LORRY Report Summary

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Final Report Summary - LORRY (Development of an innovative low rolling resistance truck tyre concept in combination with a full scale simulation tool box for tyre performance in function of material and road parameters)

Executive Summary:
The transport area is responsible for around 58% of the global fuel consumption over the world, and of around 20% of the global CO2 emissions. Transport systems activities will continue to grow in the future, the EU is therefore currently facing an important challenge to reduce in a significant way transport systems carbon footprint through a mutation of the classic transport systems into intelligent transport systems: greener, safer and smarter. The objective set-up by the EU is to reduce transport GHG emissions by 60% by 2050. This objective concerns in particular road transport and trucks. Tyre Rolling Resistance can account up to one third of the total fuel consumption. Therefore, in order to reduce consequently trucks' fuel consumption and overall carbon footprint through the development and the demonstration (through fleet tests) of innovative low Rolling Resistance tyre concept (innovative designs combined with innovative materials) with a comprehensive toolbox for fuel saving management. The objective of the LORRY project was to achieve 20% of improvement in terms of Rolling Resistance, while improving in the same time the tyre wear and wet safety performance. These improvements will feed coming tailored trucks and sustainable EU trucks initiatives.

To reach this overall objective, innovative tyre concept designs have been investigated and combined by GY: i) WAGAN blade technology, ii) Multizone tread pattern concept (dual concept). The innovative concepts have showed promising improvements in wear and RR during laboratory tests and have thus been further integrated in the prototype LORRY tyres used for the fleet tests.

In parallel to these innovative designs and in order to develop and mix the best compounds candidates for the fleet tests, the project consortium has studied and combined effects and properties of innovative raw materials like Carbon Nano Tubes (CNT), new developed carbon blacks or silica. The most promising materials have been mixed in compounds and characterized. Finally, the best candidates compounds for the fleet tests have been mixed in three iterations (two tire build iterations) and when combined with innovative tyre concept designs mentioned above. At laboratory scale, the LORRY prototype steer tyres showed, very promising improvement in terms of wear and RR, with a reduction by 25% of the RR performance.

Additionally, during the project, enhanced models and methods to predict material and tyre behaviour during the development phase have been developed: i) Tyre laser sensor methodology to predict RR, ii) Predictive viscoelastic RR test, iii) Predictive measurement of material behaviour under dynamic constraints through bi-axial tear fatigue machine, iv) Wear characterization through innovative lab tribometer. These enhanced methodologies, have allowed to reach a better understanding of the phenomena and material/tyre behaviors. They will be further used in particular for the development of innovative/enhanced tyre concepts with the aim of improving RR or wear performances.

Then fleet tests have been performed with three selected fleet companies in order to assess the performance of LORRY tyre prototypes. These tests have particularly allowed to validate the expected wear improvements through the innovative tyres performances, however these tests didn’t allowed the consortium to assess the improvements in terms of fuel consumption (RR resistance). Therefore, additional and non-foreseen coast down measurements have been performed highlight
improvement for LORRY steer tyres of around 15%. The difference between the lab measurements and the coast down measurements is probably linked to the following parameters: tyre temperature and road pavement properties. Finally a method for predicting rolling resistance and tread wear for a given truck-tyre combination traveling over an arbitrary route with a corresponding velocity profile has been developed. Then data from the performed fleet tests have fed the model, highlighting a strong correlation with actual tyre results.

As a general conclusion, the LORRY project has allowed developing innovative tyre designs and materials to significantly improve tyre wear and RR performances, but also developing enhanced measurement methods and predictive tools. Based on these promising results, further innovative materials must be investigated in order to reach enhanced performances and additional tests must be performed in particular to better understand the influence of pavement properties. This will be probably done through collaborations with the LORRY partners.

Project Context and Objectives:

Background

Greening of transportation is one of the major actual societal challenges. Transport sector depends on oil for about 96% of its energy needs; it accounts for 58% of the global oil consumption and about 20% of Green House Gas emissions. Latest projections on global oil use predict another increase in transportation activity of almost 90% in the next decade. Transport system will remain an essential vector for a strong economic growth and needs to cope with the challenges of energy and material resources of the future. This growth is still challenging the European transport system and especially long distance road transport. A mutation from a classical transport system to an intelligent transport system appears to be an absolute necessity: greener, safer and smarter.

To tackle the outlined challenge, the European Commission published in March 2011 its new white paper ‘Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system’. This white paper provides a comprehensive strategy for preparing European Transport Area for the Future. At the same time, it gives a vision for a competitive and sustainable transport system while reducing dramatically carbon emissions in transport (aim is 60 % by 2050). To bring this vision to reality, technological innovation is a key issue because it can act directly on vehicles’ efficiency through new engines, materials and design.

According to the Work Programme 2012 of the active Framework Programme (FP7) research and innovation projects are crucial to contribute substantially in greener, safer and more efficient mobility in all modes of transport. Since 2007 and more specifically after the launch of the recovery plan in 2008, the EU has launched and promoted various programmes in the context of the greening of surface transport. Through the European Green Car initiative a series of measures have already been taken to boost Research, Development and Innovation to increase global competitiveness for automotive industries with the deployment of new generations of trucks, buses and cars which are life and environment compliant. With the launch of the Public-Private Partnership (PPP), the European Commission encouraged research on possible solutions that can significantly contribute to a greener and sustainable economy for transport sector. Around 50 projects have already been launched through the European Green Car Initiative, covering different research fields like: new Li-Ion batteries and their manufacturing, light weighting of vehicles, vehicle electrification. Today’s priorities for heavy duty vehicles are the efficiency of vehicles by energy management, aerodynamics and low rolling resistance, as well as eco-driving and innovative truck designs.

Overall Objectives

Project ‘LORRY - Development of an innovative low rolling resistance truck tyre concept in combination with a full scale engineering tool box for tyre and material design in function of road parameters’ will actively promote the EU’s objective of a holistic approach for an intelligent transport system. It will contribute to a greener, safer and more efficient mobility in freight transport (part of societal challenges 1 and 2 of Transport Work Programme) by combining a new tyre concept and a comprehensive tool for energy efficient heavy duty transportation. The presented project addresses the greening of surface transport by the reduction of global oil use.

For heavy duty vehicles, well known impact factors to fuel consumption in relation to tyre rolling resistance are: tyre inflation pressure, vehicle load, wheel alignment, cruise speed, driving style, road conditions and weather conditions.
It has been established that tyre rolling resistance can account for as much as one third of the total fuel consumption of a truck, while the contribution is recognized to be at least one quarter in any case. The RR parameter cannot only be analyzed as a stand-alone parameter but is strongly correlated to other listed parameters. LORRY project thus proposes to study rolling resistance in its whole environment, and optimize truck fuel consumption by correlating it with tyre pressure, load, driving style, road and weather conditions.

The overall objective of the presented project is to develop a new tyre concept to reduce trucks carbon footprint. Scientific aims are a gain of 5% in truck fuel consumption, a gain of 20% in tyre rolling resistance and a gain of 20% in tyre wear reduction. These results will go beyond expectation for tailored trucks given in the EGCI roadmap for 2020. These gains will be obtained without compromising tyre safety, wet grip and wear resistance. Concept will be demonstrated on trucks long haul to answer main priority of the European Green Car Initiative (EGCI) strategy [4]. A virtual road performance measurement tool will be developed allowing optimization and leaning road transportation via heavy duty vehicle. The strongly multidisciplinary consortium supported by transportation and standardization key players will ensure a holistic approach and will guarantee European regulation compliance and market acceptance of the project outcomes. These results will participate in the Innovation Union initiative of European Commission by promoting more sustainable behavior.

The proposed project is fully in line with the EU transportation strategy by addressing the full cycle of research, innovation and deployment in a fully integrated way. The most promising technologies in terms of innovative materials, tread patterns and tyre monitoring systems are part of the project. Integration of these solutions in a global concept is mandatory (a single solution to grow out of oil is not realistic) to tackle trucks energy consumption appetite.

LORRY project proposes improvements in tread pattern technology, material composition and processing in combination with enhanced characterization and simulation tools lead to a more complete understanding of tyre performance in function of material and road parameters. Indeed the tyre performance benefits will be directly demonstrated through experimentation but also complemented by virtual performance assessment tools. Research key challenges of the project are: understanding interaction between new tread pattern design and novel fillers in compounding, the simultaneous improvement of RR, wear and wet performance and the fine scale correlation to fuel consumption in function of driving and road parameters.

Within the LORRY project, an interdisciplinary consortium of experts in the fields of tyre technology, rubber and filler technology, nanotechnologies, composite physics, sensors and transport and road infrastructure had for objective to deliver an innovative tyre concept with proven benefits via a full scale fleet road measurement campaign. A complete set of complementary scientific evaluation methods, risk analysis (a.o. for the use and release of nanoparticles) and profitability calculations are also part of the project to ensure its success. Different “innovation outcomes” of LORRY project are the followings:

- New validated tyres including new tread pattern and material features for steer in 2 sizes,
- New validated tyres including new tread pattern and material features for trailer in 1 size,
- Technology transfer demonstration for drive tyres through inclusion of new drive tyres in the full scale tyre fleet demonstration (out of LORRY funding scope),
- New methodology for tyre deflection measurement and RR/wear/fracture-fatigue predictive measurement,
- Smart systems for tracking and analyzing trucks driving and environmental conditions,
- Virtual analytical tool for optimization of trucks fuel consumption.

