RUF capacity

RUF International, May 2010, www.ruf.dk

SUMMARY:

A RUF DualMode system can obtain very high capacity by organizing the vehicles in small trains.

The RUF vehicles access the triangular monorail at 30 km/h with a separation of 5 m. This means that a 3 m long RUF car will access the monorail every second. With this vehicle, the capacity is 3,600 veh./hour/dir. or 7,200 pass. per hour per direction.

A Mega-RUF vehicle (bus with 20 seated pass.) can obtain 48,000 seated pass./hour/dir.

If the trains are created before access to the monorail, this capacity can be increased to 72,000 pphpd.

Assumptions:

Vehicles:

Top speed on line = 150 km/h
Switch speed = 30 km/h
Acceleration to 75 km/h = 0.2 G
Acceleration from 75 to 150 km/h = 0.1 G
Deceleration from 150 km/h to 30 km/h = 0.2 G
Emergency brake deceleration = 1 G

Giga-ruf: Standard container carried by 2 RUF boogies
Mega-ruf: 20 seated passengers in a 7 m long vehicle (no standing)
Maxi-ruf: 10 seated passengers in a 7 m long vehicle
Midi-ruf: 6 passengers in a 4.5 m long vehicle
Ruf: 4 passengers in a 3.5 m long vehicle
Mini-ruf: 2 passengers in a 3 m long vehicle
Micro-ruf: 2 passengers in a 1 m long vehicle with 2 road wheels
Nano-ruf: 1 passenger in a 1 m long and 1 m wide vehicle.

Giga-ruf

Mega-ruf

Maxi-ruf

RUF

Mini-ruf

Micro-ruf

Nano-ruf
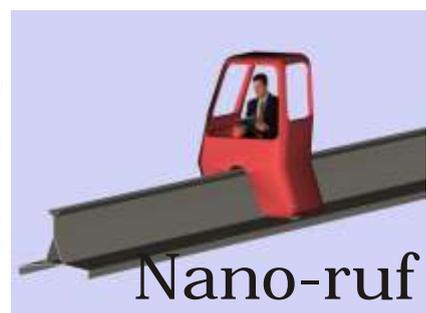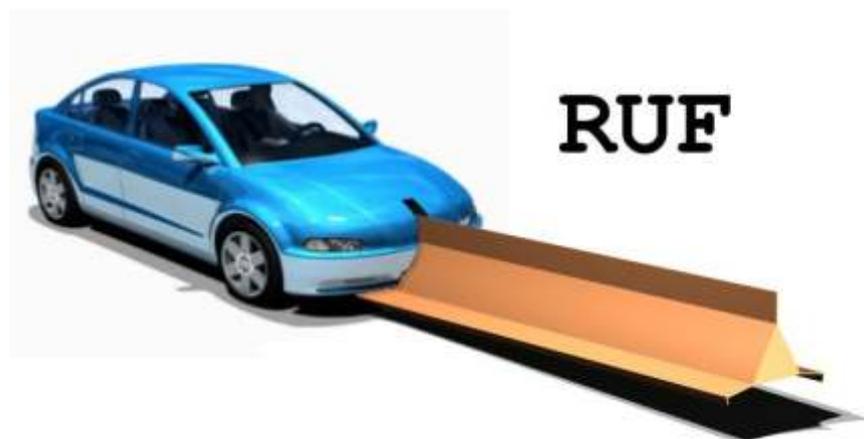
Assumptions:

System:

A RUF network is organized as junctions connected by line segments. The segments are typically 5 km long.
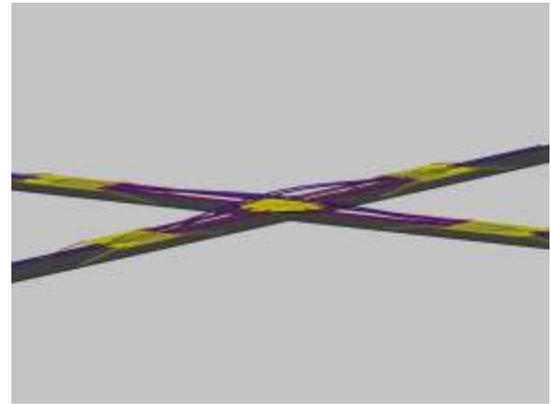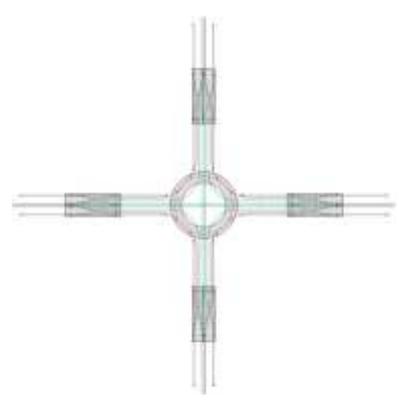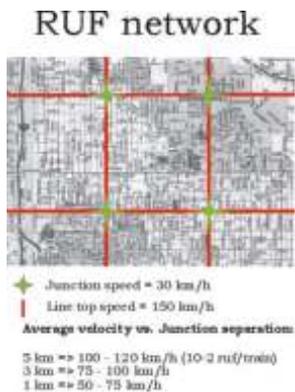
A normal junction consists of 4 satellites and a central roundabout.
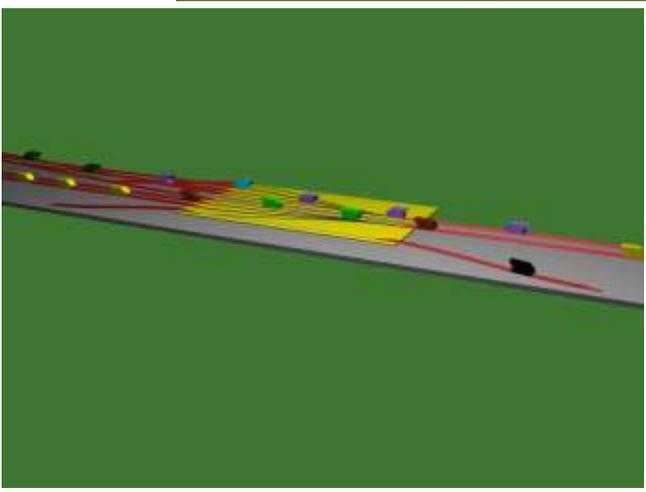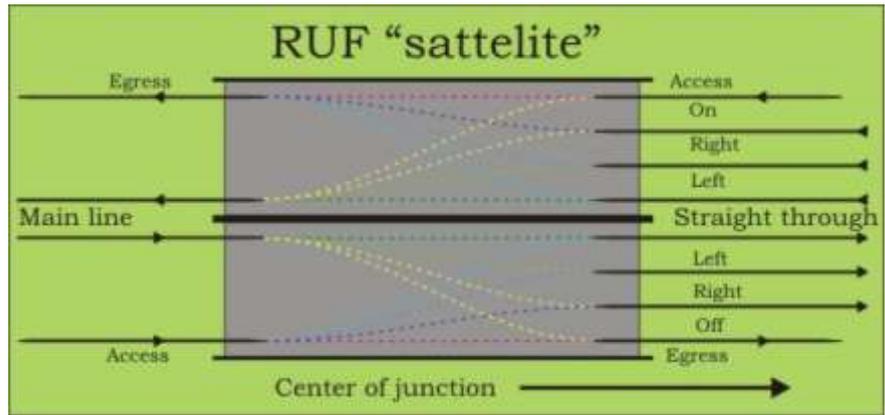
Speed profiles:

Maximum jerk of 2 m/sec^3 is applied for 1 second.
The acceleration will change from 0 to 2 m/sec^2
Both jerk and acceleration levels are within the comfort criteria
Velocity will increase in a smooth curve to Vm
Reversing the process will bring the velocity back to zero
The vehicle will have moved to a new position S5
Normally there will be a period in the middle with constant velocity at a top speed of 150 km/h if there is time to reach that level.
In order to reduce the power requirement for the drive motors, the acceleration will be limited to 1 m/sec^2 between 75 km/h and top speed.


