DOI: 10.61782/fa.2023.0263

40 YEARS INVESTIGATING TYRE/ROAD NOISE AT M+P

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ABSTRACT[*]

Road traffic is by far the largest source of environmental noise and effective mitigation measures for road traffic noise are essential for improving the wellbeing and health of people exposed to acoustic pollution.

This paper describes the development over 40 years in traffic noise research at M+P Consulting engineers in the Netherlands. It starts with the observation that tyre/road noise is the dominant source of traffic noise, not only from highways but also in urban areas. Very soon it become clear that in the generation mechanism of tyre/road noise the tyre is the source of acoustic emission but that the road surface is the decisive parameter for how much noise is emitted by the tyre. Therefor the development of low noise pavements has become one of the most important tools available to reduce the emission of traffic noise.

The paper follows the growth of knowledge and technology on tyre/road interaction noise at M+P over 40 years and highlights some of the key developments.

Keywords: *road traffic, pavement, tyre, tyre/road noise*

1. INTRODUCTION

The history of controlling road traffic noise is as old as the road traffic itself. Already in the middle ages horse wagons and coaches were not allowed to enter the city during night-time. In 1865 the UK Red Flag Act stipulated that a person with a red flag shall walk in front of a vehicle with a combustion engine in order to warn bystanders for the terrific noise produced by that vehicle. In the first half of the 20th century road traffic was characterized by frequent horn honking, partly because of the regulation that at each crossing one should warn other vehicles and also because pedestrians, cyclists and other road users used the same space without taking care of the ever increasing number of cars. After the misuse of horns was taken care of by changing the regulations, educating other road users to stay at the right (left) side of the road and to cross roads perpendicular and fining misuse of the horn, road traffic noise became equivalent to exhaust noise. Consecutive national and European regulations introduced in the seventies controlled exhaust noise and power train noise in general by formulating maximum levels for road vehicles under full throttle conditions specified in ISO 362 test procedures.

Traffic noise levels however refused to decrease or even stabilize, partly because of growing traffic intensity but mainly because a major contribution was overlooked: tyre/road noise.

In the eighties M+P, among others, in the Netherlands identified that gap and started research on the origin and the nature of the rolling noise emission of road vehicles.

2. ROLE OF TYRE AND PAVEMENT

The starting position for the research program was that tyre and pavement both contributed to the noise production. Nor a freely suspended spinning tyre, nor an isolated pavement produces noise. Only the interaction between the two resulted in sound emission.

The focus was however soon directed to the pavement because that could be studied on a national scale with access to local or national road building technology. Tyre technology lies within a limited group of large manufacturers operating on a European or world-wide scale. Furthermore, noise is a local problem and low noise tyres, however important, cannot be applied on a local scale only.

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It could soon be concluded that this was an excellent choice. In the research program it was found that the effect of variations in the pavement was much larger than the effect of variations in the tyre (Figure 1). It shows that the noisiest tyre on the low noise pavement emits several decibels less than the most silent tyre on the noisiest pavement, with the biggest gap at high vehicle speeds.

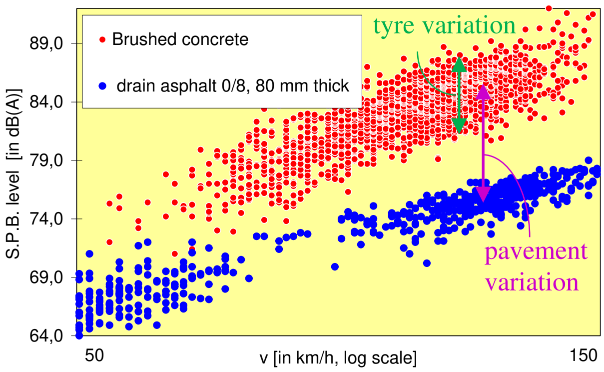

Figure 1. Measured pass-by maximum sound level vs. vehicle speed on transversely brushed concrete and 80 mm 4/8 drain asphalt

The focus on road pavements was further enhanced by the interest in Netherlands in porous pavement types, initially not for noise but to prevent traffic congestion in rainy conditions. The suppression of splash and spray allows road users to drive with high speed and small inter-vehicle distance while preserving safety.