Overall strategy of the work plan
In order to demonstrate the maximum potential of low rolling resistance truck tyres, the project deliverables were based on the following 4 key competencies:
1. Tyre tread design and construction,
2. Tyre materials design and processing,
3. Advanced tyre and material characterisation and performance modelling,
4. Tyre road campaign evaluation and modelling.
The Work Plan plan was based on 2 work packages (WP) dedicated to project management (WP7) and dissemination (WP6) and 5 technical WPs (WP 1-5). WP 1-3 were dedicated to the full loop of tyre and material experimentation and modelling (Conception phase) while WP4 and WP5 address the full scale parametric tyre road performance evaluation through experimental and virtual tools:

- **WP1 – Design of new tread pattern:** This WP aims to lead to new evolutive and multi-zone tread patterns to be integrated in an optimized low RR tyre concept and pre-validated through an extended state of the art tyre lab testing protocol but also enhanced through available features of the new enhanced characterisation tools developed by public partners through WP3.
- **WP2 – Development of advanced nano-structured compounds:** This WP had for main goal to provide new silica, carbon black and MWCNT based material solutions with tailored preparative techniques for use for tyre tread and non-tread components. This WP has benefited from the combination of the expertise from Orion specialized in Carbon Black manufacturing and technology and from DIK specialized in rubber technology and Carbon Nanotubes. CSIC will complement the expertise by providing novel analytical methods for structure property elucidation at the required nano- and micro- scale. Goodyear contributed to this WP through its silica know-how and realized the required mixing scale up trials as well as a tyre pre-validation.
- **WP3 – Enhanced characterisation and virtual analysis:** This WP consists of the development of new experimental characterization techniques for the structural response of tyres and its material components which can enhance the predictive capability for tyre rolling resistance, wear and durability. The enhanced characterization consists of a high resolution rolling tyre deformation detection by Aalto, a fracture-fatigue test by IPF and an abradability test by LPMA, both mimicking the real tyre solicitation conditions. These predictive experimental tools have been applied with their available features in the tyre and material applicative WP’s 1 and 2 but have the primary purpose to be introduced into the setup of a virtual toolbox including numerical calculation features for potential use in Tyre FEA models by Goodyear.
- **WP4 – Assessment of tyre performance – Field evaluation:**

  The work that was foreseen through this WP is illustrated by the Figure 1. This full-scale road testing phase has been monitored by Novacom, by adapting and installing the measuring sensors to collect all data of a fully instrumented fleet campaign test. The developed concept tyres will be run in configurations to have a conclusive feedback on the new tyre and material design features. Ewals Cargo Care as fleet operator ensured a large scale EU road coverage by privileged routes and the related road infrastructural information will be provided by BRRC and Aalto. ITWM will be responsible for the compatibility of data acquisition for the integration in WP5.

- **WP5 – Analysis and modelisation of tyre performance – Comprehensive tool:**

  This WP will be coordinated by Fraunhofer ITWM and enable to analyse the data from the instrumented fleet demonstration and to address the proof of concept for ultimate low RR truck tyres with integration of road and climate parameters. This virtual measurement tool links the tyre performance and road conditions. Since the field tests were not efficient to demonstrate the reduction of fuel consumption, BRRC has handled in replacement to road properties, coast down measurement tests to assess on real driving conditions the RR improvement achieved thanks to the innovative tyre concepts.

**Project Results:**

1. Development of innovative tire design (WP1)

In order to improve tyre wear and rolling resistance performances, GY has investigated innovative tyre design concepts:

- WAGAN Blade technology;
- Innovative Compound blending process flexible blend ratios;

Considering the highly positive results demonstrated through laboratory tests, these innovative concepts have been further combined with the most promising innovative tread compounds developed within the WP2. Tyres from the second tire build iterations have been used for the project fleet tests.

a. WAGAN Blade technology
The “Worn as good as New” (i.e. WAGAN) technology is based on evolutionary groove tread pattern change in function of depth. This technique was already tested on passenger tyres and the challenge here was to transfer it to truck tyre with improved features. This technology will allow to better control tread block stiffness and also to alter tread pattern with increasing mileage. Development and conception phases have been initiated thanks to CAD, Tread & Cavity Design and FEA prediction models. Such innovative concept was expected to significantly improve the RR performance of the tyre as well as the wet grip performances over the tyre lifetime.

The Figure 2 is presenting WAGAN concept adapted to mass production (must be in line with the tyre mould creation process).

After several investigations and iterations it has been decided to go for an evolutional groove concept moving from 3 to 4 ribs over time. The Figure 3 shows the evolution of tyre tread over time.

According to the laboratory tests performed on this new concept in the frame of the project, the innovative concept will lead to an improvement of the RR of 5% and at least 20% in terms of wet grip performance in comparison with Goodyear LHSII reference tyre.

b. Innovative Compound blending process flexible blend ratios

The objective through this innovative concept is to develop and assess the potential of innovative process based on a multiple Gear Pump (GP) principle allowing blending non-productive and ultra-accelerators to produce novel RMT treads with a dial-in custom compound that is either homogeneous or stratified. Indeed the idea behind this concept (see Figure 4) is that if the layered high wear and low RR compounds are blended to provide unique composite properties to stratify the RR compound and have the stiff wear compound supporting ribs/lugs, then RR rolling resistance could be improved with the same performance in terms of tread wear.

In order to assess the actual improvements achieved through the innovative concept, tyres have been built with a dual tread cap design:
- Cap 1 with a compound aiming to increase mileage;
- Cap 2 specifically selected to improve RR performances.

The tests performed have highlighted the following performances improvements thanks to the dual tread cap design:
- Endurance for candidates with dual cap > 67h (between 80h and 72 hours depending on the compounds);
- RR improved by 9 %.

c. Combining new technology features with new materials

In order to validate the combination of the different technologies investigated with innovative compounds (developed within the WP2). Tyres have thus been built and have been tested in terms of electrical resistivity, by performing Coesfeld test. The tests performed have highlighted that all compounds are showing same electrical conductivity behaviour increasing with compound physical ageing, some of them even showing no conductivity at all at early ageing stages. Such behaviour is not acceptable in view of realizing the field tests. New CB grades have been further tested to improve this performance, however the tested innovative materials have led to reduction of the RR performances.

2. Development of innovative nano-structures tyre compounds (WP2)

The main objective regarding innovative nano-structures during the LORRY project was the development of innovative compounds for the next generation of truck tyres with extreme low rolling resistance without any loss in wear properties or in fracture-fatigue resistance. For improvement of tyre compounds, the fillers have an extreme high influence on the properties beside the polymer, the crosslinking, other additives and the process. The composition of the tread compound has a high influence on the rolling resistance.
The experimental procedure used within the project consisted on combining the effects and properties of innovative raw materials like Carbon Nano Tubes (CNT), new developed carbon blacks or silica. Special preparation techniques to be used with exhaustive advanced testing followed by up-scaling and tyre building and testing. Special preparation techniques of the compounds are of high interest because of the improvement of the dispersion and distribution of nanoscale fillers in rubber and rubber blend matrices. A high dispersion of the mentioned fillers is the key for the high reinforcing potential and for improved properties of the compounds concerning an ideal balance between elasticity and damping behavior as well high strength and resistance against abrasion.

a. Selection and characterization of raw materials
To do so, new developments in carbon blacks (OEC) have been performed to improve the wear resistance without increasing the specific surface but by changing the Average Size Distribution (ASD) of the agglomerates (particles) using a new reactor design and a special modeling technique (computational fluid dynamics (CFD)). The new types ES 247 and ES 204 are optimized for low specific surface but with a high variation in Oil Absorption Number (OAN). Overall, 4 types of new developed carbon blacks (CB) and 2 well known reference types, two types of silica, a silanization agent and MWCNT (NC 7000) were selected and used for model steer tread compound preparation. The carbon blacks were characterized in terms of OAN and CTAB-adsorption. Especially the new CB grade EB 270 was produced with a special target in aggregate size distribution (ASD) similar to Corax N 121 but with a higher OAN. The new types ES 247 and ES 204 have been optimized for low specific surface but with a high variation in OAN. As silica fillers two types with different surface area were selected and used with a silanization agent. The density of active regions on the surface of the above mentioned carbon blacks in comparison to MWCNT is characterized by BET-surface measurements and calculation of the statistical distribution of the number of high surface energy regions in a gas adsorption apparatus using 2-butene. Most of the new developed Carbon Blacks showed a bi-modal distribution of active regions. So high filler-polymer interactions can be expected. The use of these CB types should lead to a promising balance between rolling resistance and wear properties. The CNT (NC 7000) were characterized in terms of aspect ratio, specific surface and surface energy by inverse gas chromatography (see Figure 5, Figure 6, Figure 7).

The reinforcing effect and dynamic properties, which give information to the expected rolling resistant of all mentioned fillers was investigated in the defined model steer compound.

b. Specific functionalization of NR and BR (DIK)
For the improvement of polymer-filler interaction cis-BR and NR were epoxidized to a defined low level (around 4 %) to receive a balance between increasing of point of Tg and polarity in the material. The optimum of polymerization temperature and time were proved in larger scales using formic acid and H2O2-solution in toluene. The optimal temperature could be defined at around 20 °C to reach the target epoxidation rates of 4-6 % over 80 min. reaction time. To investigate the interactions of epoxidized NR and BR with silica, 900 grams of each rubber were slightly epoxydized (4 to 6 mol% epoxy groups). Therefore, 8 batches were combined and mixed on the two roll mill. The material was provided for further investigation to partners of WP 2 and WP 3.

Additionally to this subtask, new achievements have been reached through mixing and investigations on compounds basing upon epoxydized and un-epoxydized rubber matrices in combination with silica (types: MP 1165, VN3) and CNT (NC 7000) as fillers. One objective was the partial substitution of silica by CNT using the approach of “Design of Experiment” (DOE) in cooperation with Goodyear.

For comparison of the compounds base upon epoxydized and non-epoxydized rubbers, cured and uncured mixtures were used. The mixing was performed in 2 stages of melt mixing technique by means of a tangential lab-mixer and a two roll mill for adding the vulcanization system. The silica-systems were silanized with the silane “X50S“ during mixing by increasing the temperature up to 150 °C by means of the rotor speed. On cured and uncured samples a large number of physical tests were carried out to characterize the influence of the epoxidation on the filler-polymer interactions and to substitute partially silica by CNT. On comparing results from both groups, some really interesting differences were obtained between the epoxy and non-epoxy compounds:
c. Compound mix and preparations

Once the raw materials have been selected, they have been mixed to be integrated in tread compounds.