RUF-speed profile
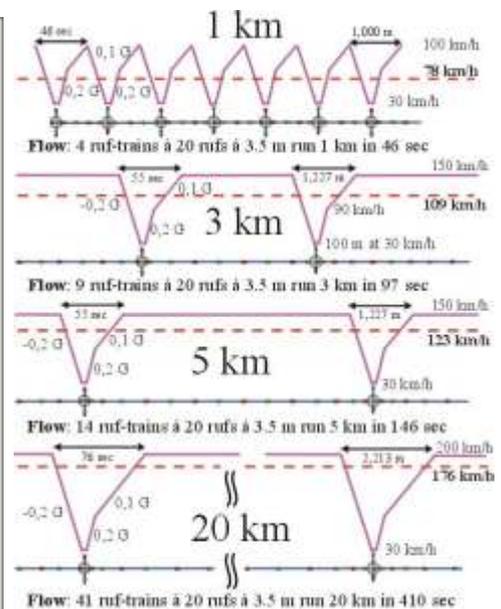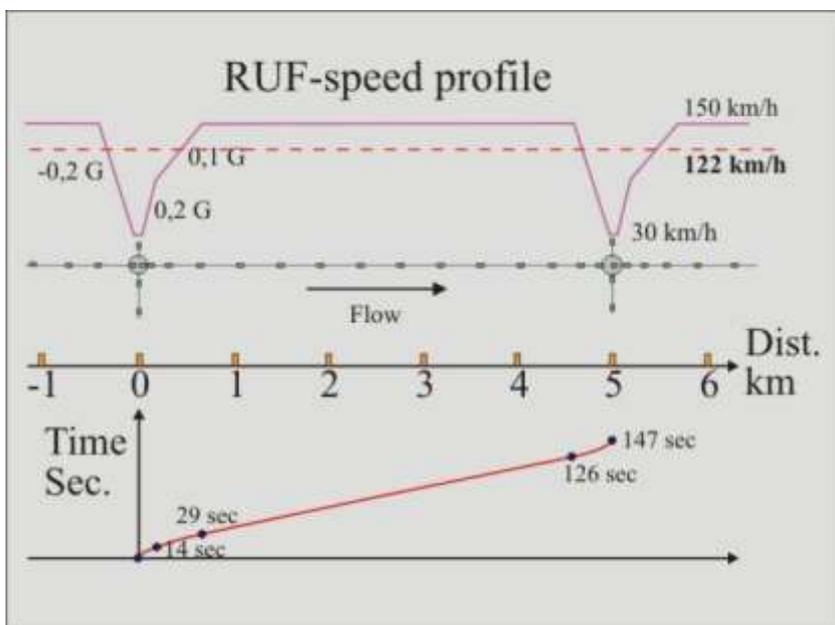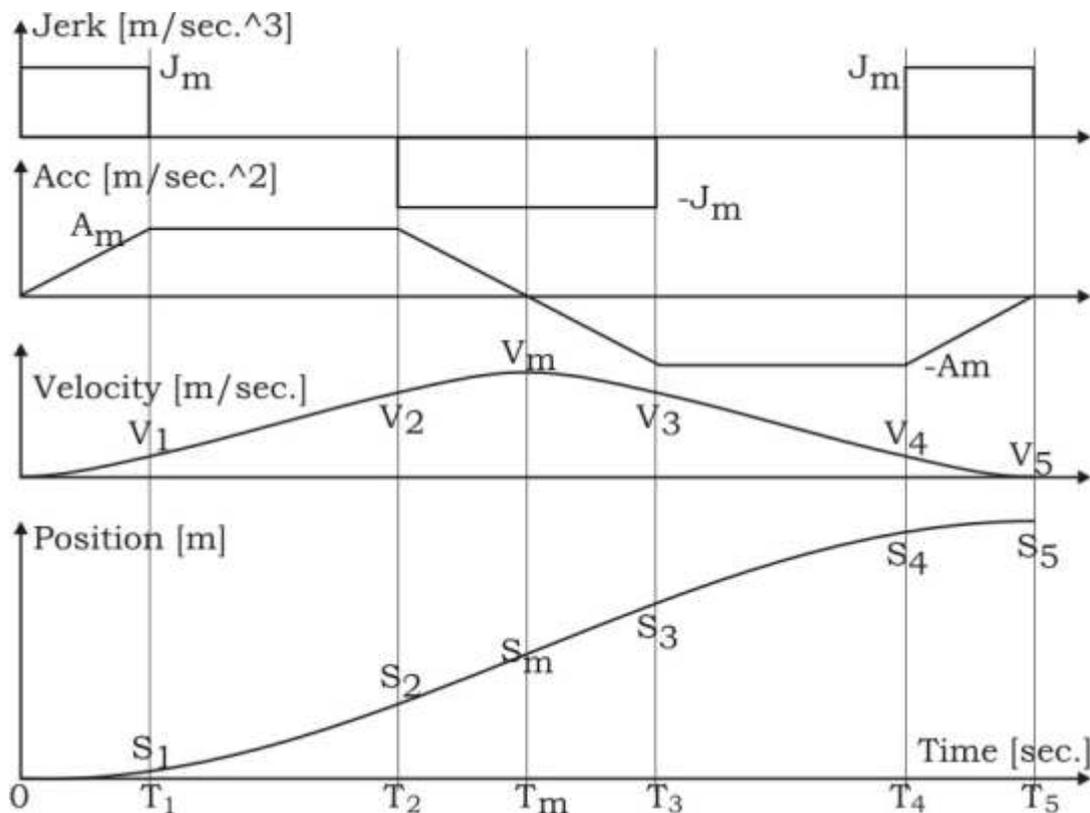
Train creation

All RUF vehicles are able to drive quite close.

The train is created on the monorail where the vehicles can be precisely controlled due to the patented drive system and the triangular monorail.

The RUF vehicles can enter the monorail individually at 30 km/h and with a 5 m separation. This means that one RUF car can enter the monorail every second at approx. 8 m/sec.

Once safely on the monorail the speed will be softly lowered to 3.5 m/sec. This will make the RUF cars softly join together in a train. When the required train length has been created, the train speeds up to top speed on the line.