Aligned with that interest M+P started doing noise tests on experimental porous road sections and found that the drive-by sound of vehicles on those sections were several decibels lower than those on conventional dense asphalt concrete, as porous surfaces turned out to effectively absorb tyre/road noise

3. DEVELOPMENT OF THE RESEARCH PROGRAM

3.1 Eindhoven Airport proving ground

In the early '90s, the possibility to use a deserted runway on Eindhoven Airport presented a major boost to the research program. Instead of being dependent on the local traffic stream and vehicle population to do any noise measurements, we could perform specific tests control all relevant parameters, vehicle type, vehicle speed, tyres and pavement type.

A series of nine pavement types were applied in two rows next to each other. There were two dense asphalt concrete sections, one with a moderate and one with fine texture, and seven porous asphalt concrete sections with variations in stone grading, thickness and aggregate type. This included two sections of double layer porous asphalt concrete. Each test section was 3 m wide and 80 m long. It was an ideal playground for acoustic research on tyre/road interaction.

3.1.1 Controlled pass-by testing of cars

The lay-out allowed recording of L_{Amax} and sound exposure levels (SEL) of individual pass-by events of cars with speeds ranging from 40 to 120 km/h. The test fleet of 20 vehicles was matched statistically to the Dutch average vehicle fleet, taking into account the age, engine type and vehicle weight. In that way, a complete assessment of the performance of the pavements with respect to Dutch conditions could be made. Pass-bys were mainly done under *coast-by* conditions: to minimize the influence of engine and exhaust noise, the engine was switched off while driving, resulting in a free rolling vehicle with no powertrain noise. Also, a smaller but still complete set of data under *cruise-by* conditions (constant speed with engine engaged) was recorded to investigate the effect of added powertrain noise.

Additionally a series of tests were performed with a single vehicle equipped with several tyres, including rib and slick tread profiles, to better understand the role of tyre choice on pavement performance.

3.1.2 Findings for passenger cars

The tests showed the large noise reducing potential of two layer porous asphalt with reductions up to 4 to 6 dB relative to a dense asphalt concrete over a wide speed range from 50 to 120 km/h.

It demonstrated the relative importance of the acoustic absorption of the porous pavement and the surface texture. Porous pavements in general exhibit a more coarse texture than dense pavements. Acoustic absorption, when well tuned, more than compensates for the extra noise resulting from this texture.

The systematic variation of tyres and pavement types emphasized the interdependence between tyre performance and pavement type. Low noise tyres (such as the slick type) complete lose their acoustic benefits when rolling on course textures, while smooth textures *enhance* differences between tyres.

3.1.3 Extension with truck tyres testing

Testing truck tyres created new challenges. A single axle, two-wheel trailer was constructed with a wheel load of around three tons. Background noise from the towing vehicle was suppressed by a 10 m bar and an ultra-low noise pick-up truck equipped with extra mufflers, skirts and rib tyres (see Figure 2). This resulted in a reduced vehicle noise that was 10 dB below the L_{Amax} of the passing tyres.

Figure 2. Ultra-low noise towing truck with test trailer used for truck tyre measurements.

A series of different truck tyres were tested, including a slick type, several tyres with a rib or block pattern and an even more coarse off-road profile. Surprisingly the noise reducing capabilities of the two-layer porous pavement for truck tyres were almost equal to that for car tyres.

3.2 Sperenberg proving ground (D)

An opportunity to complete the data set with various dense pavements was presented by the German BASt that awarded Müller-BBM and M+P a project to study the influence of texture on rolling noise in the late '90s. Again, a deserted air field, this time in Sperenberg in former East Germany, a series of 40 concrete and asphalt surfaces were laid with widely varying texture characteristics, ranging from coarse surface dressings to artificial surfaces smoothened by epoxy resins. In addition some sets of experimental surfaces were added with fixed surface textures but varying acoustic absorption and varying mechanical impedances, by including rubber. Rolling noise levels at driving speeds between 40 and 120 km/h were measured for a series of twelve normal car tyres in two sizes and a rib and slick tyre of that same sizes.