Mixing of new CB grades in tread compounds (OEC)

In general, different strategies can be applied to optimize rolling resistance of truck tyre tread compounds by carbon blacks:

a) use of improved fuel efficiency ECORAX® blacks
b) partly replacement of carbon black by silica/silane technology
c) reduction of rubber volume in the contact patch area

However, wear resistance is usually decreased, too. To overcome this drawback, smart tread compound concepts in combination with a new class of carbon blacks designed for improved abrasion performance are needed. The ASD curve of a carbon black has a big impact especially when the carbon black has a high specific surface area (subtask 2.1.1). Due to the impact of carbon black dispersion on wear performance, attention has to be paid to dispersive mixing. An intensive lab mixing study was performed to simulate an industrial 3 stage mixing process. A scientific model compound based on synthetic rubber (E-SBR) and 50 phr filler content was chosen. Since this type of polymer is known to show no self-reinforcement, differences in the final rubber performance are mainly related to the carbon black dispersion itself. The compound preparation was done using a 4 liter lab mixer with tangential rotor geometry (GK 4N). The rubber mixture was immediately dumped in the first mixing stage when the final temperature of 160°C was reached. In the re-mill and final mixing stage standard conditions were applied. The carbon black macro dispersion after the particular mixing steps was investigated via surface roughness determination by a topography method (TOPO) which expresses the dispersion quality in terms of the total defect area. Results are shown in Figure 8. In general, carbon black dispersion quality improves significantly with number of mixing steps. Furthermore, it is clearly seen that under the applied mixing conditions the Goodyear reference black N 121 disperses much better than ASTM benchmark grade for wear resistance (N134). Main reasons are the lower specific surface area in combination with its increased structure level as already mentioned before. In contrast, EB 262 yields a similar macro dispersion level like N 121 despite its much higher specific surface area and lower structure level proving the narrow ASD concept.

The comparison of the “in-rubber data” shows that narrow ASD and high structure level act in a similar way. Shore hardness, moduli, tensile strength and dynamic stiffness are increased at almost constant loss factor. Furthermore, this enhancement of rubber reinforcement is not accompanied with a significant drop in elongation at break. It is still on the same level like the ASTM benchmark grade. High stiffness in combination with high elongation at break is a good design basis for truck tread compounds in general. However, the most important fact is the confirmation of significantly improved wear performance. Testing lab wear performance using a LAT 100 abrasion tester and test conditions according to ISO 23233, wear performance improvement of 7% was found on average for different severity conditions. The applied compound concept for the steer tread makes use of this wear benefit. A cap and base design as shown in Figure 9 was chosen for the LORRY concept tyre. The base compound was characterized by lowered hysteresis at high dynamic stiffness. In contrast, the cap compound is optimized for both improved wear and low rolling resistance by combining best wear carbon black (EB 262) with high silica loading.

d. Mixing of CNT/Rubber master batches (DIK)

The CNT-masterbatches were prepared and characterized using a recipe base upon a NR/SBR 1502 /cis-BR-Blend (ratio 80/10/20 phr) and 1-9 vol.-% of CNT (NC 7000) and a sulfur-vulcanization system using S, ZnO, stearic acid and CBS. The mixing procedure consists of two steps:

1. Internal mixer - 1.5 l Vol., intermeshing rotor systems,
2. Two roll mill adding the vulcanization system.

Concerning the vulcanization behaviour, it is to summarize, that with increasing CNT-content the maximum torque difference in the rheometer tests is increasing because of increasing viscosity of the compounds with higher loadings of CNTs. The vulcanization time shift to shorter values, reaching the max. torque or t98-value. Furthermore, the reversion tendency is increasing with higher loadings. The viscoelastic properties of the un-crosslinked compounds depending on the different
loadings with CNT and on strain amplitude were characterized by means of the determination of the shear modulus. Clearly the Payne-Effect can be observed, that means, that the storage modulus is starting on defined level and is decreasing with the strain amplitude to new plateau on a lower level because of degradation of the filler-network. This is more evident at higher filler concentrations because of smaller distances between the filler particles in a defined volume. Further it is to be mentioned, that the modulus of the whole system is determined by the modulus of the unfilled polymer matrix, of the hydrodynamic effect of the filler and of the filler-filler interaction. Overall the storage modulus is increasing with the content of CNTs, especially at low amplitudes. The results show the percolation level at a CNT content of 2.5 vol. %. In comparison to carbon black (CB) filled systems the percolation level is much lower (CB-systems: 20 vol. %). A much higher reinforcement effect can be expected from the CNT. Concerning the harness measurements it could be observed, that, the hardness Shore A (according to DIN 53505) shows a linear relationship to the CNT-loading. The stress-strain measurements were performed according to DIN 53504. The measurements were carried out in two directions of the geometry of the material because of the investigation of anisotropic properties. The stress-strain curves show no anisotropy. The break energy is calculated from the area below the stress strain curves. The maximum of the curve is at 2.5 vol. % which correlates with the percolation level of CNT-filled compounds.

Moreover, two innovative mixing techniques were applied for the preparation of sulfur crosslinked NR/CNT-rubber composites used as master batches. The first one is a derivative procedure with energy saving manufacturing of CNT/rubber master batches, by combining internal mixer and an extruder equipped with a special nozzle (or die), designed for high elongation flow rates to effect an improved dispersion (see: H. Zimmermann, R. H. Schuster, ICCE 27.July 2011). The other used method, is the Continuous Dynamic Latex Compounding (CDLC), which is developed and tested at DIK for different latex-filler systems and is adjusted for the manufacturing of CNT/NR master batches (Patent: DE 10 2007 048 995 A1). Fundamentally optimizing the dynamic process a static mixing procedure using latex was performed (static latex compounding). As reference a melt mixed material is used. Extrusion using special die/nozzle has already shown effects of CNT orientation. The properties of compound have also shown considerable differences. Overall more tests are necessary to validate the actual slightly better results in latex compounding in comparison to melt mixing under concern of filler dispersion. Overall a complete program in physical characterization including process relevant parameters is performed. For investigation of the rolling resistant relevant parameters the dynamic mechanical analyses of cured sample were performed using 10 mm x 2 mm strips of vulcanized samples. As example, results from temperature sweep at 1 Hz is shown in the following graph (see Figure 10).

When comparing the filled compounds, the difference in the peak behavior has been observed with more or less same behavior at 0°C and 60°C. Extrusion using special die/nozzle has already shown effects of CNT orientation. The properties of compound have also shown considerable differences. Overall more tests are necessary to validate the actual slightly better results in latex compounding in comparison to melt mixing under concern of filler dispersion. From latex compounding results, it is to conclude that this is a better mixing strategy in terms of filler dispersion, but it is still advisable to perform more tests including variation of other parameters and with more filler concentrations. Since, one is always unsure about the properties without achieving the percolation threshold.

e. Synthesis of safe dust free handling preparations (DIK)

The safety handling of CNT in technical scale could be solved using two methods. On the one hand the preparation in tight sealed LDPE bags is a suitable method for the direct melt mixing. On the other hand the pre-preparation to a paste using mineral oil plasticizers can be used, if the recipe tolerates this. In addition to the safety handling of CNT a method for workplace air monitoring is developed, but not validated completely. The method bases on active sampling using filters, which have an appropriate pore size according to the CNT diameter of appr. 10 – 15 nm. The success in sampling CNT from the air was detected by means of SEM-analyses.

f. Partial substitution of CB and Silica by MWCNTs (DIK)

Using a Design of Experiment approach (software: “Jump” in cooperation with Goodyear) the partial substitution of silica by
CNT was tested in combination with the epoxidation of the rubbers. By the same principle the partial substitution of carbon black by CNT (hybrid systems basing upon carbon black and CNT) in the steer compound (NR/SBR/BR) for the systems CB N 121/CNT or for the system CNT/N 121/silica MP 1165 (triplet-hybrid) with different ratios between each others were investigated. The compound mixed in 1.5 l intermeshing mixer were investigated uncured and cured completely for their physical properties and process relevant parameters.

From the measurements on the N 121/CNT-systems the following most interesting results were obtained:

- The vulcanization time (t98) is decreasing linear (trend) with the sum of N 121/CNT in different ratios.
- The determination of G' on the uncured materials by means of RPA results in the perculation threshold at a filler loading of 20/4 phr (N 121/CNT). In comparison to a system filled with N 121 pure this value is at appr. 35 phr.
- By multi-hysteresis measurements the perculation threshold value is confirmed.
- For characterization of parameters for rolling resistance and for traction DMA-temperature sweeps were performed. For the rolling resistance low tan δ values between 40 and 60 °C are essential. This is the case especially for low N 121/NC7000 content. The 30/1.16 phr N 121/NC7000 sample let expect a good traction and grip at low temperatures of appr. 0°C and a good rolling resistance. Furthermore this material will show improved wear properties and strength.

The investigations on triplet hybrid systems with N 121 / NC7000 / MP1165 in the steer compound result in the best filler composition of 13.5/(10/2 phr for N 121/MP1165/NC7000 concerning the best compromise between low tan δ at appr. 60°C and a high rebound at 100 °C as well low energy dissipation in multi hysteresis. The range of ratios or concentrations of fillers were between 2-21 phr for N 121, 3.5 – 33.5 phr for silica and 2-4 phr for CNT.

g. Compound characterization
In a first step the compound characterization has been performed. To do so the processing parameters (i.e. vulcanization behaviour and rheological properties and further all interesting physical and viscoelastic properties of crosslinked steer compounds containing different loadings of the new CB types (EB 262, EB 270, ES 204 and ES 247 or of the silica (VN 2 - 130 g/m2, MP 1165 – 175 g/m2) and CNTs) were characterized in comparison to reference systems containing the high active CB N 121 (typical for steer and trailer tread compounds) or CB N 347 (typical for steer and trailer subtread compounds) for their stress-strain behaviour, hardness, rebound, dynamic properties (shear modulus, damping factor), for the perculation threshold (dielectric measurements) and filler dispersion. The most important results are summarized as follows:

h. CB and CNT-systems - dynamic mechanical properties:
Concerning the tan delta values (damping factor) in dependency on the temperature of 0 °C (typical for traction and grip) and 50 °C (relevant for rolling resistant) the CB type ES 204 is favored for low rolling resistant, and EB 270 for improved traction. The complete dynamic behavior of the systems is shown in Figure 11:

i. Silica systems - dynamic mechanical properties:
For both types of silica a very similar behavior for the damping factor at 50°C and 0°C could be observed. Concerning the rheological dynamic measurements on the un-crosslinked systems it can concluded, that the MP 1165 due to their higher specific surface show a higher reinforcing effect caused by filler-filler interaction at low strains.