The control system makes sure that every RUF car (except the front car) will push against the one in front of it. No mechanical coupling is needed.
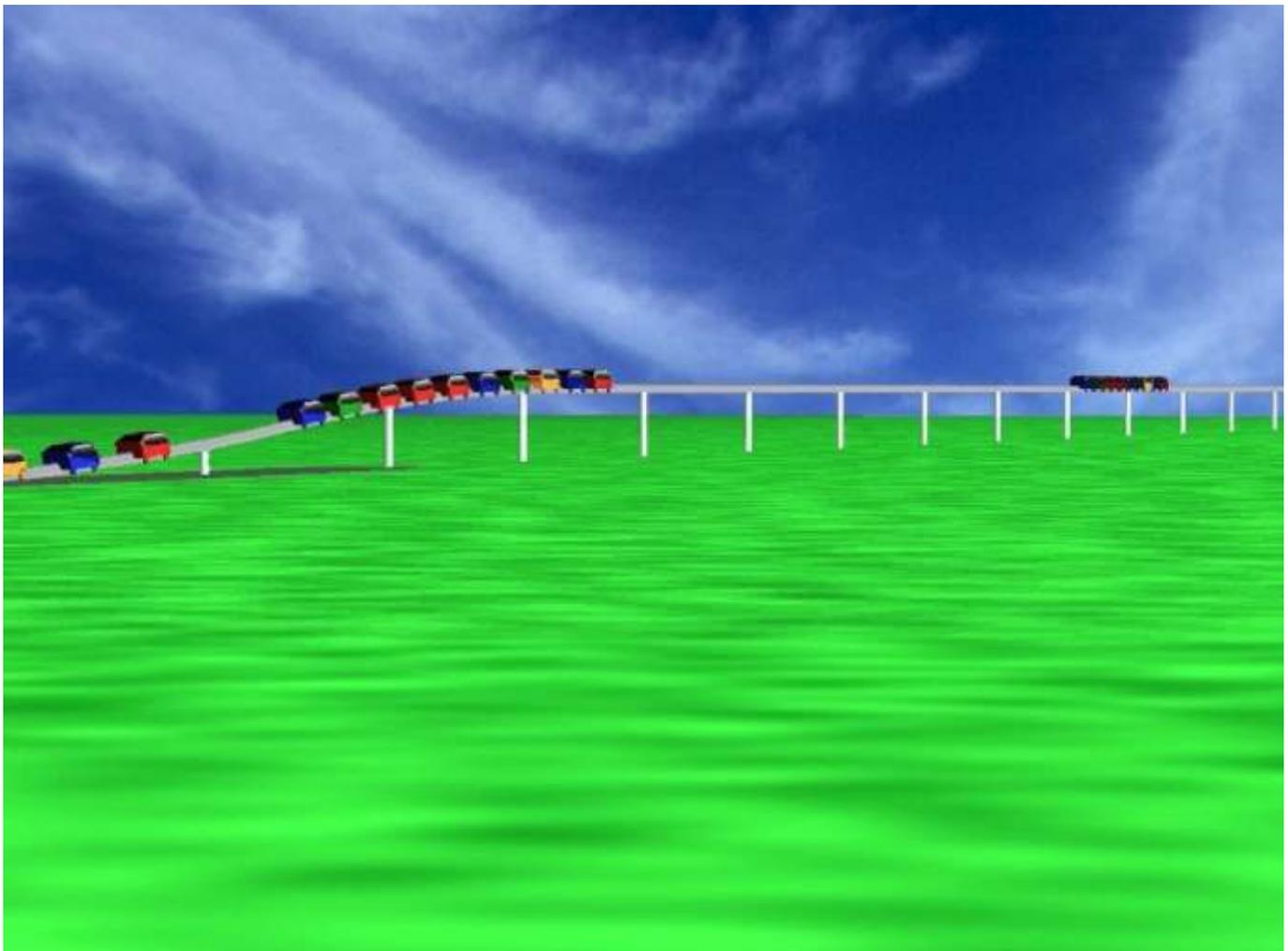
Safety

All RUF vehicles "ride" safely on top of the triangular monorail. Derailment is impossible. The drive wheels are pressed against the top of the monorail in a way so that the vehicle cannot be removed from the monorail even by a tornado.

Collisions between individual cars in a train is also impossible since they already touch each other. The front and the rear are equipped with bumpers which can press against each other in order to maintain the train as one unit and at the same time avoid damage during coupling at low speed.

During high speed the air flow will create a lift on the vehicle. On a highway this would represent a safety risk, but on the monorail it is no problem. It is actually an improvement since the weight of the vehicle will be lowered so the rolling resistance will be even lower than before.
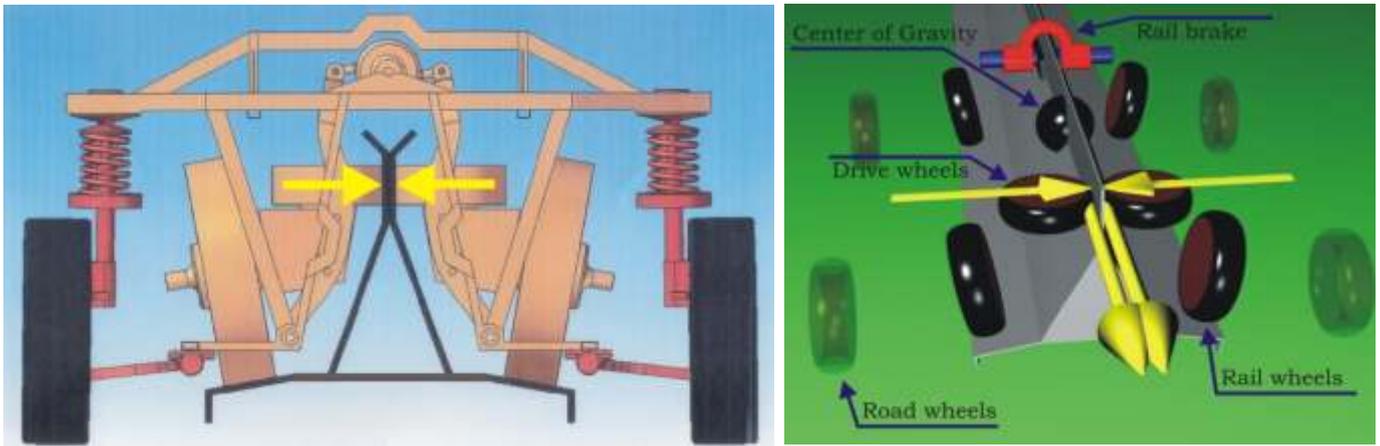
Emergency braking can be made with 1 G deceleration rate under all circumstances due to the very powerful rail brake. It is placed in the rear of the vehicle right behind the center of gravity and it can press against the top of the monorail. The pressure can be increased until the needed deceleration has been obtained.
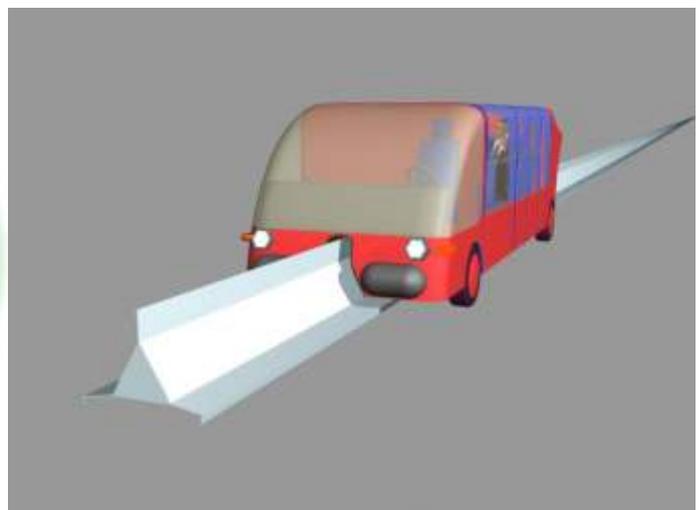
Separation

A simulator of the RUF vehicle flow on a 5 km long line between two junctions has been created with funding from EU research program CyberMove. The simulator can be found at the address: www.ruf.dk/ruftrain.exe