The resulting data set proved to be extremely relevant to understand the texture influence on rolling noise, and how tyre tread geometry and texture geometry interact in a specific way.

In an additional project with 16 truck tyres it was discovered that rib types show a sensitivity to texture changes very similar to passenger car tyres, and that block tyres show almost no sensitivity to texture variations. It further supported the earlier findings at Eindhoven Airport that acoustic absorption is extremely effective in reducing rolling noise for both steer and traction tyres.

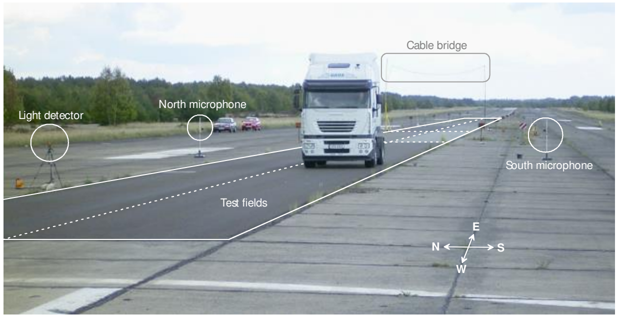

Figure 3. Overview of the Sperenberg proving ground with configuration of two rows of four microphones on each side and light switches between the test sections.

The Sperenberg investigations and the measurement database then formed the basis for the development of the SPERoN simulation model, see below.

3.3 Kloosterzande proving ground (NL)

In 2005 the findings for texture and acoustic absorption were integrated in a research project, commissioned by the Dutch Transport Ministry. The objective was to develop a tool that predicts acoustic performance of pavements taking into account the sound absorption, surface texture and airflow resistance, by hybrid physical/statistical modelling of the tyre/road contact mechanics and the acoustic radiation and propagation of tyre noise over absorbing surfaces, including reduction of the "horn-effect" [4]. The Sperenberg data set was completed with coast-by measurements on a series of 41 pavement types laid at a deserted road in Kloosterzande (NL) that included several combinations of texture and acoustic absorption characteristics. Pavement variations included variations of double-layer porous asphalt surfaces, further discussed in section 5 below. As advised by M+P, there was also room to include some very smooth and very rough surfaces (see Figure 4), outside of the texture range that would typically be applied on normal roads, but very welcome for the tyre/road interaction model development. Also, several rubber surfaces and asphalt/rubber mixtures were tested.

Figure 4. Examples of Kloosterzande asphalt variations: top: two-layer porous asphalt (2/4 mm top layer), bottom: course surface dressing (11/16 mm)

3.4 Twente proving ground

The fourth test area was located in the former military base in Twente. The Scandinavian transport ministries awarded M+P a study into the tyre noise levels of truck tyres on both the standard smooth ISO 10844 pavements and rougher pavements. From earlier studies it was known that for car tyres varying pavements do not only result in differences in average rolling noise levels but also that ranking was affected. The test results for truck tyres showed a similar behaviour, see Figure 5 and more details in [2].

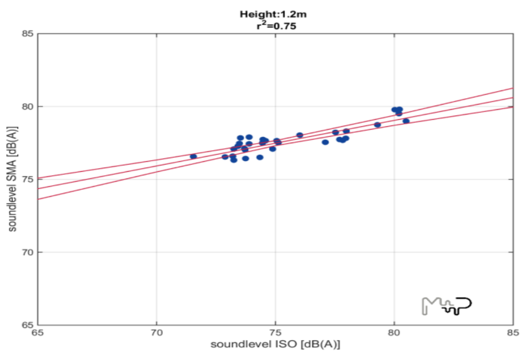

Figure 5. Relation between sound level on ISO 10844 surface and SMA11 surface for truck tyres. Apart from various small changes in ranking, typical is that level differences on a rough texture are significantly smaller than on the smooth texture shown here by the small slope of 0,25.