Then, an advanced physical mechanical characterization has been performed on the mixed materials. First, the mixing procedure on the compound basing upon N 121 45 phr or alternatively CNT 5 vol.% (2 phr) and NR 80 phr/BR 10 phr/SBR 10 phr and vulcanization system (model steer) using a 1.5 l intermeshing mixer was optimized by the variation of rotor speed. The results on physical properties including macro dispersion of N 121 and dynamic properties show, that compounds mixed with lower rotor speed (rpm) favors shorter cure time, tensile, elongation and lower hysteresis. The compounds mixed with higher rpm favors delta torque, dynamic stiffness and higher electrical conductivity. For the advanced physical compound characterization concerning the polymer-filler interaction the carbon black N 121, EB 262, N 347 and ES 204 were selected and mixed into single polymer SMR20, SBR1502, cis BR and in their blends (di- and tri-blends). The investigations on the macro-dispersion by means of DIAS (microscopic optical light reflection method) in single rubber with 45 phr CBs (N 121, EB 262, N 347, ES 204) shows, that dispersion acc. to particle size distribution decreases slightly in the order: SBR1502 > SMR20
The polymer-filler interaction parameter according to Kraus were determined by swelling experiment in toluene. The Kraus parameter for CNT NC7000 is by a factor of 1.5 higher than it is for the CBs. Interaction of CB with SBR is higher than with all other investigated polymers (styrene group). CB ES 204 shows highest filler polymer interaction in BR, SBR, NR and in their blend. The results were confirmed by additional multi-hysteresis measurements. Further investigations on the filler-polymer interaction and on spatial distribution of the crosslink density in presence of the above mentioned fillers were carried out by means of Double Quantum NMR at project partner CSIC (Spain). The used compound for these investigations were the steer compound with all different fillers, mentioned above, with concentrations from 30 – 70 phr for the carbon blacks (N 121, EB 262, EB 270, N 347, ES 204, ES 247, 25-60 phr for silica: VN 2, M P 1165 (modified with silane X50S) and 1.85 – 18.5 phr for CNT. The results are summarized below:

• The samples filled with Carbon Black ES 247 presented the higher filler-rubber interactions in comparison with the other CBs grades studied in this project. This behaviour is related to its fractal structure and surface energy.
• Addition of silica fillers modified with coupling agents (silane molecules), led to enhancement of the filler-rubber interactions as compared with the CBs.
• The carbon nanotubes are the fillers that promotes the highest density of interactions at the filler surface.

The promising mechanical and viscoelastic properties of CNT composites could be compromised or limited by the strong influence of CNT nanoparticles in the vulcanization process and the obtained rubber network structure.

For the investigations, carbon blacks N 121, EB 262, N 347 and ES 204 were used in the single rubbers and in the blends with a loading of 45 phr. Furthermore, the mixing procedure was changed between rubber and rubber/filler-batch addition for the mixing process. The method was based on the assumption that the loss modulus is increasing with the content of filler because of higher energy dissipation during dynamic load. This method can only be used for blend system, which are not miscible as highlighted by the Figure 12, showing G'' depending on temperature of N50/BR50 blend standard and batch mixing procedure and the ratio of the polymer peak. The dynamic mechanical measurement highlighted a low miscibility of polymers and low interphase of batch. CB is orientated to NR-phase especially in standard procedure according to the ratio of the polymer peak.

In a NR/BR blend the carbon blacks are orientating into the NR phase, where the tendency for orientation is increasing in the order EB 262 > N 121. The mixing procedure shows an influence but not on the type of the orientation, the system SBR/NR gives no clear result, because of the poor resolution of the method concerning this two polymers, which have a point of Tg in the same region. The system SBR/BR shows a clear orientation of the carbon blacks into the direction to the BR-phase. The evaluation in this system is not sufficient, because of the high miscibility of the polymers.

3. Development and test of innovative compounds to reduce tyre RR Coefficient (WP2)

Based on the study on innovative materials performed in the frame of the LORRY project, the objective here is to develop innovative tread compounds targeting low rolling resistance and high wear resistance and to combine these innovative compounds with innovative tyre design concepts (WP1) for the fleet tests (WP4).

The compounds distribution defined for both steer and trailer compounds are depicted in the Figure 13:

The different properties needed by the compounds can be briefly summarized as following:

• STEER A: improved wear performance and tear resistance, maintaining rolling resistance
• STEER B: improved rolling resistance, maintaining wear performance
• SUBTREAD C: improved rolling resistance, maintaining tear resistance
• TRAILER A: improved wear performance and tear resistance, maintaining rolling resistance

In order to achieve performance which should reach the project targets in terms of RR and wear performances, the formulations for the different compounds have been refined in three successive mixing iterations (and 2 tyre build iterations). The final formulations for the steer compounds of the second tyre build iterations were the following:
STEER GROUP1:
• 80/10/10 proportions for respectively Natural Rubber (NR), Polybutadiene (PBD) and Styrene-Butadiene rubber (SBR)
• 32% filler loading,
• 60 parts of filler for 100 parts of rubber
• 32 parts of carbon black (EB 262)
• 28 parts of Silica (7 parts of coupling agent)

STEER GROUP2:
• 85/15 proportions for respectively Natural Rubber (NR) and Polybutadiene (PBD)
• 30% filler loading,
• 50 parts of filler for 100 parts of rubber
• 30 parts of carbon black (N 121)
• 20 parts of Silica (5 parts of coupling agent)

It is to be noted that both recipes contain a combination of carbon black (Steer group 1: EB 262); Steer group 2: N 121) and silica (silanized).

As highlighted by the Figure 14, all steer tyres were exceeding the minimal endurance requirement for further testing in the field and the tyres of the third build iteration with the highest lab wheel endurance results were distributed to the other work packages. The rolling resistance performance of the steer tyres produced with the second build, second group steer tyres were fully meeting the project objectives of 20% reduction. It is to be noted that the experimental tire design is providing 11% improvement for the rolling resistance performance and the second compound of the last iteration, providing an additional 14%, take the result to 25% rolling resistance reduction in the test condition against the reference tire.

The steer tyres of the first group with another compound are providing less rolling resistance reduction but with -15% are still valid candidates for the wear performance evaluation.

Additionally the innovative tyres, lead to a significant improvement in terms of durability: +30% vs. currently commercialized tyre: LHS II, as depicted in the Figure 15.

However the trailer compounds only show very low improvement in terms of RR, but still an interesting performance in terms of wear performance.

A final (third) tyre build iteration has been realized with the objective of lowering the tyre electrical resistivity. New CB grades have thus been integrated in the tyres and allowed to significantly reduce the electrical resistivity. However, these new CB grades lead to reduce RR performances. GY will have to perform additional Research activities in order to solve such issues.

4. Tyre testing (WP1 & WP2)

In order to test and confirm the potential improvements achieved by the investigated innovative materials and designs. Tests have been performed:
• Standard tests by GY
• Enhanced testing procedures

a. Standard tests performed by GY

In order to assess the performance of the innovative tyre concepts (materials and designs) and especially of the different tyre build iterations (see above details about the successive iterations of tyre), GY has performed a set of tyre tests. A specifically high focus has been placed on the performance of durability tests and RR. These tests have been the major indicator in order to select the tyre for the fleet tests as well as the coast down measurement tests.
b. Enhanced testing procedures

Tests have been performed using the innovative tools and testing methodologies developed within the WP3:

• Laser sensor tyre methodologies developed by Aalto;
• Bi-axial tear fatigue machine to study the influence of the interface on crack propagation, the experiments have been performed by the IPF;
• Wear characterization thanks to the innovative tribometer developed by the LPMA.

These tests have allowed to improve our understanding on the physical phenomena involved, however these findings have not yet been used to further improve the innovative designs in order to reach enhanced wear and RR resistance.

Additional information about the tests performed can be found below.

5. Innovative characterization methodologies and tools (WP3)

a. Innovative tyre laser sensor methodology to assess Rolling Resistance

The research activities performed in LORRY-project brings new knowledge about in-plane tyre deformation to studies of tyre-road interactions. The deformations of different tyre parts, including the tread and carcass, were measured with a multi-laser tyre sensor system that was developed in the thesis. Measurements were conducted on different tyre types, both passenger car and truck tyres, and different tyre states, both new and used tyres, and under different operational factors, such as the vertical force, inflation pressure, and rotational velocity. The work contributes to the advancement of this field from the following aspects.

• A multi-laser in-tyre sensor system including both one-dimensional (1D) and two-dimensional (2D) versions has been developed to measure in-plane tyre deformations. With this novel instrument, three physical quantities, namely the tread and carcass deformations, and inner contour of tyre were obtained in measurements of a passenger car tyre and truck tyres. The Figure 16 shows the developed measurement setup.

• The effects of the vertical force, inflation pressure, and rotational velocity on the tread and carcass deformation were quantified experimentally. The Figure 17 represents the measurement setup.

• For tread deformation measurements, asymmetric patterns were observed in both the longitudinal and lateral directions. The asymmetric deformation in the longitudinal direction is linked to the rolling resistance performance of tyres (Figure 18). In the lateral direction, a load shift effect of the asymmetric deformation was found when the new tyre was under an increasing load.

• For carcass deformation measurements, coupled deformations in the radial and tangential directions were observed. The radial deformation is influenced by both the vertical and longitudinal forces. Simple indicators based solely on the radial deformation of the tyre carcass are proposed to estimate the in-plane tyre forces.

These tyre sensor studies showed that the tyre sensor can act as a powerful tool for tyre research and development. The relations between the in-plane deformation and in-plane tyre forces that have been obtained are useful in gaining an understanding of the physical mechanism of observed phenomena, e.g. the rolling resistance, and in the design of basic estimation algorithms, e.g. for the estimation of in-plane tyre forces, which are important factors in the development of green and intelligent tyres.

b. Bi-axial tear machine to predict material under dynamic constraints

The objective within this topic was to analyse the influence of the interface of rubber compounds on the fatigue crack growth behaviour. To our knowledge, no tear fatigue tests of dual compound rubbers had hitherto been reported in the literature. In
general, ample literature exists concerning the role of interfaces in (fatigue) crack growth resistance, but the majority of the publications dealt with adhesive systems, e.g. polymers bonded to metals, or with fiber-reinforced composites. The need for this research resulted from the fact that modern tyres consist of multiple rubber compounds. Each of them is tailor-designed for its specific target. But the interplay between the compounds has received little attention.