It shows that there is a long separation between trains. The braking distance between the trains is always shorter than the separation.
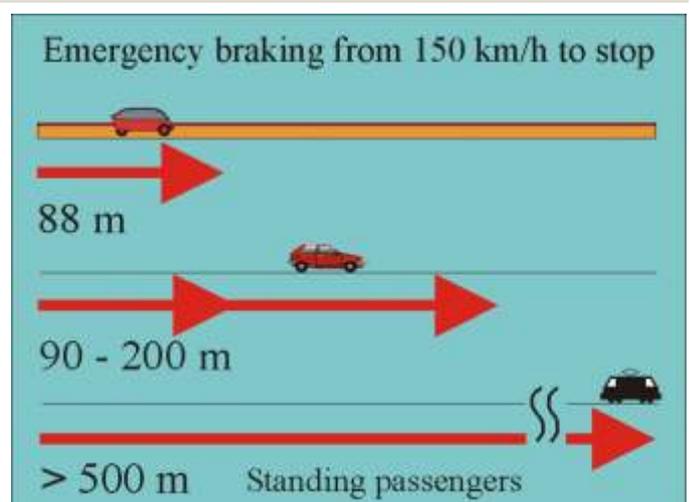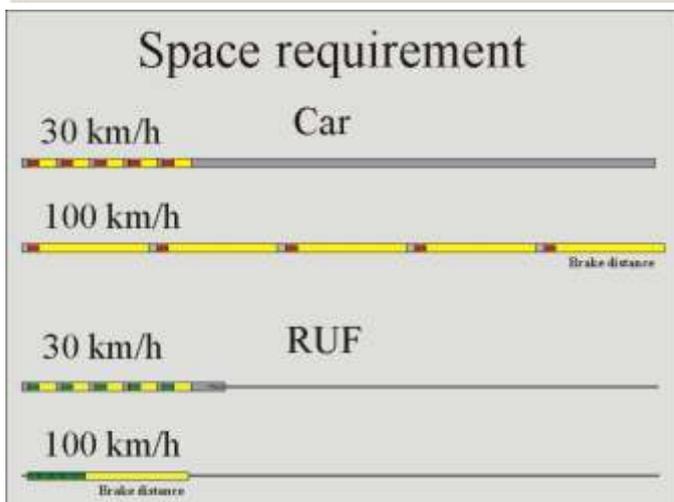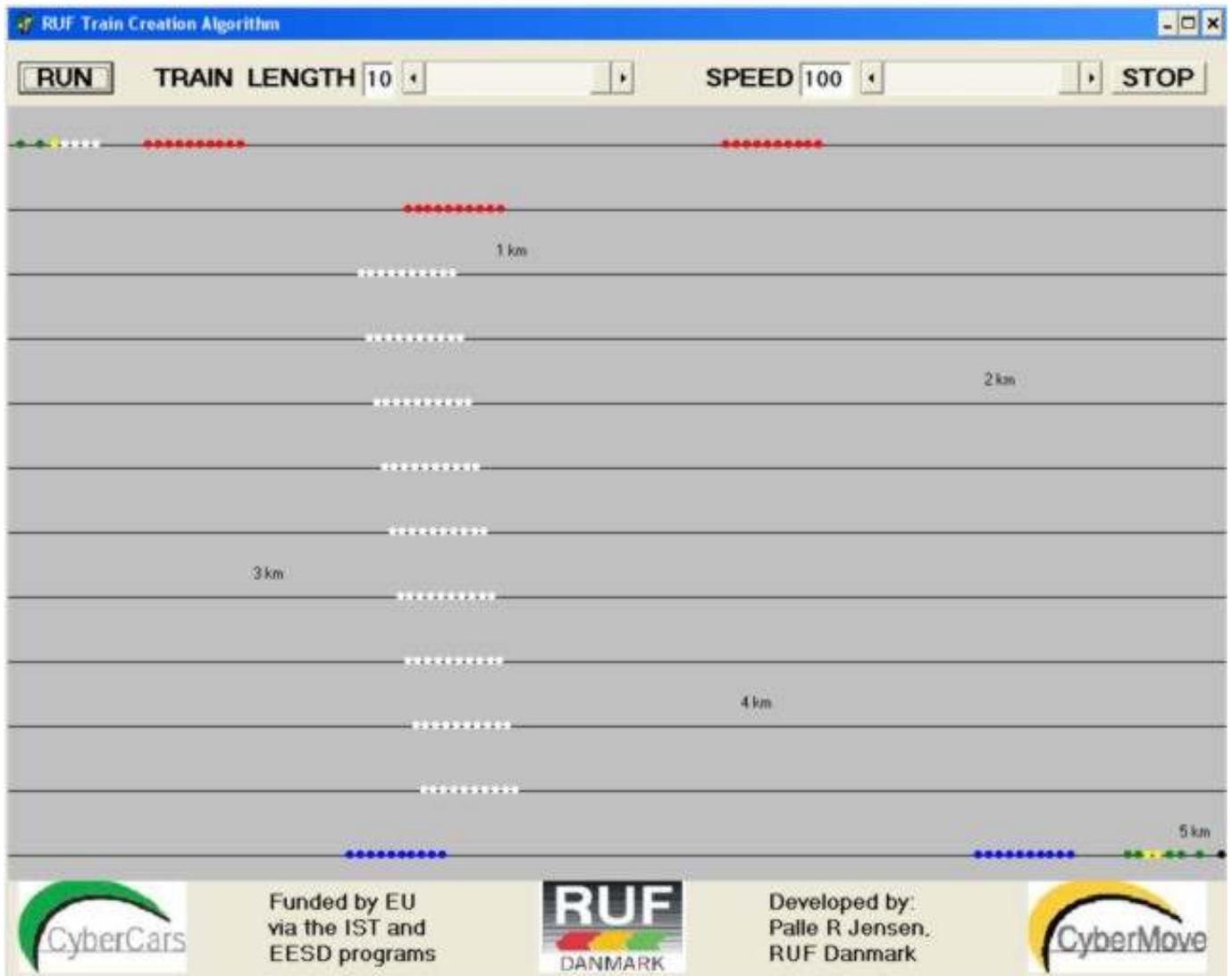
Line capacity

The absolute maximum capacity is obtained with a line with 100% mega-ruf vehicles.

Every vehicle contains 20 seated passengers sitting side by side on a bench.

The vehicle is 7 m long and when entering the monorail at 30 km/h it will need a separation of 5 m between vehicles. It takes 1.5 second per vehicle to enter the monorail at 8 m/sec (30 km/h).

20 passengers entering the monorail every 1.5 sec. means that the flow of passengers is 48,000 seated pass. per hour per direction.

If the train creation takes place on a separated rail before merging onto the main line, the capacity can be increased.

A train of 5 megarufs plus a train separation of 5 m means that in 40 m 100 seated passengers will be moved along the monorail i 5 sec.

This corresponds to:

72,000 seated passengers
per hour per direction

The more luxurious maxi-ruf has only 10 seats per vehicle of the same dimensions, so the capacity will be 24,000 or 36,000 seated pass. pphpd

Network capacity

People don't live along lines, so network capacity is more important than line capacity.

RUF systems are created as networks of monorails connecting junctions with a typical separation of 5 km.

As an example of a typical RUF network is shown the proposed RUF network for Copenhagen. With funding from EU, an analysis was made using the commuter statistics for the Greater Copenhagen area.