The study additionally identified a serious noise issue with traction tyres, which are typically used on the drive axle of international cargo trucks. It was found that on smooth textured surfaces, known to cause less rolling noise, traction tyres emit strong tonal noise at the pitch frequency corresponding to the block impacts, and higher harmonics, see Figure 6.

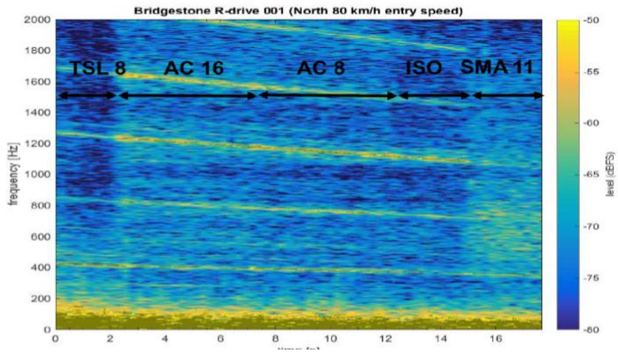

Figure 6. Narrow band spectra of rolling traction tyre over different textures. On smooth textures (e.g. AC8, ISO) the tyres pitch frequency and its higher harmonics are enhanced causing a typical whining sound.

3.5 On board data collection

To investigate the relevance of tyre/road noise in the total road traffic noise under real driving conditions, M+P in the early '00s performed a series of on-board noise measurements, in a research project for the Dutch Ministry of Environment. Several road vehicles, including different types of passenger cars, vans and small lorries, were equipped with data loggers that record vehicle speed, engine speed, accelerator position and sound levels at different positions. Microphones were places in the engine bay, near the tyre and near the exhaust.

The vehicles were driving an about 20 km circuit in an urban environment during which the data were acquired with a resolution of 1/s. After normalizing all sound data to an immission level at 7,5 m distance the results were analysed and trends could be identified, see Figure 7. Power train noise turned out to be mainly engine speed driven, while exhaust noise had a clear relation with engine load (i.e. accelerator position). The major conclusion was the dominance of rolling noise also in the urban environment. In our test runs it was found that about 95% of the total emitted sound energy of the vehicle in the urban circuit was tyre/road noise. Already at speeds of 20 km/h rolling noise dominated over powertrain noise, for passenger cars.

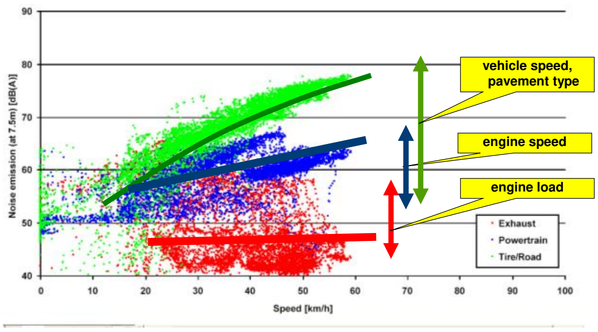

Figure 7. On-board data of a passenger car in urban driving. Each dot is a 1 s sound measurement, plotted vs. vehicle speed. Red: near the exhaust, blue: in the engine bay and green: close to the tyre. Levels normalized to 7,5 m distance.

This study corroborated the importance of understanding rolling noise, not only for traffic noise from medium and high speed roads but also in urban areas where the impact of traffic noise on the population is high.

4. FOUR PILLAR APPROACH

The studies described in chapter 3 constitutes the research work M+P has been involved in. This is only one of the four pillars on which M+P based its approach to traffic noise. The other three pillars we have contributed, and still do, are:

- *standardization* of measurement and assessment procedures and calculation schemes,
- contributions to vehicle and tyre *regulations*, mainly within UN-ECE and EU context,
- *consulting* engineering work for road authorities and road builders.

