Götz, Sebastian; Holzer, Josef; Winkler, Johann; Bernhardt, Heinz and Engelhardt, Dirk

# Agricultural Logistics – System comparison of transport concepts in grain logistics

According to a new survey, tractor tyres perform up to 30 percent of the useful life on road haulage. Therefore, it must be questioned under what conditions tractors – as an agricultural universal machine – are suitable as a transport vehicle. In this study, a standard four-wheel-tractor was compared with alternative transportation concepts in the area of road haulage to determine the conditions under which the test vehicles can optimally exploit their respective strengths.
The main test parameters were the transport capacity, required time and fuel consumption.

**Keywords**
procedure comparison, transport logistic, tractor-truck-comparison

**Abstract**
Landtechnik 66 (2011), no. 5, pp. 381–386, 7 figures, 1 table, 9 references

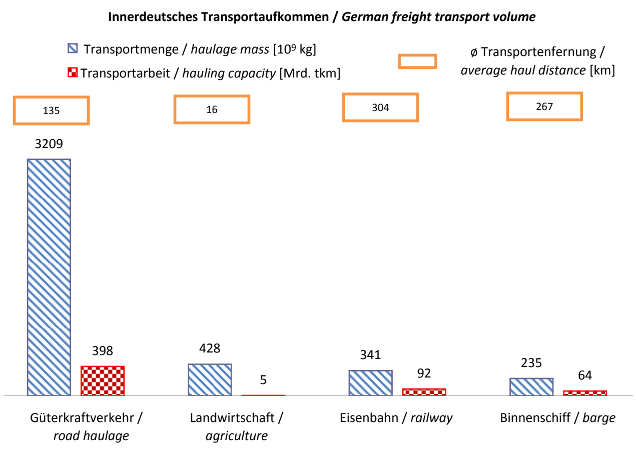
According to a new survey, tractor tires perform up to 30 percent of their service life on road haulage. Therefore, it must be questioned under which circumstances tractors (as a universal agricultural machine)are suitable as transportation vehicles. In this study, a standard four-wheel-tractor is compared with alternative transportation concepts in the area of road haulage to determine the conditions under which the test vehicles can optimally exploit their respective strengths. The main test parameters were the transport capacity, required time and fuel consumption.

Today, a multitude of elements cause an abundantly clear increase of the transport-volume in the agricultural business. A main factor is the reorganization of the agriculture itself and the industries up- and downstream. With increasing size of the agricultural businesses, the transport-volume as well as the average haulage distance is for the most growing, too. Increasing transport-volumes are also a direct result of centralization-processes in the farming business structure and the closing of numerous sugar beet processing plants. Likewise, an increasing demand of biogas substratesis boosting the agricultural transport-volume. Keeping these facts in mind, it therefore becomes a challenging question, under which circumstances a tractor is a suitable transport-vehicle and which situations require specialized transport-equipment like an Unimog or tractor-trailer.[1]

The perpetual area of conflict between agriculturist and transportation is often described using the quotation "An agriculturist is forwarding agent against his wishes". Therefore, it is self-explanatory that agricultural transports have often been the object of (scientific) investigations. Fröba and Mührel, for example, are able to show that in the Federal Republic of Germany as well as in the former DDR 40–50 % of the required working-hoursin arable farming, fall in the category of transportation and handling or storing of goods. [2,3] Recent surveysconducted by the German Agricultural Society show, that agriculturists estimate the share of road haulage of the tractor tire service life to be 30 %. [4] How important the agricultural transportation has become can be derived from **Figure 1**, which shows a comparison between the main modes of transport in the national commercial transportation.

National transportation in Germany regarding transport-volumeand transport output (product of volume times distance) is dominated by road haulage. Annually, about 3,209 x $10^9$ kg are shipped over a 135 Kilometer (km) distance by road haulage. That adds up to a total amount of nearly 400 BillionTon-Kilometers (tkm; t = metric ton = $10^3$ kg). Therefore, the Agribusiness (428 x $10^9$ kg) comes second in comparison on a quantity basis, even before rail (341 x $10^9$ kg) and inland water transport (235 x $10^9$). Regarding the transport output the agribusiness comes in last. In comparison to the other transport types, the agribusiness rather comes up with short distances (about 4 km) to accomplish the haulage of farm fertilizer or silage. The longest distances that have to be bridged in agribusiness appear, while carrying the sugar beet crop to the processing plants: On average, the transport roadway is 110 km. When weighting the roadways by the quantity of shipped goods, the average haul distanceis 16 km. The resulting transport output of 5 Billion Ton-Kilometers could be the reason why experts on logistics often underestimate the impact of agricultural transportation.