This statistics translated to the RUF network can in a program show the load on the lines in the network. It is supposed that every commuter gets the shortest route through the network.

The most heavily loaded section is from junction 43 to 44. Here 42,007 commuters will be moved during 2 hours rush hour. This can be handled with maxi-ruf in 1.75 hours.

This means that if every commuter in Copenhagen chose to go to work by maxi-ruf, the highways and the train lines would be empty !

The comfort level would be comparable to the car and travel time would in most cases be shorter. Parking problems would disappear.

The program can be found at: www.ruf.dk/rufcom.exe

Road mode capacity

In a dualmode system like RUF, passengers can be picked up at their residence by the maxi-ruf and driven to the monorail network by a chauffeur. One chauffeur can drive up to 3 maxi-rufs coupled as an articulated bus.

The operator will plan the route dynamically. In the morning most users will have an appointment with the operator, so that they will be picked at an appropriate time unless they change the appointment in advance.

A typical area between RUF monorails is 5 x 5 km. This means that in an area like the Copenhagen suburbs it would contain 25,000 homes.

A realistic part of the commuters using maxi-ruf will be 6,000 out of 15,000 possible commuters per hour.

One chauffeur can make 3 trips per hour between junctions (A to D). A maxi-ruf bus consisting of 2 maxi-rufs can move 20 passengers, so 60 passengers are moved every hour by one chauffeur. The tour to the junction will typically take 10 minutes. If the fare is 10 Danish Kr (approx $2) the operator will not need subsidies.

During 2 hours of rush hour one chauffeur can move 120 passengers to the system. This means that 100 chauffeurs are needed to cover this area. For the total network approx. 5000 chauffeurs are needed.

Outside rush hours, they will drive with single maxi-rufs and will also be used for delivery of goods and services for the local community.

1.000 homes/km²
25.000 homes
30.000 go to work
15.000 departures/hour
6.000 using maxi-ruf
A: 600/hour
D: 2.400/hour
15-60 sec. between maxi
Route = typically 8 km
20 stops = 300 sec.
300 sec. = 5 min.
Avg. speed. = 32 km/h
Trip = 5 + 15 = 20 min.
Avg. tour time = 10 min.
3 trips/hour
Maxi + chauff. = 300 kr/h
One trip = 100 kr
10 kr/trip => No subsidy
Up to 3 maxi/chauffeur

10% A 5 km B 20%
5 km
30% C D 40%
Centre

Capacity quality

The same capacity can be obtained in 2 ways. Either as with normal trains using large units at low frequency or with small units as in RUF but with high frequency.
Passengers hate to be slaves of a timetable, so it is much better to have high capacity using high frequency.

Low quality

← 20.000 pass/h

High quality

← 20.000 pass/h

Bus / Train : Rigid timetable

Time

RUF : No timetable

Spatial capacity

Modern cities have a lack of available Right of Way.
As a consequence, it is important to use the space efficiently.

In the RUF system all passengers are seated. This means that the dimensions of the maxi-ruf vehicles can be much smaller than for traditional transit vehicles.

Many light rail system uses overhead wires for power supply. The required height will be typically 4 m.

Highways also need to be able to allow big trucks to use them, so any bridge need to be 4 m high. Since a road vehicle cannot be precisely controlled laterally, the required width is 3.5 m.

The spatial efficiency becomes especially important when tunnels are required. It is very expensive to dig tunnels, so a system like RUF where two lines with maxi-ruf can use one standard tunnel will be economically attractive.
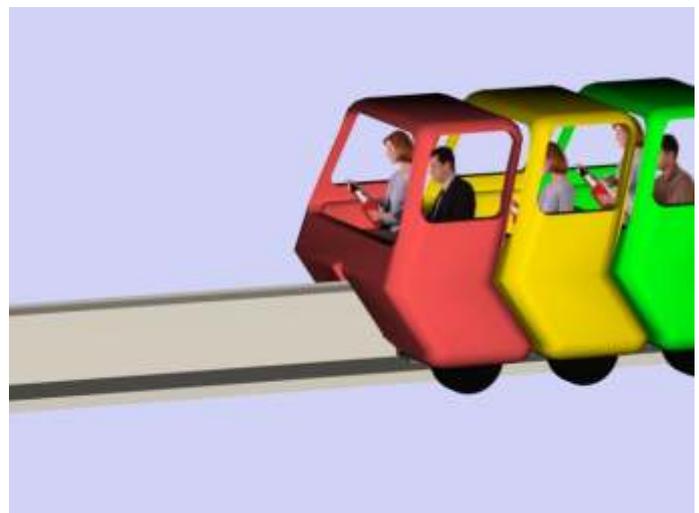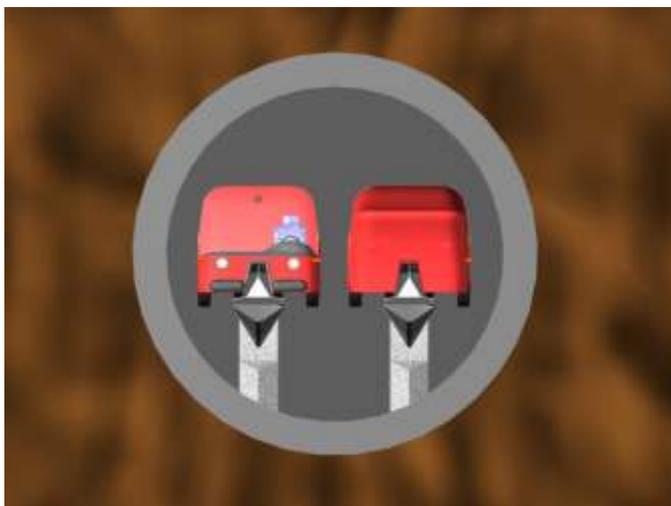
Necessary cross-section

Road	Light Rail	RUF
3,5 x 4 m	3 x 4 m	2,5 x 2,5 m
Max 8.000/h	Max 20.000/h	Max 20.000/h

Max passenger flow per m²

571	1667	3200

Mini_metro:
2,65 x 3,40 m

Maxi-ruf
2,00 x 2,00 m

Flexible capacity

In order to prevent empty vehicles, it is important to be able to change the length of a train dynamically.
This is normally difficult in a train system with rail bound heavy traincars. The consequence is that much of the time the trains drive almost empty.

In a system like RUF where the vehicles create and dissolve trains all the time, there is a much better match between capacity and demand.

It is difficult and dangerous for a train to change direction along the line. It will require that some of the train cars switch to the other direction and the train driver walks to the other end of the train.