Experience convinced us that only by an open exchange of data and findings between these four areas, the best overall results can be achieved. It has been our role as a company to facilitate and foster this exchange, bringing government authorities, university researchers, policy makers and standardization committees together. This concept is sketched in Figure 8 and further detailed below.

4.1 Standardization and calculating schemes

The vast amount of test results obtained under controlled conditions on proving grounds was found to be an excellent source to develop and improve procedures described in ISO and CEN standards.

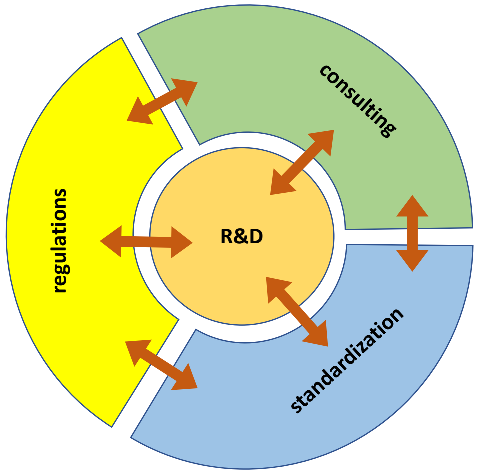

Figure 8. Concept of the M+P approach to rolling noise research. Only by a continuous exchange of data and insights between disciplines effective advancement is possible.

Contributions were made to several noise standards for pavements, vehicles and tyres, such as ISO 10844 on the properties of test tracks for road vehicles and tyres, ISO 11819-1 (SPB) and -2 (CPX) measurement methods for the assessment of the influence of the pavement on traffic noise, the ISO 362 series for the noise emission of road vehicles and ISO 13325 for tyres. In parallel the experiences and measurement data for surface characterisation of the pavement test fields was input to the development of surface texture and in-situ sound absorption measurement devices and related standards such as ISO 13472 for absorption and ISO 13473 for texture.

In the Netherlands, the development and application of low noise pavements saw a big rise in the early ‘00s. As a result of government grants made available for municipalities to apply such pavements in urban areas, road contractors started to develop a wide range of pavement products. Developments for high-speed roads were further enhanced by a noise innovation programme led by the national road authority, Rijkswaterstaat. Based on CPX- and SPB-measurements performed by M+P and others, the national road noise assessment method was supplied with correction factors to incorporate the effect on calculated traffic noise emissions. These correction factors have later been integrated into the European road vehicle emission model in CNOSSOS-EU (EU Directives 2015/996 and 2021/1226).

4.2 SPERoN model development

Using the initial measurement data from the Sperenberg project, ground-breaking research work was done by Chalmers University (Göteborg), aided by Müller-BBM and M+P, to develop a simulation model that could predict rolling noise levels for different car and truck tyres on any pavement. The pavement is characterized here by its surface texture, airflow resistance and sound absorption characteristics. Tyres are represented mainly by their tyre mobility and 3D tread profile. The model was labelled SPERoN (**S**tatistical **P**hysical **E**xplanation of **Ro**lling **N**oise), which indicates that it is a hybrid model: the interaction between tyre and pavement are physically modelled to calculate the dynamic contact forces, which are then fed into a statistical model to obtain the vibrational and aerodynamic rolling noise levels.

speron

Figure 9. SPERoN logo

The SPERoN model was later extended with research work from the EU projects ITARI and SILENCE, the German LeiStra projects and the Dutch noise innovation program (IPG). M+P contributed with dedicated measurements of the horn effect, and modelling the effect of pavement sound absorption on the tyre horn radiation efficiency [4], see Figure 10. M+P and Müller-BBM also developed a software application that packaged the SPERoN model in a relatively fast and user-friendly acoustic optimization tool.