Experiments were thus carried out to study the tear fatigue behavior of dual compound samples. A model compound, consisting of unfilled and black-filled rubbers, was used.

The results are as follows:

A) When going from the hard to the soft compound, the crack simply propagates across the interface. On the other hand, when going from the soft to the hard phase, the crack is slowed down when approaching the interface and then it might be deflected such that it propagates along the interface, perpendicular to the initial crack growth direction. In other cases, the crack was not deflected, but simply continued to grow straight into the hard compound. Which of the two routes is taken could depend on the smoothness of the interface. A unique feature, that was observed only in this sample geometry, but was observed on multiple of these specimens, was crack initiation at the interface. While the sample underwent tear fatigue, new crack tips were initiated at the interfaces between the hard and the soft material far away from the actual crack tip of the original crack. Starting from this new crack tip, the crack propagated into both compounds and might later merge with the original crack. The crack growth rates in each of the compounds (sufficiently far away from an interface) are roughly the same as in the corresponding pure compounds.

B) It is observed that the crack front is not perpendicular to the crack growth direction any more. Instead, the crack tip advances faster on the side with the filled material, while the crack tip on the side with the unfilled material lags somewhat behind. This is probably related to the higher elongation at break of the unfilled material. The crack growth rate is faster than in the individual pure samples. It is hypothesized that the interface adds defects to the material and leads to local stress concentrations, elevating the crack growth rate.

C) If the interface is almost parallel to the crack propagation direction and the crack starts in the softer material (see Figure 19), the crack propagated much faster than in the pure compound. Catastrophic crack growth was observed in several samples once it approached the rough interface, i.e. the sample failed completely within one load cycle. The catastrophic propagation occurs along the interface, but not directly at the interface. Such catastrophic failure was not observed in samples with a smoother interface. This transition from stable to unstable crack growth without changing the load amplitude was only observed in samples with special interface geometry C (one horizontal interface, with the interface normal oriented perpendicular to the crack growth direction and along the tensile direction).

The effect on the product lifetime is obviously tremendous.

When the notch was applied to the filled compound, the crack growth rate is reduced by roughly 40% as compared to the pure sample.

The differences in crack growth behaviours – compared to the pure references - are supposedly due to the different moduli of the compounds. Keeping the load amplitude constant, the local strain is increased in the soft phase and reduced in the stiffer phase. For this reason, crack growth is faster, or even catastrophic, if the notch is made in the soft phase; and crack growth is slower when the notch is made in the filled phase. If the crack hits the interface, which is almost parallel to the crack growth direction, crack growth is accelerated due to the inherent weakness of the interface. This might finally lead to catastrophic failure because the resulting crack tip after fast crack propagation is much sharper, leading to a higher concentration of stresses.

To summarize, depending on the orientation of the interface with respect to the crack growth direction, the crack growth behavior can be altered significantly in comparison to the pure materials without interface. The crack growth behavior is governed by the local stress and strain fields in the vicinity of the crack tip, which however might be affected by the global interface geometry.

The objective of sub-task 3.3.2 was to investigate the fatigue behavior of bulk materials. Therefore the biaxial-tester of the IPF was extended with respect to an increase of the relevant strain range to about 120 % in both directions with simultaneous reduction of the mass of clamps to increase the attainable frequencies resp. amplitudes. Additionally the clamping system was improved with respect to the homogeneity of the strain fields over the whole specimen for constitutive material
characterization. By digital image correlation, using e.g. the ARAMIS system from GOM, it is now possible to estimate local strain fields of extended homogeneous samples as well as pre-cracked samples. Furthermore it enables an online strain estimation which again enables a strain-controlled operation of the biaxial-tester.

For the characterization of local energy dissipation and the estimation of tearing energy the concept of J-integral was checked. It could be found, that it can be used to approximate the dissipative situation (see Figure 20). But it was also found that the dissipation in the bulk material surrounding the crack tip is responsible for a dependence of the estimated total dissipated energy from the integration path. This apparently path dependence can be managed by an extended formulation of the J-integral taking this bulk dissipation into account.

Comparing of local and global approaches for the estimation of tearing energy it could be found in detail, that many of the commonly used global approaches are strongly limited to their applicability due to non-homogeneities of the real strain fields. Only by the use of a full strain field it becomes possible to overcome these discrepancies. Furthermore, for the constitutive description of materials behaviour it is inevitable to take the hysteresis behaviour of the material into account, despite of its hyper-elasticity.

While abraders like LAT100 and others are currently used in the field of rubber abrasion, the mapping of results to wear in real usage conditions remains questionable, and on the other hand, these types of abraders do not allow detailed in-situ study of microscopic wear mechanisms. Therefore, there was clearly an added value in the development of laboratory tribometer to perform accelerated tests representative of tyre tread abrasion wear in realistic soft usage conditions (representative for long haul service).

c. Wear Characterisation through innovative laboratory tribometer (LPMA)

The objective was first to develop a proprietary laboratory tribometer and secondly to deliver test results and enhanced understanding of wear mechanisms.

The innovative laboratory tribometer device (see Figure 21) developed allows accelerated and quantitative measurements of the abrasion wear of rubber samples. The design of the device is modular and based on rubbing a rubber sample onto a rotating disk (pin-on-disk) with intermittent contact, in open cycle (i.e. worn debris are eliminated from the contact zone). A disk with any surface nature and roughness can be used. The sample is fixed to a movable part which allows dynamical modulation of normal load and fully independent control of contact time, frequency of contacts (or equivalently, of the relaxation time between two successive contacts) and sliding velocity. The device is fully processor controlled. The sample thickness and diameter can be adjusted to obtain the proper representative average contact pressure. A cylindrical sample or a hemispherical sample may be advantageously used as well. Sample and rotating disk are enclosed in a temperature and atmosphere controlled enclosure. Temperature can be varied from 20°C to 80°C. Specimen deformation and wear are measured in-situ in real time with a high resolution digital camera, in comparison to a reference unworn sample. The device allows performing accelerated friction and wear tests which are realistic (close to real usage conditions in terms of kinematics of the contact, frequency and temperature, ‘open cycle’ conditions, i.e. worn debris are eliminated from the contact zone); fast screening of friction and wear properties of series of elastomer samples; in-situ, real time follow-up of sample evolution during test and measuring the wear in-situ in real time with high sensitivity. Dynamic loading conditions representative of those in a rolling truck tyre can be matched.

Within one day (8 hour test), a total slipping length of order 1000 m can be accumulated with representative test parameter values (with a 50 ms contact of frequency 10 Hz and sliding velocity 0.1 ms-1). We estimate that this corresponds roughly to 1/4 of the total slip length accumulated in soft driving conditions on highway by a tyre truck during its whole lifetime (105 driven kilometers).

An optical camera allows high resolution visualization of the sample throughout the test and dynamical, real time recording of the sample deformation during one contact. An effective time resolution of 1ms when recording the dynamics of one contact can be achieved by a stroboscopic technique. High resolution optical follow-up of the sample thickness along a wear test also allows in-situ, quantitative measurements of the material loss, i.e. of wear, without having to remove the sample to weight it.
This is a key feature of the developed tribometer. The tribometer has been developed within an internal collaboration between two CNRS labs, LPMA and LTDS (Laboratoire de Tribomologie et Dynamic des Systèmes, Ecully). A request for patenting the device has been submitted by Solvay and CNRS (which are the responsible entities for LPMA).

Once the innovative tribometer set-up, it has first been a crucial issue to assess that contact conditions in the laboratory device can effectively be considered to be representative of real contact conditions of a rolling tyre tread. At this regard, several aspects of the contact conditions have been analyzed. More systematic wear measurements were then achieved and interesting new effects have been evidenced.

We have focused our study on a series of five samples made of the same elastomer matrix (a mixed NR80BR10SBR10 matrix), reinforced with either a conventional N121 carbon black or a carbon black specifically designed to enhance the wear performance, with 45 and 55 phr filler in both cases. A reference Steer sample was used also for comparison (sample were provided by DIK within WP2).

1. Conditions of sliding without self-blocking and force profile during a contact. To get rid of self-blocking instabilities on entering the contact, it was shown that it is necessary to fix a small non-zero incident angle for the contact between the disk and the abrading substrate, as shown in Figure 22. Accordingly, the force profile during one contact (typical contact duration 0.2 to 0.5 sec) has been analyzed in details. This was necessary to infer the effective sliding length corresponding to each contact.

2. Validation of in-situ optical wear measurements. Absolute sample-to-surface distance is optically measured along the test, which, together with load measurements, allows constructing extremely precise indentation (load vs indentation distance) curves. It is observed that indentation curves are systematically shifted with the increase of wear, as illustrated in Figure 23 (left). Two mechanism may contribute to this drift: Mullins effect and wear. The shift was quantified using the data between 20 and 40 N. Using the indentation curve obtained after a sliding length of around 16.6 m as a reference curve (to get rid of the Mullins effect), it was shown that the drift of indentation distance (related to the change in sample thickness) along the test is indeed correlated to weight loss (graph on right). The different slopes corresponding to different test conditions correspond to different overall areas of wear patterns.

3. Effect of the contact frequency. As a most noticeable result, the impact of the time delay between two successive contacts has been evidenced. This highlights the importance of fatigue (cycling loading) for the wear. Increasing the relaxation time between two successive contacts drastically increases the rate of wear (Figure 24). This is a completely new result, which was not comprehensively reported before in abrasion tests. Note that, regarding the relationship between the rate of wear and viscoelastic properties of the materials, essentially the effect of the sliding velocity has been reported to date in a publication by Grosch. Conversely, the effect of the sliding velocity is comparatively weaker. Within the studied series, this dependence is sensitive to the type of filler. 45 EB262 has more stable wear under different contact mode. This may give CB EB262 a better wear resistance and more importantly, its wear property may perhaps be easier to predict by the lab wear test. This shows that intermittent contact conditions (which are more realistic compared to usage condition) shall give quite different results from continuous tests. This result could be obtained thanks to the specific design of the developed tribometer.