In a dualmode system like RUF it is less of a problem. The maxi-ruf can leave the line at a junction and safely drive to the opposite access rail for entry. This means that the number of vehicles used on a line can vary dynamically to match the demand much better than with a train.
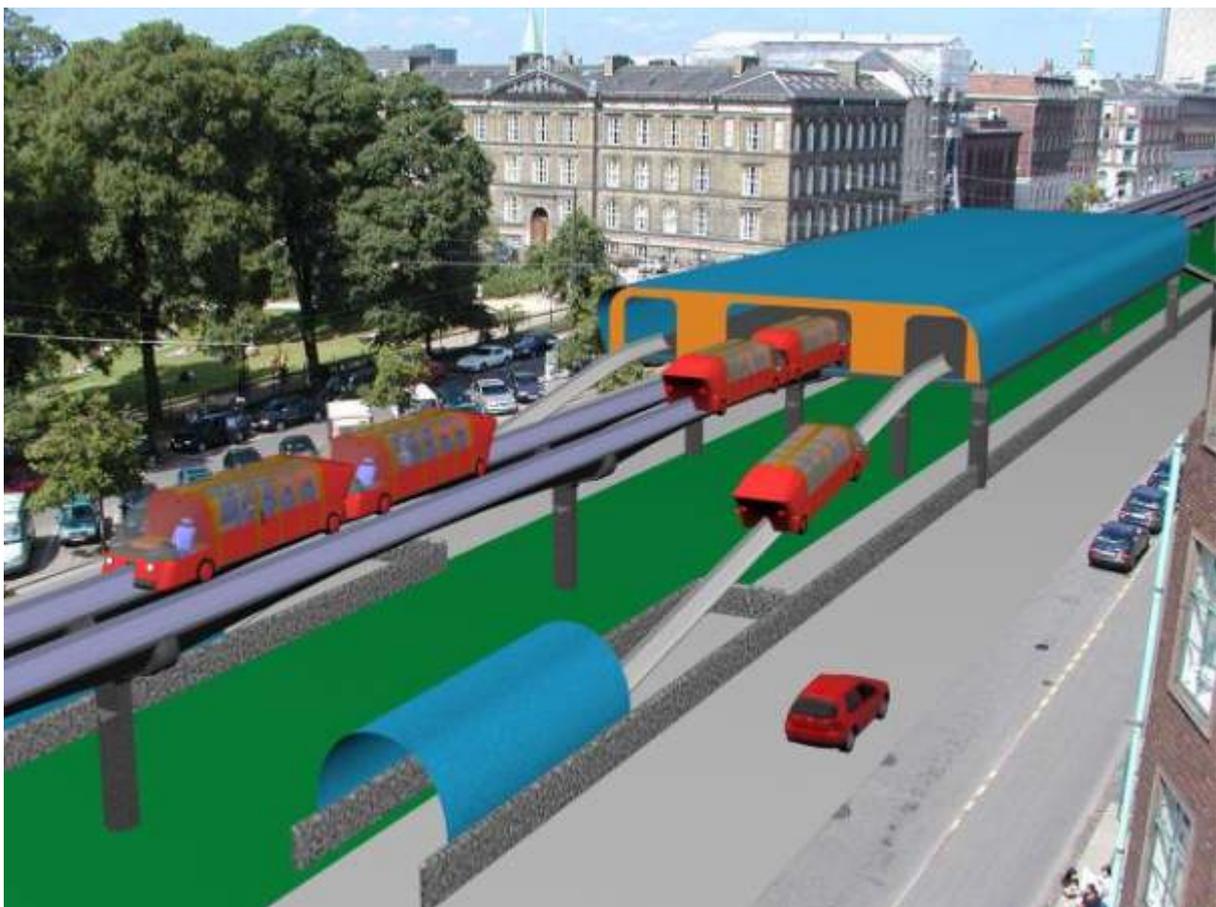

Train = fixed length

RUF-train = variable length

Dwell time considerations

The capacity of a system depends on the dwell time at the stations.
A normal train system has stations ON-LINE.
The dwell time for a commuter train is typically 25 seconds. This time is wasted time for most of the passengers and is a limitation in the available capacity of the system. The faster the system can effectively move its passengers, the higher the capacity.

RUF uses OFF-LINE stations and the line speed is higher than the train.
RUF slows down to 30 km/h at junctions, but it doesn't stop unless it has reached its final destination.
This means that it takes shorter time to deliver passengers between stations, so the vehicles are used more efficiently.

S-train line in Copenhagen vs. RUF

RUF 89 km/h   Train 55 km/h
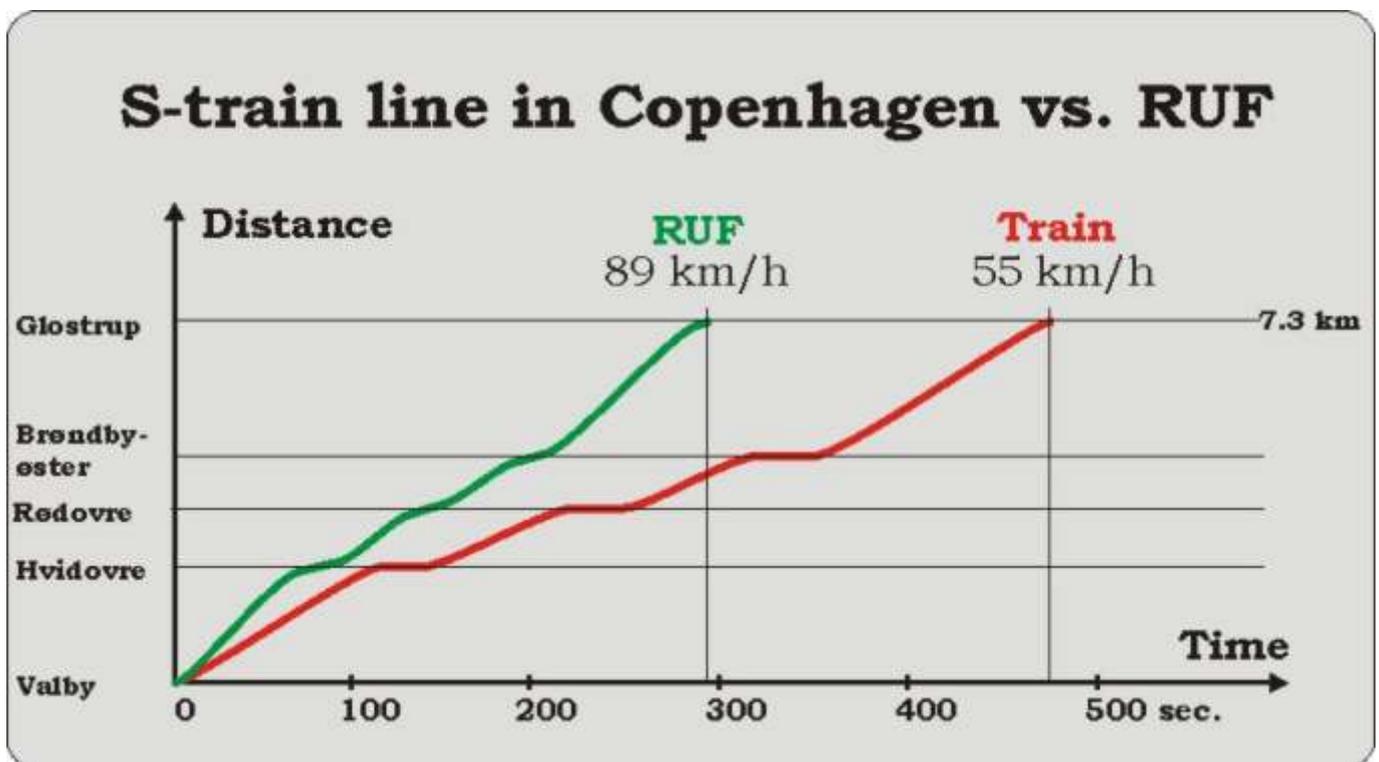
Junction speed = 30 km/h
Line top speed = 150 km/h

Average velocity vs. Junction separation:

5 km => 100 - 120 km/h (10-2 ruf/train)
3 km => 75 - 100 km/h
1 km => 50 - 75 km/h

Problem prevention

The capacity of a system will be reduced if there are many accidents or malfunctions. In a traditional train line system, a problem can block the whole line.