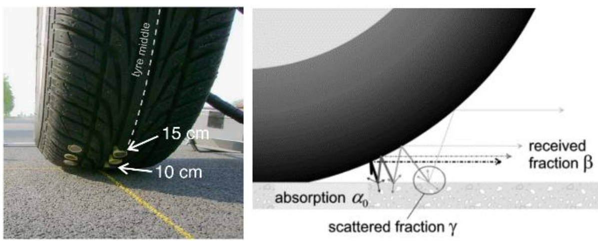

Figure 10. Left: mockup receiver with microphones mounted in the tyre tread; right: modelling approach for sound reflections inside the tyre/road "horn"

Having such a calculation model available is essential for road contractors wanting to develop new low-noise pavement products. With SPERoN, texture, sound absorption and flow resistance could be optimized prior to actual road construction. Using measurements on laboratory test samples, the acoustic performance of asphalt and concrete variations could be assessed and improved, without the need to construct outdoor test sections that allowed actual noise measurements on a passing vehicle.

4.3 Regulatory work

New road vehicles and their tyres have to comply with technical regulations including standards for the noise emission (70/157 EU and amendments or the related UN/ECE regulations R117, R41 and R51). An essential component in this is the test method, which shall be reproducible, representative and universally applicable. Since the pass-by test geometry is very similar to the coast- and cruise-by procedures used in pavement research, we could contribute with insights in L_{Amax} versus SEL data, constraints in the procedures and influence of the pavement and propagation area on the pass-by levels.

Moreover, extensive data from on board monitoring of road vehicle noise and noise data from widely varying tyre populations contributed to the reproducibility and representativity aspects in the method. We were given the opportunity to contribute with these findings in the EU ERGA-NOISE and UN/ECE GRB meetings.

4.4 Consulting engineering

The last but not least pillar constitutes of the numerous small, medium and large projects on acoustic evaluation and monitoring of pavements with the SPB or CPX method. These projects not only generated huge amounts of data, extremely relevant for understanding the initial and age related performance of pavements, but also valuable insights in potential improvements of standardized procedures. The knowledge on tyre/road interaction processes is further increased since not only performance data but also functional data were recorded such as texture and acoustic absorption.

Over the years more than 100.000 individual pass-by events are recorded and CPX data from over 2000 pavement sections could be added to the data base. The data on aging of the acoustic performance of various types of pavements were studied for the European Road directorates (CEDR) and its results made available through http://www.questim.org/

5. SPECIAL TOPICS

In this part a few topics are highlighted since their relevance for the field of road traffic noise control is more than average.

5.1 Development of two layer porous asphalt

A special topic in the 40 years of research of M+P is the development of two-layer porous asphalt (Figure 11). Here, a fine-graded open top layer reduces tyre vibration and air pumping noise while a coarse sublayer allows tuning of the acoustic absorption characteristics and increases drainage. First results from the Welschap proving ground in 1989 already indicated a high noise reduction of 5 to 6 dB for cars relative to dense asphalt concrete at medium speeds. Later, a full size test program on several stretches of Dutch highways revealed its potential for durable noise suppression for cars and, importantly, also for heavy vehicles.

Figure 11. Side view of two-layer porous asphalt.

At this moment about 500 km of Dutch highway is covered to maintain noise limits around the infrastructure.

5.2 Development of pavement measurement systems

In order to obtain a full grip on tyre/road interaction noise, experimental data is essential. M+P has developed several measurement instruments for detailed assessment of both the functional performance of the pavement with the statistical pass-by procedure or the close proximity procedure and the intrinsic surface properties such as 3D surface texture and in-situ acoustic absorption.

The technology was standardized in a continuous cooperation with relevant ISO working groups and currently dozens of customers all over the world now use M+P equipment for their specialized pavement research.

Figure 12. Three of the CPX systems developed and manufactured by M+P.

5.3 Development of the harmonized EU noise model

In a close international cooperation within the framework of the EU 4th and 5th framework projects HARMONOISE and IMAGINE, M+P has developed the source model for road vehicles for the EU-CNOSSOS noise calculation scheme. Interesting is that the model distinguishes between powertrain noise and rolling noise. On base of the large data base with on-board acoustic measurements from all kinds of vehicles under a wide variety of driving conditions we were able to develop a coherent description that takes into account age, weight, engine type effects and the relevant influence of the pavement on both rolling noise and powertrain noise. An example for a single vehicle is given in Figure 70 above.