4. Correlation between wear and intrinsic material properties. We have attempted to correlate the wear to intrinsic material properties (mechanical properties in the linear/non-linear regimes, ultimate properties). Material properties were characterized by DIK (linear regime) and IPF (fatigue crack propagation under cycling loading). Extensive friction measurements were performed.

We have shown that it is effectively possible to enhance the resistance to wear by using appropriately designed carbon black filler, without modifying significantly the material properties, in terms of elastic modulus, stored energy density, loss modulus or friction. The samples do not exhibit very different figures as regards their mechanical characterization, and it is difficult to assess clear differences in their friction/wear properties as well.

A model for wear consisting in the propagation of wear ridges, based on observation of wear patterns, has been proposed to map wear results to measurements of fatigue crack propagation under cycling loading. Care must be taken however to properly scale the tearing energy available in the sample in either case.
Finally, some tests have been performed on innovative concepts developed within WP1 and WP2. The study has then been focused on a series of five samples made of the same elastomer matrix (a mixed NR80BR10SBR10 matrix), reinforced with either a conventional N121 carbon black or a carbon black specifically designed to enhance the wear performance, with 45 and 55 phr filler in both cases. A reference Steer sample was used also for comparison (sample were provided by DIK within WP2).

It seems that sample NI 121 55 phr exhibit superior wear performance compared to other samples. The effect of the filler volume fraction is more pronounced for NI121 than for EB262. Reference sample DIK steer does not show much superior performance compared to other samples reinforced with 55 phr fillers. It is comparable to N121 filled with 55 phr N121 carbon black. This might indicate that there is still some space for progress to improve the performance.

6. Performance of fleet tests (WP4)

a. Definition phase and preparation of the fleet test

The first step within the LORRY project has been to select the parameters to be followed and to set-up the required hardware.

To do so, the following list of channels have been carefully evaluated by the project partners Ewals, Novacom and Fraunhofer ITWM: GPS-data; load and/or total mass of the vehicle; ambient temperature; wind information; mileage; fuel consumption (cumulative); engine speed and torque; speed; acceleration; tire pressure; tire temperature; driver actions (accelerator, clutch, brake, retarder, gear shift, steering wheel angle).

Finally, it is to be noted that the partners have selected an existing product, the DG on-board unit for trailers, in order to measure in real time geo-location, speed, tyre pressure of every wheel, fuel consumption, and other parameters specified by the test strategy.

Following such evaluation, Tire Pressure Monitoring hardware has been installed on assets from Ewals Cargo care and Schenker Europe in order to fine tune the measurement system, which shall be used during the field test.

A second major step has been the selection of the customers and routes for the fleet tests.

Overall, three different customers have been selected for the fleet tests
• Visbeen (more than 150,000 km with LORRY tyres)
• TNT express (more than 150,000 km with LORRY tyres)
• Weijers (more than 100,000 km with LORRY tyres)

The Figure 25 highlights the selected routes for the fleet tests with Visbeen

b. Realization of the fleet tests

Once the LORRY tyres and reference tyres received, trucks have been equipped with the tyres and also with all selected devices in order to ensure the collection the required data for analysis all along the fleet tests (see Figure 26, Figure 27, Figure 28, Figure 29).

It is to be noted that the reference tyres for these fleet tests were the FUELMAX tyre from GY.

After the first thousands of kilometers had been run, the consortium understood that wear improvement was easily measurable with this methodology and it proved good results in line with the project objectives. However, the fuel consumption measurement method didn’t prove to be sufficiently reliable to calculate Rolling Resistance improvements. This was mainly due to the fact that too many non-controlled variables produce higher impact in fuel consumption than that of the tyres’ RR improvement itself: driver behaviour, tyre temperature, traffic conditions, local wind speed and direction, etc. Therefore, it has been decided to perform non-foreseen Coast Down measurement tests (see below) replacing the original activities related to
the influence of pavement properties, since it has been considered by the consortium that it was of high priority for the project to demonstrate through field tests, the RR improvements achieved with innovative truck tyre concepts. Indeed improvement of RR performances is the

As conclusion, in terms of Wear performance, according to the measurements and after about more than 170,000 kilometres run, the fleet tests results proved that LORRY tyres present a notable decrease in wear with respect to the reference tyres (more than 1 millimetre saving in LORRY tyres wear with respect to the reference ones). This results is thus fully in line with the lab tests performed by GY, and with the project objectives.

Finally it is to be noted that all data collected during the fleet tests have fed the modelling tool developed by the Fraunhofer ITWM within he WP5 (see below)

c. Coast down measurements

As mentioned above, the fleet tests were not sufficiently reliable in order to measure properly the improvement achieved in terms of fuel consumption and thus RR. The consortium decided thus to run coast down measurements tests.

A coast down measurement means that a vehicle is accelerating up to an initial speed (vinit). Once vinit is reached, the driver stabilizes the speed and drives straight until a line is reached marking the beginning of the test zone. At that very moment, the driver uncouples the gear and keeps the free rolling (coasting) vehicle on a straight trajectory. Vinit is noted by the co-driver at the moment of the passage of the line. The vehicle gradually loses speed due to energy dissipation (rolling resistance of the tyres, air resistance, losses in the ball bearings...). After a fixed distance (in this case, exactly 500 m) is covered, the driver notes the remaining speed (vend) and brakes the vehicle. With vinit and vend the dissipated energy can be calculated, as well as the power which would be needed to keep the vehicle on a steady speed and the magnitude of the dissipating force.

In order to assess the rolling resistance at a representative speed, as vinit the maximum vehicle speed (85 km/h) is used. Two successive coast down measurement tests have been performed within the LORRY project: one in Twente and another one in Venlo (see Figure 30).

The first test session in Twente allowed to prove the robustness of the measurement method to demonstrate fleet consumption improvement, however the results were highly below the expectations since only the steer tyres were leading to significant RR improvements.

Therefore a second tests session has been organized by using only LORRY Steer tyre prototypes. Per tyre a difference of 10.5 N has hence been measured. The mass of the vehicles is 7300 kg and the normal force per tyre equals 11935 N. The typical rolling resistance coefficient for a truck tyre is 0.006, which yields a rolling resistance force per tyre of 71.6 N. The reduction of rolling resistance coefficient of the prototype steering axle tyre and based on these Venlo measurement can then be estimated as 15 %, which is a little bit below the lab results (i.e. 25%).

Two parameters, which have been studied during these tests might be responsible of such discrepancies:

- Influence of the temperature (a temperature dependence of 0.6 %/°C can be assumed);
- Influence of the pavement properties (see Figure 31), still to be more carefully investigated;

These results were very promising and interesting. Nevertheless, to go further in the assessment of the influence of pavement properties on fuel consumption, it would be mandatory to perform additional measurement on other pavements. This has not been possible in the timeline of the project due to the late deliveries of tyres nor within the original budget of the project, considering the necessity of additional tests for the fuel consumption.

7. Prediction of truck tyre performance from load cases to vehicle usage in the field (WP 5)

Within the project a method for predicting rolling resistance and tread wear for a given truck-tyre combination traveling over an arbitrary route with a corresponding velocity profile has been developed. The considered tyre is available as a structural model and the vehicle is modeled within a multi-body environment. The developed modelling workflow is illustrated in Figure 32. The basic idea is to decompose real life routes into a suitable set of load cases that can be better analysed in the lab or
through numerical simulations. At first, load cases have been defined in such a way that, on the one hand, they include most of the parameters that influence the energy consumption of a tyre and, on the other hand, it is also easy to discretize arbitrary routes with given speed profile into the resulting load cases. These include variation of curvature radius, longitudinal slope and driving speed. For all the defined load cases the tyre performance is computed and the results are stored in a pre-calculated look-up table.

This modelling workflow has been evaluated on a reference track with existing measurements. The track is about 80 km long and has a nice combination of freeways, country roads, district roads, federal highways and city roads. For predicting the energy loss for the given route including speed profile the setup is discretized into the pre-defined load cases and the indicators for rolling resistance and tread wear for each element are extrapolated from the look-up table. The results of the data extrapolation are illustrated for the rolling resistance indicator in Figure 32. One can clearly recognize the segments with high curvature, high slope and high speed (e.g. long motorway section in the south-west). Additionally, the load case extrapolation results have been compared against a pure full reference simulation including MBS and tyre simulations for all tyres. The look-up table method slightly overestimates the energy loss indicators for non-powered tyres while it underestimates the same for the powered ones. Nevertheless, the overall sum for the complete track shows only a deviation of less than one percent for the rolling resistance and less than four percent for the tread wear which is still a rather good estimation. Especially if one considers that the full reference simulation takes four days of simulation time per tyre, where the look-up table results are produced in a couple of minutes. Of course one has to note that the look-up table itself has been produced taking a simulation time of three days for all tyres, but these results can be reused for arbitrary routes including speed profiles using the same truck-tyre combination.

8. Analysis of the Fleet measurements with the innovative predictive tool (WP5)

The Weijers fleet measurements were conducted from mid of December 2015 to the end of February 2016. The resulting fuel consumption data has been provided as mean values on a per-day-basis. Besides total and mean fuel consumption data, the driving distance and mean driving speed have been additional information. In total 70.000 km fleet measurement data has been collected. Figure 33 illustrates the mean fuel consumption data for the reference and the prototype tyre and the different driving schedules for both vehicles. The corresponding driving distance as well as the number of measurement days varied. Table 1 summarizes some basic statistics for the fleet measurements. One can see that the fuel consumption for the prototype tyre lies even 3% above the value of the reference tyre whereas the prototype tyre data scatters a bit less, which can also be recognized from the higher gradient in Figure 33. However, the observed deviations between the two vehicles are rather small and more related to different influencing factors like driver behaviour (braking/accelerating), wind/rain, traffic conditions etc. By analysing the real driving routes which could be reconstructed from monitored GPS data, one can rule out the major influence factor topography. Applying dedicated geo-referenced analysis methods revealed that in a statistical sense the driving schedules for both vehicles with respect to slopes and curves have been comparable and thus are not responsible for observed deviations. Especially this result proofs the reliability of the fleet measurement setup where the basic idea has been to collect a rather large number of fleet data in order to compensate the statistical variability and thereby provide representative mean results.

