrans rail transport system, a transport system capable of accommodating all current transport needs in Europe in volume terms will be created. However, in order to bring the transport system sufficiently close to the transport needs, the ComplexTrans system will have to be implemented on about a quarter of the European rail network (approx. 50,000 km, approx.
Small compartments for 2/1 or 4/2 seated/lying persons on the upper floor allow comfortable individual transport day and night. Compartments not occupied by passengers are used for the transport of delivery boxes. On the lower floor, passenger transport in own coupemobiles or passenger transport modules as well as cargo transport in freight transport modules is possible. The flexible combination of passenger/freight transport ensures full capacity utilisation and self-financing of ComplexTrans trains.

The ComplexTrans network of fast trains resembles "land ferries" that traverse Europe, taking everything—passengers, passengers with their cars, freight transport modules with goods and fast rail wagons with bulky or heavy cargo.
1000 terminals). Even at this scale, ComplexTrans will be fully self-financing, with transport prices comparable to or lower than today’s market prices.

It can be said that ComplexTrans more than meets the EU/EC’s objective of shifting the majority of freight and passenger transport to rail in order to reduce both energy intensity and CO2 emissions. Importantly, this task can be met by ComplexTrans without any restrictions on road and air transport and without operating subsidies in favour of rail transport. It is sufficient for the EU/EC to support only the initial development and evolution of the system and then the rail system will transform itself into the backbone of European transport. ComplexTrans also helps to protect against the spread of contagious diseases in public transport.

4.2 Replacement of continental air connections by fast night trains

The ambition of the ComplexTrans system is to take over most of the road transport of passengers and goods over medium (from 150 km for passenger transport and from 50 to 100 km for freight transport) and long distances.

In addition, the ComplexTrans system is also capable of taking over a significant part of continental air passenger transport. Thanks to the possibility of using night time for transport in fast ComplexTrans trains (and thus a head start of \(8 \times 200 = 1600\) km), rail transport up to a distance of almost 3000 km is more time-efficient than air transport and up to a distance of about 2300 km. It is possible to make a working round trip in one day and two nights, with more than 6 h available for the actual handling of work matters at the destination (Figure 14).

In this way, up to about 90% of continental European air destinations can be replaced by rail, and passenger volumes are even higher, because in the destinations with the highest passenger numbers (Berlin, Brussels, Zurich, Milan, Paris, …) it will be possible to replace air transport by rail to an even greater share. (Figure 15).

Figure 14. ComplexTrans day-night trains with an operating speed of 230 km/h and three operating modes (direct, stopping and during night slowed stopping train) will replace very fast trains and planes up to distance of 3000 km and make super fast technologies (Maglev, Hyperloop) unnecessary.
4.3 Urban transport

4.3.1 Urban passenger transport

The road passenger transport in the ComplexTrans system is based on private cars called coupemobiles—i.e. passenger cars with a large cabin for five passengers with extendable axles, which have four roof grip holes for vertical handling and, if necessary, couplers for coupling into road trains (platoons). These features enable the following changes in urban transport:

4.3.2 Parking

Coupemobiles allow to reduce parking requirements in two ways—by retracted axles during parking and by lifted parking (Figure 16).

Figure 15. From Brussels by fast train in one day and two nights to almost every corner of Europe and back. Red—3.5 h, violet—3.5 h + one night by slowed stop train, green—3.5 h + one night by stop train, blue—3.5 h + one night by direct train).

Figure 16. Parking perpendicular to the sidewalks reduces the need for parking spaces by a factor of two (left). Advanced car overhead parking systems (right); parking over pavements, parking towers or balcony parking—reducing the need for parking areas at least by a half. During advanced parking, the batteries of the coupemobiles are automatically connected to the power grid.
4.3.3 Driving private vehicles in platoons to reduce traffic density

The front and rear axles of coupemobiles can be fitted with couplers. By means of couplings several (2–6) coupemobiles can be joined into a platoon, controlled by the driver of the front vehicle. The platoons also allow for increased traffic light crossings throughput and will be able to use standardised lightweight intersection bridges to further reduce traffic density (Figure 17).

4.3.4 Use of private vehicles in public transport

It is likely that drivers registered to ride in the platoons will travel through the city frequently and over a sufficiently long route. Therefore, they could offer free seats in their car (coupemobile) to public transport passengers during their journey. Similar to Uber, for example (Figure 18).

