Fit for urban challenges – Light Rail Systems

At the end of the 19th century, the tram became the first mass transportation system suitable for densely populated and historical city structures around the world. Using electric propulsion to transport large numbers of people gave cities the opportunity to spatially expand while maintaining high accessibility. But success was not lasting: soon the automobile pushed tram systems out of the cities. In the US, the automotive industry did not hesitate to buy up and systematically shut down various tram systems to increase demand and space for their own products.

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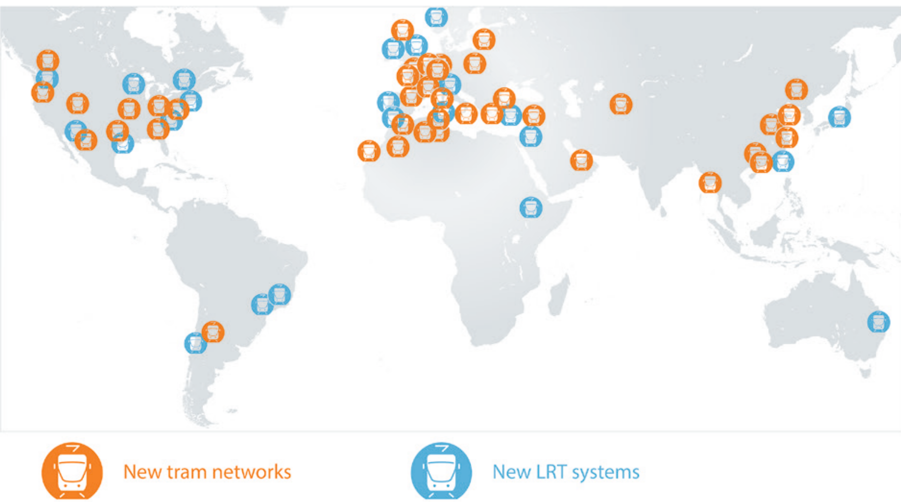
However, the "car-friendly city", a doctrine for urban planning of the 1950s, soon led to deserted city centres. The paradigms of urban planning began to change, the quality of urban spaces, especially in city centres, returned into focus. [1] This development coincided with a global oil crisis that lead to a further demand for energy-efficient public transportation systems.

1. A growing market

Trams and light rail systems (from now on light rail systems) were soon regarded as a cost-efficient alternative to costly state-of-the-art subway systems. Originating in West Germany, so-called "Stadtbahn"-systems were soon implemented in various cities in Europe and the United States. In France, the launch of the Nantes light rail network in 1985 marked the start of a remarkable development. No less than 26 all-new tram systems have since been opened in France.

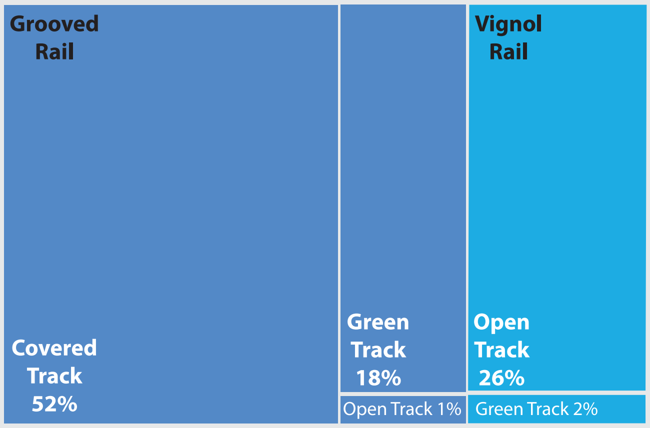
Following the rise of new light rail systems in France, West Germany and other European cities, light rail systems have established themselves as a popular way of providing high-level public transportation services in urban areas. Compared to subway systems, the investment costs are moderate; compared to cheaper bus systems, performance and – not to be neglected – public perception are better. In French cities, light rail systems are often well nestled into urban spaces through integrated architecture and striking, colourful vehicle design. Green track design and catenary-free routes are options that aid in further adapting light rail infrastructure to its surroundings.