Fig. 1




German freight transport volume (own calculations)

Fig. 2

Tractor trailer truck

Fig. 3

Unimog U 500 with 3-axle trailor

## Material and Methods

The conducted examination included the analysis of seven vehicle configurations. Variant 1 represents classic agricultural logistics: A standard four-wheel-tractor, mediumpower spectrum (140 kW) combined with two 2-axle trailers (triple side-dump body, **Figure 2**). A set of this kind is available at most farms and, therefore, is considered as standard variant for the transport examination.

Variant 2 contains a tractor of a higher power spectrum (240 kW). The input rating can be classified between Unimog and tractor-trailer. In consequence to its construction, the maximum speed is 60 kilometers per hour (kmH).

Transport Variant 3 is a combination of Unimog and a 3-axle trailer (triple side-dump body, **Figure 3**).The provided vehicle is a U 500 with an actual power output of 210 kW and Euro 5 emission standard. At this point it is necessary to mention, that, in contrast to all the other variants, the gross vehicle weight in this configuration is only 38 t instead of 40 t what affects the meaning of the term "maximum payload". The Unimog is licensed as motor tractor in agriculture and forestry and is permitted – by directive through public authorities to § 30 of the German Road Traffic Licensing Regulations – only a maximum pay load of 40 % of its gross vehicle weight. Speaking of a gross vehicle weight of 15 t, hence, the maximum payload is only 6 t. The gross vehicle weight of the already mentioned 3-axle-trailer is 24 t. With a dead weight of 6,7 t, the payload is 17,3 t.

To compare and contrast the Unimog-Variant to the experimental series of the tractor-trailer-versions, in variant 4 the Unimog is combined with a road semi-trailer via dolly. This vehicle configuration factors out thelower maximum payload difficulty of variant 3 since it is now seen as articulated train and, therefore, is permitted a maximum payload of 40 t.

A vehicle configuration as seen in Variant 4 is building the transition between agricultural transport and actual road haulage. Variant 5 falls under the same category as it combines a standard four-wheel-tractor via dolly-axle with a semi-trailer. The dolly-axle (**Figure 4**) is the long missing link between agricultural motor tractor and semi-trailer, since the dolly can be hitched with conventional semi-trailers but can be moved by tractor. That enables safe transportation on unhitched rural roads. That way, the loaded semi-trailer can be movedto a central collecting point by tractor and is picked up by a semi-trailer tractor for further transport from there.

Variant 6 and 7 both contain semi-trailer tractors but differ in their emission standard and engine output. These semi-trailer tractors are both used in road haulage by default (**Figure 5**)

The semi-trailer tractor used in variant 6, has a power output of 323 kW and is classified in emission standard Euro 5 due to its ad-blue technology. It is equipped with 12 automatically shiftable gears and current safety standards. The second semi-trailer tractor that is used for variant 7 was constructed in 2005 and is equipped with a 335 kW V6-engine, a semiautomatic 8-gearshift and is Euro 3 classified. An overview on the relevant parameter and employed vehicles is shown in **Table 1**.

The chosen test track is equal to the average profile of common German agricultural transportation distances. [8] All-in-all the circuit length is 36,6 km and can be divided in overland and highway sections. The 17,1 km overland section consists of 1,3 km rural roads, 3 km of cross-town routes, 6,5 km country roads and 5 km federal roads, all in different stages of development. The altitude difference to be surmounted in the overland section is measured with 60m which emerge from up and downhill grades in the range of 3–5 %. The highway section with a length of 19,5 km consists of two highway segments and one segment of multilane federal road. Since only the vehicle

Fig. 4


*Dolly with semi trailer*

Fig. 5

*Articulated lorry*

configuration variants 3, 6 and 7 provide the required speed, these vehicles only use the highway section of the test circuit.

Each vehicle variant is driven three times with three different loads (that means 9 times in total) in the circuit by a trained and experienced driver.

The three tested states of loading are "empty", "partly-loaded" (12,5 t) and "fully-loaded" (ca. 23 to). The current position, speed and altitude above sea level of the test vehicles are constantly collected during each test run via 12-channel DGPS-Receiver.The diesel fuel consumption is determined by flow measuring for each section of the test circuit. The applied flow measuring device AIC 4008 Veritas (Automotive Information & Control Systems) determines the effective fuel-consumption by leading the return flow in front of the metering box of the measuring device, into the inlet flow.