However, the use of the modelling tool confirmed that fleet measurements could not show a meaningful statistical difference between both setups. This is mainly due to the rather bad performance of the prototype trailer tyre which could not be compensated with the improved performance of the steering axle tyres. But the coast down measurements have well proved the improvements achieved in terms of steer tyres were leading to significant improvements in terms of RR.

Potential Impact:

The main expected impact of the LORRY project was related to the demonstration of low rolling resistance truck tyres including in particular new tread patterns, innovative chemical composition of tyres and smart solutions, while maintaining or improving other performances such as wear/durability performances. Considering the very promising results achieved and detailed within the section 1.1.3 the LORRY project has thus highly contributed to this impact and globally is highly
contributing to the “greening” of the transportation area, leading to a high impact on the environment.

Since the project was gathering actors from a very broad range of areas, the LORRY project will also generate breakthrough in other areas than just “truck tyre industry” and transportation in general: Indeed the LORRY project will have also an impact on the following areas:

- Nano-structure materials;
- Physical characterization methodology;
- Sensor technology area;
- Smart solutions for key truck tyre parameters monitoring;
- Modelling area.

Additionally, it is worth noting that the findings of the LORRY project will need further investigations. This will be specifically done through new collaborations between the LORRY partners, amongst others we can list the following research activities, generated thanks to the LORRY project can be listed (the list is not exhaustive):

- Investigations on new filler systems (including carbon nanotubes) to continue reducing RR performances while improving wear and other durability performances
- Investigations on new tyre compounds or designs thanks to the enhanced understanding of the physical phenomena thanks to the innovative tribometer for wear characterization or biaxial-tester for tear fatigue or laser sensor technology for RR assessment.
- Performance on additional tyre field tests in order to better understand the influence of pavement properties on Rolling resistance and fuel consumption.

Finally, numerous dissemination activities have been performed and will continue to be performed after the end of the project.

I. Overall impact of the project on tyre industry (lowering of tyre rolling resistance) and contribution to Green Car Initiative and environment

As it has been reported within the previous sections, the LORRY project has allowed to develop and demonstrate innovative truck tyre tread patterns concepts (WAGAN blade technology and innovative compound blending process) combined with enhanced tread tyre compounds leading to significant improvements in terms of durability and RR performances. Indeed, at laboratory scale, the best prototype steer tyre concepts have demonstrated an improvement in terms of RR of up to 25%, which was beyond the initial project objectives of 20%. These results have been partly confirmed by the coast down measurements tests demonstrating 15% of RR improvements. The discrepancies between lab tests and coast down measurement tests is probably highly due to the pavement properties of the actual road used for the tests. However since the demonstration phase of the project has been shortened it has not been possible to accurately study the influence of the pavement properties on tyre roads. This will be further performed through additional collaborative R&D activities between the LORRY partners. On top of that, unfortunately due to the bad performances of drive tyres (which constitute the majority of the truck tyres) it has not been possible to accurately assess the influence on the fuel consumption. Nevertheless the findings achieved during the project for steer tyre concepts can be integrated now in drive tyres after some adaptations in order to reach significant fuel consumption savings.

Indeed with the demonstrated RR improvements for truck tyres (between 15 and 25% of improvements), the LORRY project represents thus a significant breakthrough compared to existing tyres in terms of RR performances.

Therefore, fleet operator as well as truck manufacturers will get great advantages in having these tyres on their trucks and trailers: they will be environmental policies compliant, can set future standards and they will save money. The actors of the whole supply chain (from raw materials producers to fleet operators) and not just Goodyear as the tire supplier can now advertise on the use of such technologies showing a “green way of thinking” to customers, political masters
and citizens.

In particular it is to be noted that LORRY findings are going well beyond the EU 2015 impact initially targeted of 10% tyre RR improvement. Improving tyre RR without negatively impacting other tyre parameters is an ongoing challenging task in tyre industry. The combined set of technologies developed in LORRY is selected to favorably and simultaneously tyre wear/mileage, wet grip and tyre weight. At the same time, durability of the tyres have been significantly improved which would offer better punching resistance.

As described, for tyre users, benefits from the research in the framework of LORRY will not be limited to a better RR. Tyre specifications have highlighted higher values for safety and longevity parameters as well, in parallel tyre price will be maintained at the market level thanks to the parallel weight reduction measures, providing tyres users with important competitive advantages.

As depicted in the previous section 1.1.3 this project has joined the tyre, material and transportation know-how of private companies with the scientific expert knowledge of public partners. Enhancement in predictive design at macro scale of tyre design and micro scale of material design resulting in reliable structure property relationships which are validated through various development and simulation phases is essential. Indeed the road campaign simulation tool and the tyre and material simulation tools sum up to a powerful full scale simulation capability to predict tyre performance today and in the future. This will lead to a significantly gain in development cycle time (up to 2 years can be estimated) and in R&D resources is a most relevant allowing consortium member to deliver innovations in a shorter timeframe. This will be particularly demonstrated during further collaboration in particular between GY and academic partners (DIK, CSIC, LPMA, Aalto, IPF) but also OEC regarding CB developments. Indeed thanks to the promising results achieved during the project the partners will try to go further on innovative tyre concepts to improve even more their RR performances.

In the meantime GY will perform activities in view of integrating innovative designs and compounds into commercial truck tyres to be proposed to fleet companies.

On top of the development and demonstration activities performed during the LORRY project (focus on steer and trailer tyres), improvement for overall truck rolling resistance is also impacted by the quality of “drive” tyres. If we want to decrease the environmental impact factor in terms of actual global truck fleet consumption, an improvement on drive tyres by transferring and adapting technologies developed within the consortium budget for steer/trailer performance is mandatory. Based on results obtained before real fleet demonstration phase, another project has been launched to prove the transferability and contribution of drive tyres. This project will be financed by Goodyear own research funding scheme. In this case, with a decrease of 20% in RR on drive tyres added to the decrease obtained in the framework of LORRY, we might reach more than 25% in overall truck rolling resistance, improving trucks fuel savings by about 6 - 8%.

Considering the project achievements, the LORRY project largely contributes to tackle the challenges set by the Green Car EGCI Truck Roadmap and the 2020 Truck Manufacturer vision aiming a 20% CO2 reduction per ton per km transported good by 2020.

Indeed, if we assume the current rules of transfer from RR to actual fuel consumption with a factor of 3 to 4, the average 20% (the demonstrated RR improvements during the project was between 15% and 25%) reduction over 12 mounted tyres results in a 5% reduced fuel consumption. Taking the current standard of 1 liter Diesel per tonne per 100 km and the fact that 1 liter Diesel leads to 2.68 kg CO2, we come and the total number of transported goods of $8*10E12$ of Tonne*km/year, heavy duty truck transportation results in an annual emission of 600,000 ktonnes CO2 in EU (30 liter/100 km per truck). Our project in case of 100% on Goodyear Heavy Duty Tyres use would thus contribute to an annual reduction of 30,000 ktonnes CO2 multiplied by 10% of market share means ultimately 3,000 ktonnes CO2 per year.

Similarly we can calculate the impact in relation to tyre wear emission particles. A truck tyre contributes with 50-70 mg worn particles /km /tyre , taking into account a 15 kg wearable tread , this amounts to a mileage of about 200,000 to 300,000 kms per tyre covering a typical spread from steer to trailer tyres.
About 90% of the tyre worn fraction is non-breathable, equals grosser particle size than 10 micron. 10% of the particles correspond to the breathable dust fraction of either 10 micron or 2.5 micron. Tyre wear accounts for 6% of the PM10 dust fraction and 3% of the PM2.5 fraction of all traffic related breathable dust emission. A truck tyre taking typical driving conditions are taken into accounts with a factor 10-15 times higher than a passenger tyre. Taking again the aforementioned figures of transported goods of 8*10E12 of ton*km/year into account, we reach a total heavy duty truck mileage in Europe of 2.6 E11 kms and thus a particle emission reduction through the 10% wear improvement of Goodyear heavy duty tyres of 130 tonnes per year compared to the total tyre debris emission truck and passenger transport combined of 400,000 tons.

As outlined, the immediate LORRY project outcome is fully in line with actual needs of the current greening transportation sector as well as the objective of the reduction of greenhouse gases. Lowering rolling resistance of heavy duty vehicle is one of the first steps in the whole restructuring and reorganization of transport system. LORRY project is tailored to cope also with other pillars of the Truck EU Roadmaps. The potential for increasing road safety and energy efficiency of long haul trucks is spread in 3 main pillars: vehicle efficiency, driver efficiency and driveline efficiency. LORRY will impact on vehicle and driver efficiencies with improvement on tyres and virtual measurement campaign. Beyond the concept of tailored trucks, sustainable trucks which are forecasted for 2025 will show fully convertible trucks which need fully adapted tyres. Concepts developed within the LORRY project framework will be ready for adaptation to these new trucks types (multi-functional wheels, control and adaptation of RR online). By monitoring and giving orientation on driving conditions, LORRY contributes to the first steps of the evolution of tyre driving to semi automation. Data and recommendations from the project will be helpful for the establishment of the better automated driving conditions for fuels savings.

The impact of the LORRY project on environment as well as on citizen welfare is clearly demonstrated. In many points LORRY project is fully aligned with EU policies listed in the background section of this project. LORRY’s expectation is a long step forward in the reduction of trucks carbon footprint for future generations.

Finally, as already announced, the project itself have a strong impact on scientific community, especially through enhanced public-private partnerships and the creation of synergies between LORRY partners are done. This will lead to cooperation for creation of scientific excellence through scientific articles and the creation of high scientific level jobs. The project will also have an economic impact on scientific jobs creation in Europe. The members of the consortium are spread all over Europe and have fully complementary fields of competencies. This makes LORRY unique by the degree of integration of multiple partners to achieve such an ambitious objective. The project will have impact all along the tyre creation value chain, from material side to the assessment of tyre versus driver behavior.