After the millennium, the number of new light rail systems has rapidly increased, especially in growing economies outside Europe. In Turkey, for example, ten completely new systems have been put into service, with many more currently under construction. Turkey is just one example for a hotspot of light rail development with many other new systems in the United States and North Africa. Chinese cities that mainly used to implement subway systems

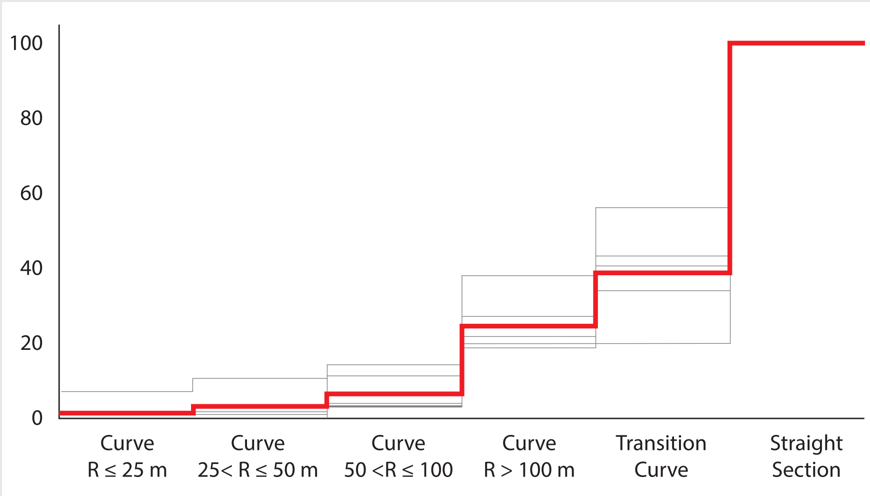


1: Tram (red) and Light Rail Systems (blue) implemented after 2000 in the past have just recently turned their attention towards tram systems after 2010 which led to a further boost.

Overall, the trend continues rapidly in an upward direction. After 2010, this can be primarily attributed to the market entry of Chinese Cities. There is also a trend in the type of systems – at the beginning of the upturn, "Stadtbahn" or "LRT"-systems that underpass city centres in tunnels while being operated on surface level on the outer branches were more favored. Recently, tram systems with level guidance through the city centres have become more popular. The implementation of modern tram systems along with a reduction of car traffic has become recognised practice for urban planning.



2: Average distribution of track design by total network length



3: Average distribution of single design elements by total network length

2. In harmony with urban space

The current success of light rail systems can not only be explained by providing efficient mobility services but also by their ability to be well integrated into and even upgrade urban space. This promotion – achieved by both substitution of car traffic and creation of visually appealing streets by implementing the "product" tram – is counteracted by emissions caused by the system. Light rail systems emit noise and vibration caused by a steel wheel rolling on steel rails.

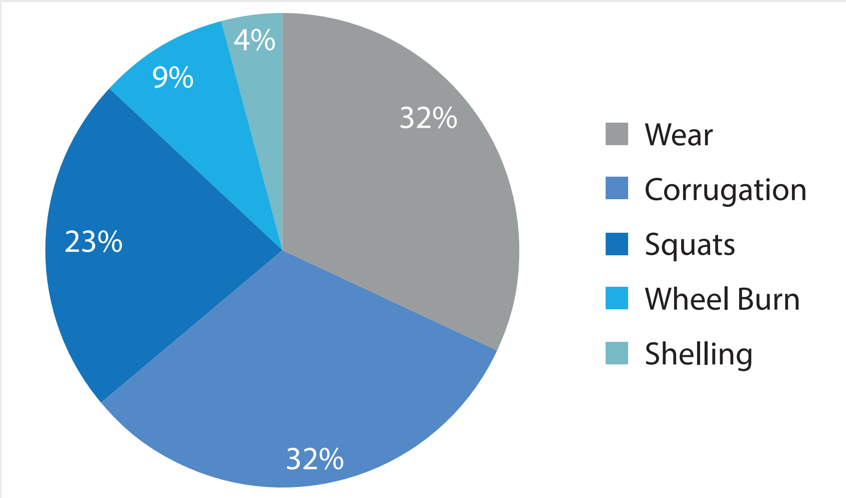
It is well proven that noise and vibration have a negative impact on human well-being. In addition to direct effects such as increased hearing loss, sleep disturbances and tension, persistent exposure to noise also has a negative effect on cognitive performance and human hormone balance. [2] Subsequently, noise pollution leads to increased hospitalisation and increased mortality. [3] A Dutch research team calculated that in the EU alone, noise pollution caused the loss of one million "productive life years" in the form of productivity reductions, hospitalisation and increased mortality. [4]

In urban areas, the possibilities of reflecting or absorbing such emissions by means of physical noise barriers are hardly feasible due to the tracks' level integration into street space. Therefore, it is necessary to avoid or reduce noise emissions at their origin. The roughness of both wheel and rail lead to vibration excitation and this subsequently to noise propagation. In order to reduce emissions, both wheels and rails have to be kept as plane as possible. While steel wheels are usually relatively smooth due to regular lathing, rough track surfaces are considered responsible for most noise emissions. In the following chapter, light rail tracks and their properties regarding emissions will be examined.