## Results

The cumulated lap-times of the overland section are shown in **Figure 6**. Comparing the lap-times of the unloaded to the fully loaded trips it becomes obvious that the time difference is very small when driving semi-trailer trucks (variant 6, 7) or the 240-kW-tractor (variant 2). The gross load weight of 40 t in combination with the route altitudes of the chosen circuit obviously is not enough of a challenge for the engines to raise the lap times explicitly. The fully loaded 240 kW tractor (variant 2) achieves the same lap-times as the Unimog. The analysis

Table 1

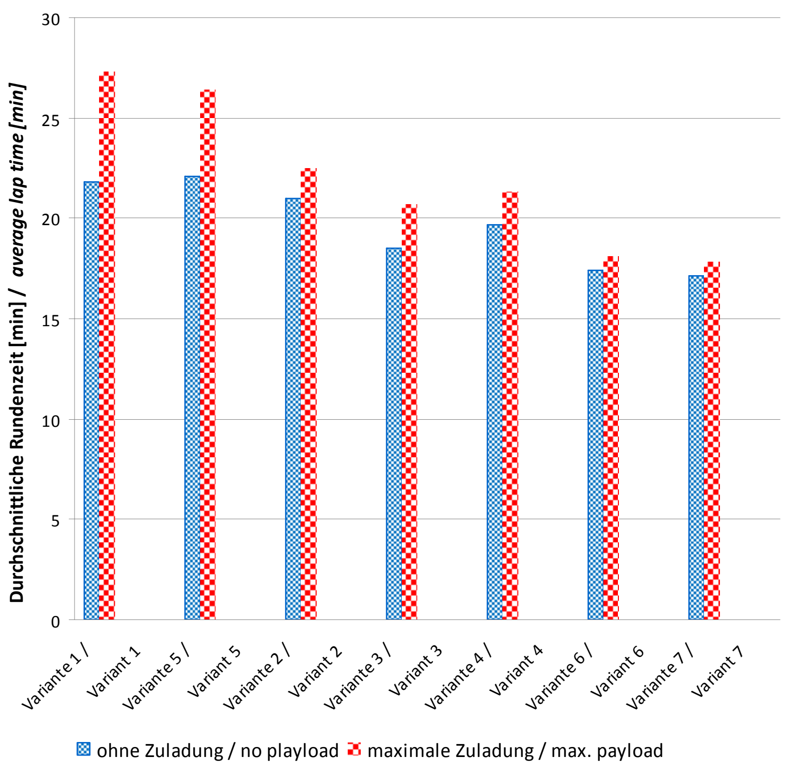
*Vehicle type overview*

| **Kennwert** *Parameter* | **Einheit** *Unit* | **Schlepper/*Tractor*** | | | **Unimog** | | **Sattelzug/*Articulated lorry*** | |
|---|---|---|---|---|---|---|---|---|
| | | **Variante 1** *Variant 1* | **Variante 5** *Variant 5* | **Variante 2** *Variant 2* | **Variante 3** *Variant 3* | **Variante 4** *Variant 4* | **Variante 6** *Variant 6* | **Variante 7** *Variant 7* |
| Nennleistung *Nominal power* | kW/PS | 140/190 | 140/190 | >240/>326 | 210/286 | 210/286 | 323/439 | 320/455 |
| Zuglänge *Train length* | m | 18,30 | 16,55 | 18,75 | 15,40 | 17,50 | 13,60 | 13,6 |
| Leergewicht Zugmaschine *Unloaded weight of tractor* | kg | 7 185 | 7 185 | 10 895 | 8 115 | 8 115 | 7 600 | 7 900 |
| Leergewicht Anhänger *Unloaded weight of tractor* | kg | 9 536 | 10 395 | 9 536 | 6 700 | 10395 | 8 595 | 8 595 |
| Zulässiges Gesamtgewicht *Gross vehicle weight* | kg | 40 000 | 40 000 | 40 000 | 38 000 | 40 000 | 40 000 | 40 000 |
| Zuggewicht leer *Unloaded trailer truck* | kg | 16 721 | 17 580 | 20 431 | 14 700 | 18 510 | 16 195 | 16 495 |
| Max. Zuladung *Max. payload* | kg | 23 279 | 22 420 | 19 569 | 23 300 | 21 490 | 23 805 | 23 505 |