II. Specific impact on nano-structured compounds

As mentioned above, the LORRY project allowed to make significant breakthrough in terms of new materials for truck tyre compounds.

Globally, concerning the new materials investigated during the project, concepts based on silica, carbon black and CNT will be transferable to other industry application, both in terms of material specification and process know how. After the validation phase within LORRY framework, some study cases will be launched for potential transfer to other types of industries strongly dependent to materials quality and mixing process. The CNT material and adapted process engineering can be a breakthrough for future industrial applications beyond tyres.

More specifically, concerning the influence of new filler systems and their potential on the elastomer properties is investigated, especially concerning low rolling resistance and good abrasion resistance for tyres. It is shown, that the use of CNTs results in high reinforcement factors in comparison to carbon black systems as benchmark. New developed carbon black types (OEC) with small particle size distribution in combination with specific surface activity effect improved properties, especially in combination with high filler dispersion. The innovative carbon black materials...
developed in the framework of the LORRY project have successfully proven to lower truck tire rolling resistance without negative impact on tread wear performance. Orion Engineered Carbons is currently evaluating further exploitation fields for the tire industry. In addition to the already tested stirring and trailer tire applications, the usage of these kind of carbon blacks for the driving axles of commercial vehicles seems to be very promising. Successful commercialization will need several additional scale-up trials to offer the most attractive cost-performance solution to the market. Depending on customer feedbacks final commercialization of these grades is targeted within the next 5 years.

Concerning costs of raw materials on the one hand and elastomer properties and efficient processing in mixing resulting in improved filler dispersion on the other hand, is shown for hybrid systems (CNT/CB-combinations), which have a high potential for future work. The development of alternative mixing technics like continuous mixing in the latex phase are efficient for modern elastomer materials. Modification of the polymers show new promising paths for improved filler-polymer interaction without loss in dynamic properties of the pure rubber. Complete characterization of raw materials and mixed compounds using high sophisticated analytical technics gives an important input for the rubber laboratories and research institutions. Furthermore an optimized processing and handling of CNT, because of their unclear toxicity, is developed, which will increase the use of such high potential fillers for the future. The results of the work are useful for contributions on international and national conferences and for teaching in academic or practical orientated research groups from rubber industry and polymer chemistry or physics. From the technical view, the results gives a lot of information and fundamental knowledge for future strategies in tyre industry and opens new approaches for other industrial applications.

III. Specific Impact on Physical characterization of material

Concerning biaxial tear fatigue analysis (IPF), modern tyres consist of multiple rubber compounds, each of which is tailor-designed for its specific target. For instance, a modern truck tyre tread layer contains several compounds to balance grip, wear and fuel efficiency. While each of the materials is optimized for its purpose, the interplay between the compounds has received little attention. Therefore, in our work, the influence of the interface on the fatigue crack growth behaviour was studied. A model compound, consisting of unfilled and black-filled rubbers, was studied. Depending on the orientation of the interface with respect to the crack growth direction, the crack growth behaviour can be altered significantly in comparison to the pure materials without interface. The crack growth behaviour is governed by the local stress and strain fields in the vicinity of the crack tip, which however might be affected by the global interface geometry. Biaxial tear fatigue analysis has the potential to bring simple lab tests closer to the loading conditions encountered in a tyre under operation – thus potentially improving the correlation between track/drum and lab tests. The biaxial tear fatigue tester was fundamentally improved, but further steps need to be undertaken to enhance reproducibility and reduce scatter.

Concerning the innovative tribometer developed by the LPMA, The new device paves the way to the development of an entirely new field of tribological studies on elastomer-type materials. It potentially allows both performing accelerated tests, which may be crucial for the screening of large series of formulated materials, and in-situ in depth scientific characterization of wear mechanisms. This may allow for more quantitative correlation of wear mechanisms to other intrinsic material properties. Therefore, the impact on the development of tyre materials with enhanced compromise of properties (durability vs rolling resistance and/or grip) may be extremely important. A request for “Patenting” the device has been submitted by Solvay and CNRS (which are the responsible entities for LPMA). The results of the study of wear mechanisms performed during the project will give rise to publications in International refereed journals and/or public communications. However, scientific publication and public communication has been delayed till Patent request is under examination. A first publication draft is delivered for internal communication strictly limited to partners of the LORRY project. This device will also be further used to achieve technical breakthrough in other technical applications than tyre industrial: medical applications and industry inspection applications.

IV. Impact on sensor technology
During the project an innovative laser-sensor technology used for tyre deformation has been developed by Aalto, the main impact was a significant contribution on better understanding of tyre contact phenomenon and tyre deformations that is a root-cause for rolling resistance (AALTO).

We feel that project has increased knowledge of importance of rolling resistance on fuel consumption in wider societal context.

Such tool will potentially be considered a standard tool into normal R&D processes in tyre industry (GY).

On top of that such too might be transferable to other applications: i.e. various engineering and construction parts other than tyres and even non-elastomeric constructions. Indeed, the high resolution and detection capabilities of these tests are of value and interest to various industry sectors, in particular for measurement devices suppliers.

V. Specific impact on smart solutions for key truck tyre parameters monitoring

During the project Novacom has used existing TPMS solutions to track the selected key parameters: the DG on-board unit for trailers, in order to measure in real time geo-location, speed, tyre pressure of every wheel, fuel consumption, and all other parameters as specified by the test strategy. The used solutions have proved their efficiency to track these parameters during the fleet tests.

For Novacom the main impact has been to collaborate with new companies and research institutions that are presently developing cutting edge technologies for road transportation. Novacom has acquired useful knowledge about technologies beyond state of the art that may lead to future commercial advantages. Future collaborations with the partners of the LORRY project are envisaged and may eventually lead to open new markets or explore new technologies that are relevant for our business. Especially additional tests with enhanced characteristics would in particular be necessary to carefully assess the impacts of innovative tyres on durability. They will be indeed further interested for additional fleet tests leading for them to significant savings thanks to an optimization of truck fuel consumption and

VI. Specific impact on modelling

Within WP5 Fraunhofer ITWM developed a consistent methodology for estimating tyre performance parameters such as rolling resistance or tread wear dependent on the one hand side on vehicle parameters (including physical tyre parameters modelled via the structural tyre model family CDTire) and on the other side on environmental parameters given by dedicated route descriptions (translated to input parameters speed, curvature, slope). This consistent methodology allows for the first time to bring the tyre properties with the highest environmental impact – namely wear and rolling resistance – in a predictive way in virtual product development for the vehicle-tyre system. This opens up tremendous opportunities for future tyre engineering, as it allows for assessing tyre/vehicle and environmental parameters within an integrated approach.

The basic idea is to decompose real life routes into a suitable set of load cases that can be better analysed in the lab or through numerical simulations. Arbitrary routes are then discretized into these pre-defined load cases and the indicators for rolling resistance and tread wear for each element are extrapolated from a pre-computed look-up table. By this, results are produced very efficiently in only a couple of minutes instead of days of simulation time and in addition within an acceptable degree of accuracy. Moreover, the look-up tables can be reused for arbitrary routes including speed profiles using the same truck-tyre combination. This methodology is not limited to (heavy duty) truck tyre technology, it may be transferred to other application domains such as passenger car tyres as well.

The Lorry fleet measurements which have been setup in WP4 and evaluated in WP5, proofed to be a valuable instrument. The telematics in combination with geo-localization permitted real time fleet tracking and the collection of environmental impact parameters including road topography, driving speed and climate conditions. By analysing the real driving routes which could be reconstructed from monitored GPS data in the fleet measurements, Fraunhofer ITWM applied dedicated geo-referenced
analysis methods using their software Virtual Measurement Campaign (VMC) and this revealed that in a statistical sense the driving schedules for the two measurement vehicles with respect to slopes and curves have been comparable and thus have not been responsible for observed deviations in fuel consumption data although the driving schedules for both vehicles have been different. Especially this result proofed the reliability of the fleet measurement setup where the basic idea has been to collect a rather large number of fleet data in order to compensate the statistical variability and thereby provide representative mean results.

The results of WP4 and WP5 show that data analysis enhanced with geo-referenced data and methods offers new opportunities not only in vehicle engineering (especially tyres and drivetrain) but also towards authorities and the general public where the relation between standardized test results and the performance in the real application is discussed intensively.

VII. Dissemination

The LORRY dissemination plan generates an effective flow of information and publicity about the objectives and results of the project, contributions made to European knowledge and scientific excellence, the value of collaboration on a Europe-wide scale, and benefits to EU citizens in general to promote the socio-economic impact of the research.

a. Global framework of communication

In addition to company use of findings and patents issued from the cooperative work, a global framework has been defined to communicate as broadly and economically possible all of expected results and foster new usages and ideas in many countries in the world in addition to European ones. Experience shows the need to use multi-canal approach, meaning the use of media relation, in addition to internet presence, forum and boots presence, ... enriched by solid substance and attractive shape as highlighted in following points.

BRRC was in charge of setting up of the LORRY website and updating it regularly. Moreover, a simple and attractive logo plus a simple communication chart have been defined to ensure instant perception of expected innovation and breakthrough. The LORRY logo produced at the beginning of the project has been used in all documents related to the project (deliverables, website, communications, leaflet...).

b. Dissemination to the general public

A video has been broadcasted through Euronews Channel, early in the project to promote the project objectives.

Dissemination to the scientific community

New knowledge has been disseminated in the form of publications, contributions and participation at international conferences, workshops and summits, industrial fairs.

LORRY partners published in major international journals in the materials and biomedical fields (see Section1.2). Additionally the LORRY project has been published on the EC Horizon 2020 website, in “Projects stories” section.

LORRY partners promoted the organization of sessions on selected conferences where the results of projects are displayed to large audiences. This was for instance the case of the Mid-term seminar organized early in 2015 in Cologne during the Tyre Technology Conference.

List of Websites:

The address of the project public website is given on the front page of this report http://www.lorryproject.eu/
The main contact is the project coordinator: Dr. Benoit DUEZ, Goodyear.

Related information

| Result In Brief | Intelligent surface transport technology for more fuel-efficient trucks |

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