3. Light rail track characteristics

As part of the European rail initiative Shift2Rail – which focuses on solutions for environmentally friendly as well as socially and economically sustainable rail infrastructure – a research project was conducted to examine challenges and problems for light rail infrastructure operators while developing potential strategies and approaches to efficiently meet future requirements. As part of this project, a survey has been conducted among 25 light rail network-operators to collect characteristics and constraints of urban rail networks as well as strategic approaches and challenges to a low-emission infrastructure.

Requirements for track design of light rail systems differ from those for mainline railway infrastructure. Often sharing street space with car traffic, tracks have to be embedded into road surfaces. Dense and well-grown city centres require narrow curves and steep gradients. These different requirements and constraints along with urban networks having grown and developed isolated from one another result in a variety of superstructure designs. Image 2 shows the average distribution of principle superstructure designs by operators taking part in the survey. Obviously, embedded track using grooved rails is the predominant track design, while Vignol rails are mainly used for open track sections. Green track, covered by a layer of vegetation, is regarded as the most attractive for urban areas and is applied to about one fifth of the total network length.



4: Occurrence of the most common defects to rail surface in light rail networks

The distribution of elements of horizontal alignment, as displayed in image 3, shows that on average more than 60 % of total network lengths consist of straight sections. However, about 3 % of total network length consist of curves with radii lower than 50 meters, which generally lead to both high wear rates and curve squeal noise emissions. In other words, there is an average of more than 2 curves of that category in every kilometre of a light rail network. Differences can be recognised regarding the types of network. While newly built networks avoid narrow curves of radii much lower than 50 meters, the absolute minimum radius in traditionally grown networks is 17 meters. Compared to the Austrian mainline railway network with a minimum radius of 190 m, a difference in minimum radius in the dimension of factor 10 can be derived.

The combination of track embedded into public space as well as narrow curves and service intervals of down to only two minutes lead to high acting forces on the rails. These impacts cause wear, rolling contact fatigue and single-fault conditions to the rail's surface and running edge and thereby increase the rails' roughness.

5: Common rail defects for grooved rails: Wheel burn (left) and corrugation (right)

When asked to name common defects to the rail surface occurring in their networks, operators named wear and rail corrugation 17 times each, the latter usually caused by differential slip in curves. Squats – buckles of the rail's surface – occur in 12 cases. Wheel burn caused by wheel slip due to large vehicle-accelerations during operation, was named by 5 operators. Image 4 gives an overview over the most common rail defects, while image 5 shows two of these common damages to the rail's surface.

Most defects lead to rough and unsteady rail surfaces and cause noise and vibration emissions when vehicles run over them. 55 % of all operators state that noise and vibration emission are real issues for them. It is expected that public perception and legal requirements concerning emissions will further raise the bar for operators in the future due to both higher standards and higher loads. Eight out of ten operators are used to reacting to complaints by resident by taking measures to reduce emissions.

4. Tackling emissions

The reduction of operating speed on specific sections of the network is a proper way to instantly reduce emissions and is applied by half of the surveyed operators as a reaction to complaints. However, this leads to a decrease in service level due to reduced capacity and, therefore, should not be applied as a permanent measure. Another measure to reduce emissions without treating the cause is to alter the friction between rail and wheel by conditioning either rails or wheels. This is usually applied in narrow curves where the geometrical conditions lead to curve squeal noises and are therefore independent from the rail's surface structure.

When trying to reduce noise and vibration emissions caused by a rough rail surface, the rail itself has to be treated. Measures to effectively mitigate or prevent rail defects as described in the previous section essentially include build-up welding and rail grinding. Build-up welding is the only measure that adds material to the rail and counteracts abrasive wear but can only be applied to grooved rails. After manual or mechanical build-up welding, rails have to be grinded to exactly restore profile geometry and provide a plane surface.