of the average speed shows, that modern tractors are, on country roads, able to compete with semi-trailer trucks, this is due to modern gearboxes. Looking at the lap-times (in direct comparison of unloaded and fully loaded states) the same picture occurs. The variants containing the tractors need 21–27 minutes to complete one circuit and are closely outmatched by the unimog (18–21 minutes). The best lap-times were achieved driving the semi-trailer trucks (17–18 minutes). At a closer look, these times result from a higher average speed in built-up areas. At first, this sounds rather astonishing because the tractor variants have actually quite similar dimensions as the semi-trailer trucks, but in the end, their acceleration-performance is not as good. To get statistically verified results when looking at the single circuit sections (rural road/built-up areas/outside of built-up areas/highway) the vehicle variants have to be allocated in three groups: tractor, Unimog and semi-trailer truck. The results of the performed Anova-Analysis show, that the groups have a weak significant influence on the performance time ($p < 0,09$) and the average speed in kilometers per hour ($p < 0,01$). Significant, however is the share of the circuit section on the average speed ($p < 1,27 \times 10^{-6}$) as a result – for example – of a speed limit of 30 km/h in one of the built-up areas. **Figure 7** shows the measured fuel consumption of each vehicle variant in empty and fully loaded status. Taking a closer look into the tractor-group, it becomes obvious that while driving empty, the 140-kW tractor, combined with the dolly-axle and the semi-trailer is most fuel-efficient. Compared to the two 2-axle-trailer variant, the dolly/semi-trailer configuration uses 47 L fuel and therefore, 1 L less per 100 kilometers. A possible explanation could be the special (high pressure) tires of the semi-trailer, which are optimal equipment for the transport business. This finding confirms the research results of Seufert [9] who found, that the fuel consumption could vary up to 3 L/h when directly comparing low and high-pressure tires. The 243-kW-tractor has a significant higher fuel consumption, which can be traced back to its higher dead weight and the higher unloaded weight of the whole vehicle configuration. Even when fully loaded, a similar result as in the unloaded state can be discovered. The fuel consumption, of course, is located on a higher level: On country roads, the 140 kW tractor uses 71 L, when combined with two 2-axle trailers and 68 L, when hitched with the semi-trailer. The 240-kW-tractor, on the other hand, uses 81 L on exactly the same distance. The Unimog combined with a 3-axle trailer uses 32 L/100 km when driving empty and 53 L/km when driving fully loaded which indicates its specialization as a transport vehicle. The combination of Unimog and semi-trailer uses 36 L fuel/100 km when driving empty and 58 L when running fully loaded. What should be kept in mind is the following fact – the semi-trailer variant was allowed a maximum gross vehicle weight of 40 t while the Unimog/3-axle trailer variant was only allowed 38 t.

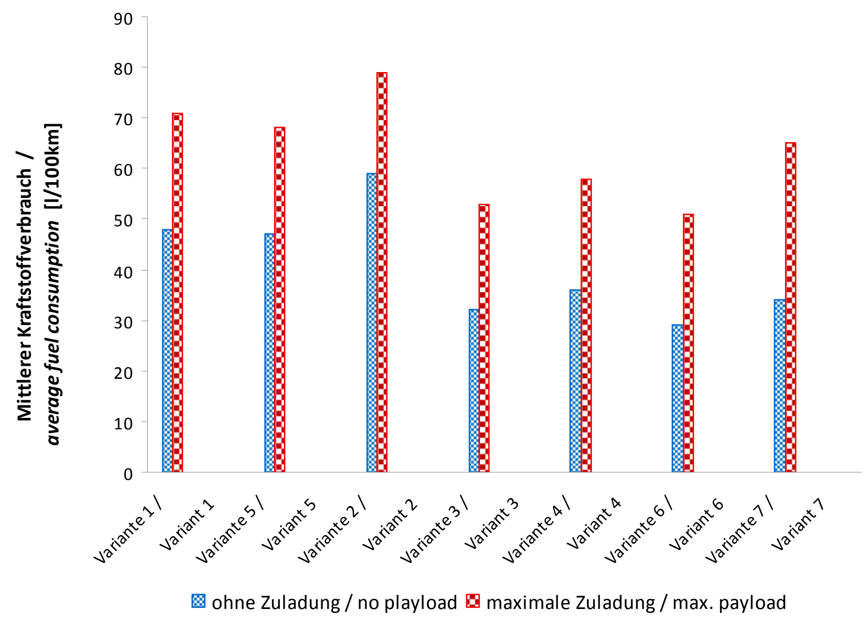
The semi-trailer truck 1 shows a fuel consumption of 29 L/100km while driving empty in the overland section of the circuit. The semi-trailer truck 2 uses 34 L/100 km on exactly

Fig. 6




*Average lap time at the trip 'overland drive' of all test vehicles*

Fig. 7




*Average fuel consumption per 100 km of all test vehicles*

the same section. The average fuel consumption of semi-trailer truck 1 while driving fully loaded (40 t gross vehicle weight) is 51 L/100 km and 62 L/100 km for semi-trailer truck 2. The difference in fuel consumption seems to be higher, when driving loaded trucks. In this case, the additional fuel-consumption is a result of a combination of technique and driving style.