Many of the potential problems appear at the stations. Trains entering a platform at high speed is used by many people who want to kill themself. This happens every second week in Copenhagen on the S-train system.

RUF stations cannot be used to commit suicide. The RUF vehicles only move fast when they are safely separated from the passengers. The stations in RUF are OFF-LINE stations, so a problem on a platform will not affect the main line function.

A power failure on the train line will stop the whole line.

RUF has batteries in all vehicles, so a power failure on the monorail will not stop the system from functioning.

TRAIN: Problem at X => System breakdown
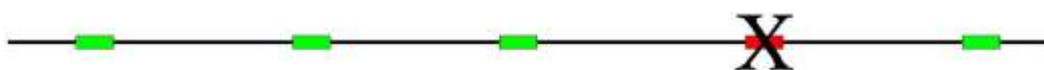
RUF: Problem at X => 96% functionality

20%
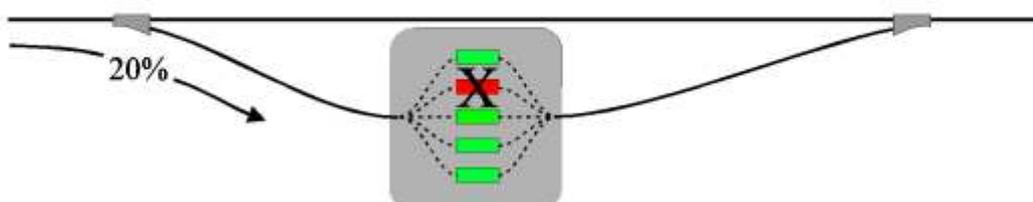
Access capacity improvements

The capacity of a system can be improved by creation of trains before access to the main line.

With a 5 m safety distance at 30 km/h between the vehicles when entering the monorail, the number of vehicles per hour is limited to 3,600.

If the trains are created on a special rail before access to the main line, the trains can enter with a safety distanen the trains.

A train with 10 RUF cars of 3 m length plus 5 m safety distance adds up to a 35 m. It takes 35/8 = 4.4 seconds for a train to enter the monorail.

In this way the capacity can sefely be increased to 1 RUF car every 0.44 sec. or 8,200 per hour.

If every RUF car has 1.2 passengers on average, the passenger flow will be

### 9,800 seated passengers per hour per direction
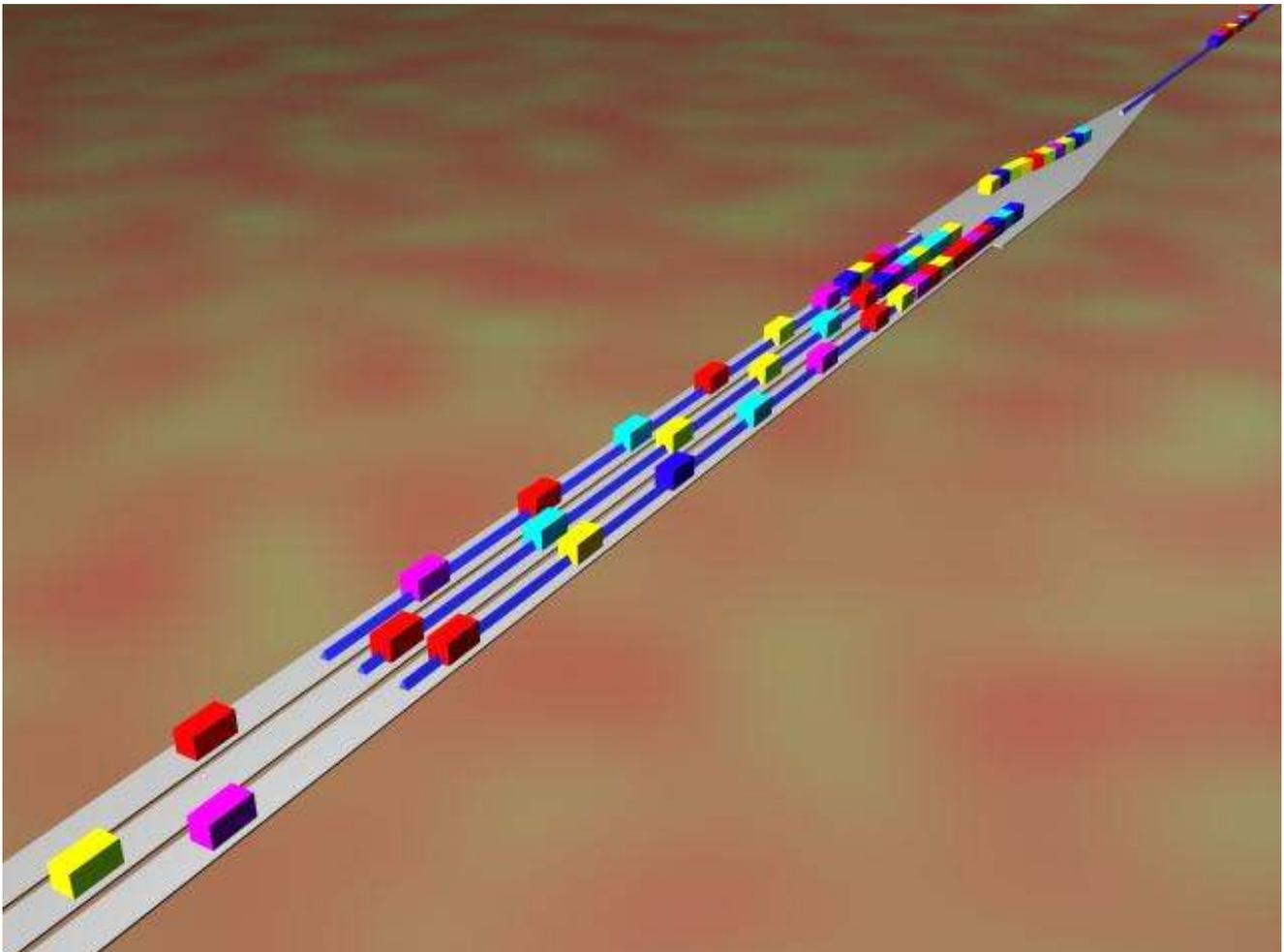
Junction capacity

A junction with 4 directions consists of 4 satellites and a central structure. Simpler junctions are used if only access and egress is possible.

The junction can be the limiting factor in a systems capacity.
In order to avoid that, RUF junctions are structured in such a way that the vehicle flow is split up into several directions at the entrance to the satellite. This structure allows for change of direction and merging of flows from different directions.