Rail grinding aims to remove rail damages and profile errors. However, this does not necessarily lead to a reduction in emissions since the rail surface's roughness depends on the applied grinding technique. In addition and especially when applied preventively, it reduces the occurrence of rail defects in the first place and therefore has a positive effect on the rail's lifespan.

In general, rail grinding can be carried out by

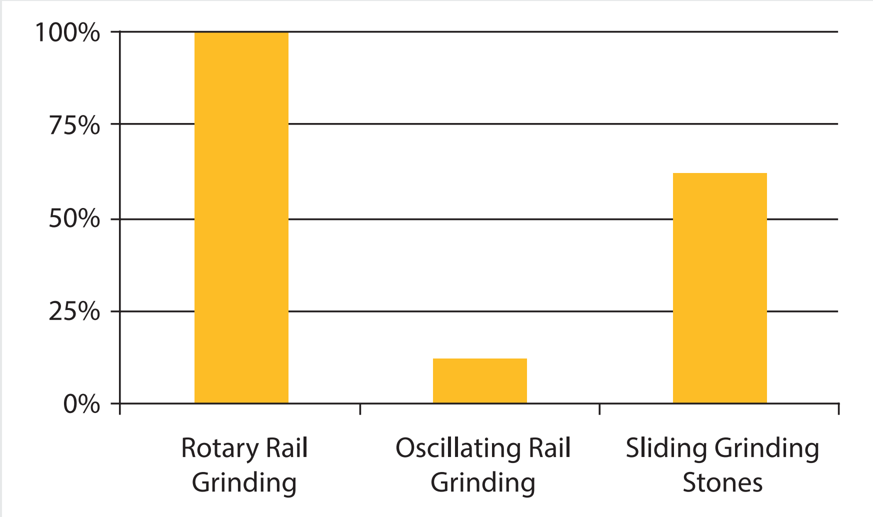
- Sliding grinding stones,
- Rotary rail grinding,
- Oscillating rail grinding.

Applying sliding grinding stones is the basic technique for rail grinding. Grinding stones are pressed on to the rail's head with a certain pressure and are pulled along the track by a vehicle. Only very little material can be removed in a single operation. Low noise emissions and operating speeds up to 30 kilometres per hour allow application of this technique during regular service hours. Since only its head is treated, the rail's profile cannot be altered.

Rotary rail grinding is a method where usually 6 to 8 rotating abrasive wheels can be aimed at the rail head in different angles. This technique produces fairly high emissions such as flying sparks, dust and noise. The rail's surface after the application of grinding with rotating disks or wheels is relatively rough compared to the other techniques. However, it is usually possible to alter the rail's geometry with this technique.

Oscillating rail grinding is a further improvement of the sliding grinding stones method. To increase the maximum removal of material, the grindstone oscillates in the direction of the rail axis. Since chatter marks on the freshly grinded rails lie in the direction of travel, noise generation of passing vehicles is reduced to a minimum [5, 6]. It also provides a very homogeneous removal of corrugations and other surface irregularities. Due to geometrical constraints such as the minimum curve radius, this method has not been applicable to light rail tracks so far.

Right now, all operators use rotary grinding techniques, at least for spot treatment and reprofiling. However, more than 50% of operators additionally apply sliding grinding stones that require many passages in order to cause an effect. Oscillating grinding is carried out in very few networks that have a large share of open track using Vignol rails. It is so far not applicable for grooved rail sections with narrow curves.



6: Usage of grinding techniques by network operators

However, in terms of effectiveness regarding avoidance and reduction of emissions and rail defects, oscillating rail grinding is seen to hold great potential. Therefore, the development of a prototype grinding machine for oscillating rail grinding of light rail tracks is part of a further project within the Shift2Rail initiative.

5. Conclusion

After a decline in the 20th century, light rail systems have boomed in recent years. They have become the system of choice to provide high-quality public transport systems in urban areas. Taking into account that the urbanisation both in relative and in absolute figures is a global phenomenon and believed to significantly raise within the upcoming centuries [7], the need for efficient and high capacity transportation systems will further increase. However, the minimisation of harmful noise emissions is essential for public acceptance and successful integration into urban spaces. Rolling noise, the main source of sound emissions from light rail systems, is significantly influenced by the rail's surface and its specific damage patterns. Besides current techniques, oscillating rail grinding is believed to further improve the potential for preventive noise mitigation. The present survey, conducted as part of the Shift2Rail initiative among network operators, shows network characteristics as well as current problems and approaches concerning noise emissions and preventive approaches.

6. Acknowledgements

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