4.3.5 Freight transport in the city (door-to-door)

For road freight transport in cities, the ComplexTrans system primarily uses four-wheeled freight transport modules with their own electric battery drive, retractable axles and 90° swivelling wheels (Figure 19).

4.3.6 Delivery boxes

For the transport of small consignments (up to 0.5 × 0.5 × 1 m) there are delivery boxes with variable partitions, transported in ComplexTrans trains on the upper deck in places not occupied by passengers (Figure 20).

Figure 17. Private coupemobiles, travelling in a similar direction, can be grouped together in tight platoons during the journey (especially in cities, but also outside them). The platoons reduce traffic density by up to three times and can take advantage of some traffic benefits (e.g. lightweight intersection bridges—see right).

Figure 18. Platoons of private coupemobiles can also be used for organised public transport on a voluntary basis. The owners of the coupemobiles enter into a contract with a transport operator and the latter organises via an app ad-hoc the use of the free spaces in the coupemobiles for the transport of registered passengers during their journey through the city. This creates a complementary high-capacity, comfortable transport system that is able to reduce traffic density by up to three times and benefits all its users—passengers, coupemobile owners and transport operators.
4.4 Intercity road transport

Although all ComplexTrans vehicles are electric, their intercity operation will also be more efficient and at least as convenient as that of internal combustion engine vehicles.

4.4.1 ComplexTrans intercity passenger road transport

The private passenger intercity road transport in the ComplexTrans system is primarily provided by private cars, called coupemobiles (Figure 21—left). The maximum operating speed of coupemobiles is approximately 130 km/h and the range up to 200 km. For longer distances, it is advisable to use also train transport (Figure 21—right).
For bigger range (about 500 km) the traction battery can also be replaced by a so-called range extender (Figure 21—left), which is an electric generator powered by a combustion engine (fossil fuel or e-fuel) or a hydrogen cell (H2).

The coupémobiles, equipped with a coupling, will be able to be combined into platoons for longer distance transport (Figure 21—left). This will save energy consumption due to the reduction in aerodynamic drag and the crews of some coupémobiles will be able to work, amuse or rest during the journey.

4.4.2 ComplexTrans intercity road freight transport

It is assumed that distances of over 50–100 km will be covered by freight transport modules primarily using the train. For shorter distances, freight transport modules will be transported by road in road platoons with a guide vehicle (Figure 21—bottom left).

Trucks will continue to be used for the transport of large or heavy goods, but there will be fewer of them. Truck trailers or sea containers can be transported by ComplexTrans fast freight waggons.

4.5 The contribution of ComplexTrans to electromobility

The ComplexTrans ground transport system uses only electrically powered vehicles with three types of power supply for transporting people and goods.

4.5.1 Types of power supply for electric drives

The first type is to supply the electric drive of double-deck railway units from the overhead line.

The second type of power supply is battery power, which is used for passenger cars (coupémobiles), for road freight and passenger transport modules and local for fast freight rail waggons. The traction battery is unified with dimensions of about 60 × 40 × 35 cm, has a capacity of 30–40 kWh and is easily replaceable from the back/side using standardised handling equipment.

The third type is the supply of power to the electric drive by a range extender, powered primarily by a hydrogen fuel cell, but also by an internal combustion engine burning synthetic or fossil fuel, which is temporarily placed at the rear of the coupémobile.

4.5.2 Attractive e-mobility

E-mobility, as it is practiced today, is not very attractive because a battery of sufficient capacity is very expensive and increases the price of vehicles disproportionately, because charging the battery even with the most powerful chargers (350 kW) takes 15 times longer than refilling the tank with fossil fuel, because building a sufficient charging network will be very difficult, and because searching for refuelling places a disproportionate burden on the owner of the electric vehicle. Today’s EVs provide half the utility value for twice the price.

ComplexTrans cars, however, eliminate all these problems in the following way (Figure 22):

Possibility to replace the battery from the back and parking of the coupémobiles perpendicular to the pavement allow discharged batteries to be swapped for charged ones anywhere via distribution vehicles. The traction battery can remain in the ownership of the distributor and the price of a new vehicle is comparable with the price of
a conventional internal combustion engine car. This will have a positive effect on the interest in electric vehicles even amongst less well-off people.