A functioning simple junction (no left turn) can be demonstrated using the simulator at www.ruf.dk/rufsim.exe.
The function is described in www.ruf.dk/rufsim.doc

It is shown that a flow of 1 ruf vehicle per second in a random sequence can be handled in most cases. In case of a possible conflict due to too many vehicles, some of the vehicles can be redirected to follow a slightly longer path than the shortest in the network.
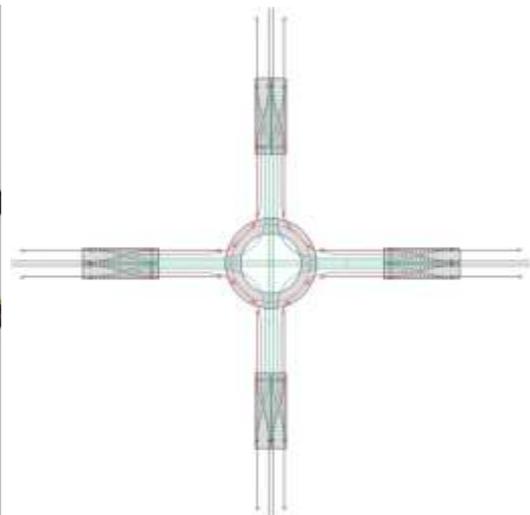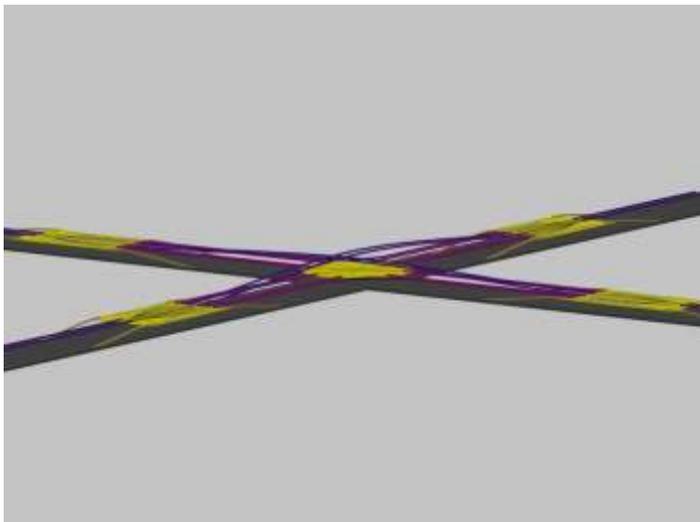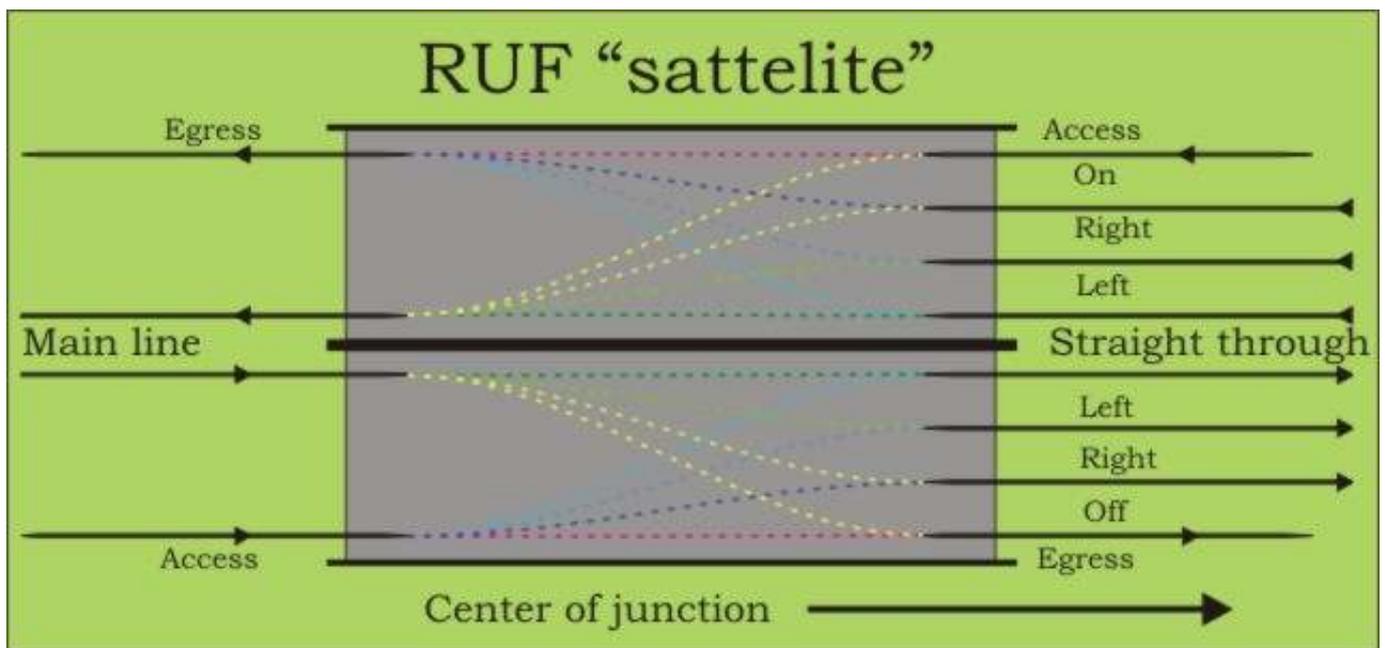
Street capacity

It is impossible to place highways close to city centres without destroying the city. For that reason the central of Copenhagen has been kept free from highways. The traffic flow to the city center is controlled by a traffic light at the ends of all highways. Only so many cars are allowed access to the center so that no gridlock is created in the city. The consequence is that the congestion is limited to the end of the highways, but also that the cars have to use the city streets longer than if the highways were running closer to the center.

If a RUF network was realised, the cars need not use the streets for more than short distances.
This is possible because a RUF monorail is a kind of electric highway. Low noise and no near pollution.
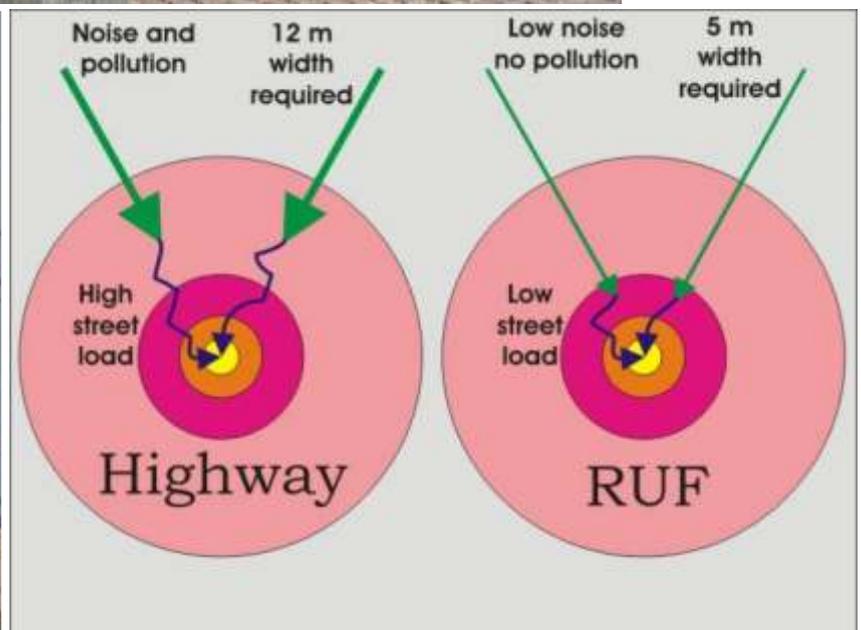
Conclusion

The patented drivesystem in RUF makes it possible to create a transport system consisting of a variety of vehicles.

It is also possible to run the vehicles at very high frequency in an automated mode.

The dualmode principle makes it possible to substitute bus and train in public transport and offer a seamless kind of public transport which can compete directly with the car.

The drive system used in electric RUF cars makes it possible to add much more capacity to the existing traffic corridors so that congestion can be avoided.

Electric RUF cars use much less energy and the small batteries are recharged on the monorail.

All in all RUF is a very atrractive system with high capacity. As public transport 72,000 seated pphpd can be obtained.
As a car system, 7,200 pphpd can be obtained

FIG.3