5.4 International cooperation

Since the issue of traffic noise in different countries of the EU shows large similarities, it is efficient to seek cooperation with research institutes in other countries and M+P has worked with several institutes in more than 12 countries in the EU and beyond in the USA and Japan. Such cooperation is stimulated by the European commission by the consecutive R&D framework programs. M+P participated and was WP leader in HARMONOISE, IMAGINE, SYLVIA, ROTRANOMO, SILENCE and recently NEMO. Such programs presented great opportunities to further develop measurement techniques, know-how on tyre/road interaction, road vehicle noise models and create a network that forms the basis of further fruitful bilateral cooperation.

6. DISCUSSION AND CONCLUSION

This paper presents a development of research and development in rolling noise from road vehicles and their tyres over a period of about 40 years. The insight that the pavement is the dominating factor in the generation of road traffic noise has focused the work on low-noise pavements. However, it is impossible to optimize the pavement if the properties of the tyre are not well understood, as the tyre is the main source of road traffic noise. This was shown for smooth (low texture) surfaces that are generally low-noise, but on which some truck traction tyres become very noisy and emit tonal noise related to the block impact frequency.

The development and application of low-noise pavements is still relevant today and tomorrow, perhaps even more so than before. While electrification of the vehicle fleet will minimize the powertrain noise, the tyre/road noise will remain. In the light of the European Commission's recent ambitions in their Zero Pollution Action Plan to reduce the impact of transport noise by 30% by 2030, and given the fact that road traffic is by far the largest source of this impact, low-noise tyres and pavements should be a top priority.

Although 40 years old, the topic of low-noise pavements should keep up with modern times. Today's world focuses on sustainability, climate, energy and air quality, also for road transport. This means that low-noise pavements should also be recyclable and produced at lower temperatures, for instance. Luckily, some of these environmental goals go hand in hand: low-texture pavements are not only low-noise, but also reduce rolling resistance, leading to lower fuel or battery power consumption. Safety, particularly wet braking, does require some micro and mega texture. By careful adjusting texture levels in the different wavelengths areas an optimal balance can be achieved. Low texture also leads to lower tyre wear and the air voids in the pavement do not only absorb sound, but also trap these tyre/road wear particles, preventing them to end up in the soil and waterways. Research on this is increasing, such as in the NEMO project (https://nemo-cities.eu), reported also in Forum Acusticum 2023.

As discussed in this paper, the approach to the reduction of road traffic noise, and tyre/road noise in particular, requires work in all of the four pillars presented. For a successful implementation of the research work, it should be closely linked to consultancy, regulations and standardization. Private companies such as M+P have a unique position as they are able to bridge the gap between policy makers, researchers and industry. Policy makers approach us as engineers, supplying data and other technical information, while pavement and tyre manufacturers ask our help to understanding and implement policy regulations.

7. ACKNOWLEDGEMENT

The achievements of M+P on tyre/road noise, vehicle noise, test procedures and measurement systems has demonstrated the potential of international cooperation. The growth from the first attempts to get a grip on the effect of the pavement in 1986 to the present situation where we are active worldwide as supplier of measurement systems, test track certifications, ISO standard developments and know-how is only made possible by cooperation with many other organisations in- and outside of Europe, and the financial research grants from the European Commission.

More important have been the Dutch ministries of Environment and Transport that have set high standards for our roads, and who acknowledged the value of sharing in the international research arena, supporting the activities in these areas. Also, the German and Scandinavian Transport ministries presented chances for M+P and their partners to perform extensive R&D projects on texture influences on rolling noise for both car and truck tyres.

As a private company, we depend on the dedication of our clients to this research topic. Without their interest and financial support we could not have performed these large research projects and would not have been able to play such a major role in this field over the last 40 years.

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40 years of research comes with many more publications that cannot be listed here. Please visit https://mp.nl/en/publicaties for other references.