The fact that the battery is not part of the vehicle will also boost the used EV market, as the condition of the battery will not affect the marketability of the vehicle and the used EV will have the same battery as a new EV.

There is no limit to the range of the car because it takes only tens of seconds to change the battery and the battery can be replaced by a range extender, with which the range increases to at least 500 km and the tank can be refilled in a few minutes. The battery can also be changed anywhere and there is no risk of “range anxiety”.

The owner of the electric car will also be free of the need to worry about charging the battery forever.

### 4.6 Supporting renewable energy with system ComplexTrans

The ComplexTrans system strongly supports renewable electricity (solar and wind) by creating a giant electricity storage that is connected to the grid much more frequently than other EV systems. The batteries of coupémobiles are automatically connected to the electricity grid not only when they are recharged at central charging stations, but also when they are transported on trains or when they are parked in all non-standard ways. And importantly, the owner of the traction batteries is the electricity distributor, who will find it much easier and more willing to switch to V2G mode and easily decide to switch the batteries to stationary energy storage mode.

### 4.7 Benefits of ComplexTrans to reduce energy consumption and emissions and protect the climate

The ComplexTrans system can be powered entirely by electricity, partly by hydrogen produced from water using electricity. If all sources of electricity are renewable, ComplexTrans ground transport will become fully renewable and completely emission-free.

The ComplexTrans system is capable of transporting all passengers and most of the goods, carried by the freight transport modules, using only electricity and largely by rail, consuming less energy.

The ComplexTrans rail transport is also capable of completely replacing continental air transport up to a distance of about 3000 km and replaces the fossil fuels by electricity.
Large and heavy goods will continue to be transported by trucks or sea containers. Also semitrailers and containers are transported on the ComplexTrans system by fast electric rail waggons, and first and last mile services may be provided by electric or hydrogen powered trucks.

Thus, the vast majority of passenger and freight transport can be provided emission-free by ComplexTrans.

5. Conclusion and future works

The ComplexTrans system, full combination of rail and road, is able to take over the vast majority of overland transport of people and goods between and also within cities, and a large part of continental air transport, using only electricity supplied to the vehicles via catenary, traction battery or in the form of hydrogen converted into electricity in the fuel cell.

In doing so, the ComplexTrans system retains all the advantages of individual mobility and also mass transit takes on the character of individual transport, making it more attractive.

With the same mobility, the traffic load on cities is reduced (up to 3–10 times), parking requirements are reduced (up to 2 times) and the supply of parking is increased without taking up new space (at least 2 times).

The electromobility of the ComplexTrans system becomes attractive, and in cooperation with renewable sources of electricity, land transport becomes independent of fossil fuels and climate neutral.

The speed and safety of land transport will be increased by transferring a significant part of the transport capacity from the road to day and night fast trains, crossing Europe at speed of over 200 km/h and effectively replacing continental air transport up to a distance of about 3000 km.

The efficient combination of passenger and freight transport makes the ComplexTrans railway self-financing, and through efficient cooperation with road the rail is able to provide door-door transport for people and freight.

The implementation of the system can be phased over decades, but it is advisable to start as soon as possible because climate change will not wait, fossil fuel shortages loom and current European transport is not optimal. However, several steps need to be taken before implementation can begin.

First of all, there needs to be a broad European consensus on the implementation of ComplexTrans, because the ComplexTrans project will not happen without broad European support.

Next, the joint development of all major components needs to be done and a standard has to be developed to ensure the compatibility of all system components. All components will need to be manufactured and tested.

Furthermore, a pilot project will need to be put into operation and the ComplexTrans standard will need to be refined on this basis. It can be estimated that the pilot project can be put into operation within 10 years from the start of the project (kick-off).

As soon as the pilot project starts to show positive results, it will be possible to start the implementation of ComplexTrans on a wide scale.

It would be highly advisable for the development and provision of the basis for the production of ComplexTrans components to be carried out under the auspices of the EU, as the project is too large for the business community and, moreover, its development could be hampered by an overly competitive environment.
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Author details

Jiri Hofman*, Roman Cermak and Jiri Korinek
University of West Bohemia, Pilsen, Czech Republic

*Address all correspondence to: jihofman@kks.zcu.cz
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