## Conclusion

Transport logisticsin farmingincreases its importance due to the increasing size of the agricultural businesses. The right choice of transportation system depends on different factors. These are the accruing amount of goods and their timely distribution as well as the distance of transportation, in the form of field-to-farmyard – or farmyard-to-storage building – distance. The identified fuel-consumptions show, that -regarding only road-haulage activity – standard tractorsare no competitorsto special transport vehicles. But the fuel consumption is only one factor contrasting the transportation concepts. The standard four-wheel tractor stands out in a direct comparison from the other experimental variants, since it can be used economically for different jobs on the farm and has for field and forest conditions necessary off-road capability. In many cases, such as the corn harvesting or during the application of fertilizer, the transport vehicle must also have a high off-road ability, if working with a single-phase process. A separation, in process technology for field and road transport, requires an additional capital expenditure and thus reduces the relative advantage of the transport vehicles. Thinking of such a separation of process technologies, it is urgently necessary to calculate the step accurately. Often it is more favorable for the individual farmer to use the standard tractor on field and simultaneously as a transport vehicle on the road, to achieve high utilization rates for the equipment. But if a separation of the process technologiesis actually performed, it can often be used economically only by specialized service providers or very large farms, as only then a sufficient utilization rate is reached. Alternatively, smaller companies can “source-out”the transportation to specialized agricultural trucking companies or rent appropriate vehicles for the harvesting season.

Since standard tractors are designed for very different applications, their use in transport logistics onlyaffects the agricultural sector, in which it is mandatory for working, respectively driving, on the fields. The lap times on the road with “empty runs” have shown that the modern standard tractor is with maximum speed of 50 and 60 km/h to the truck, with a speed limit on country roads of 60 km/h, not so inferior. For longer transportation, the truck – due to the advantages of 80-kmh-gearing and a possibility of using the highway – has a better play off. The low fuel consumption of the Unimog is comparable with that of the truck. It must be noted, however, thatthe Unimogused inthe driving testwas equipped with tires that are specialized for driving on streets. That had a positive influence on its transport characteristicsand – compared to the AS-profile – led to lower fuel consumption. The Unimog is – in this case – due to its four-wheel drive although navigating the field, but since it is equippedwith tires that are meant to be driven on the street it has limited off-road capabilityunder unfavorable weather conditions. Its top speed and handling characteristics are similar to those of the truck and yet it can be used in a wider range of agricultural tasks. The lap times show that the semi-trailer trucks could play off their strengths under full load and – due to their high performance engine – cancover long ascending slopes at maximum speed.The lap times are another important indicator for the selection of the right transport system. It should be noted also, that -to ensure a flowing transport chain during the harvest – transport units with a similar loading-capacity are chosen.

For long-haul operations, the truck is, due to its high average speed, the most appropriate vehicle because it is faster in normal traffic conditions. Therefore, it is very important especially for trucks to achieve a very high mileage per year.

For tractors, the required annual utilization in many cases is not achieved through transport. For a more detailed calculation the exact requirements of the tractor have to be taken into account in order to evaluate the transport via tractor more accurately. Regardless of the chosen transport vehicle in the future – as in commercial road haulage – even in the field of agricultural transport,appropriate return-loads will be a must when driving distances of 60–80 km to reduce the number of empty-runs.

Therefore, the formation of regional and supra-regional agricultural networks isa necessary step to transport the accruing quantities, tobetter organize and use thevehicles at full capacity. Further studies with extended data base and data density are focused on the determination of a regression equation to estimate the fuel requirements and the transport time in line with regional and company characteristics. This database will include a traffic count at several sections of the circuit, as well as vehicle-specific drag-curves for evaluating the trafficability of bottlenecks and country lanes.

## Literature


[1] Kowalewsky, H.-H. (2009): Landwirtschaftliche Transporte mit Schlepper oder Lkw. Land & Forst 16, S. 47–49

[2] Fröba, N. (1994): Landwirtschaftliches Transportwesen. Landtechnik 49(6), S. 264–266

[3] Mührel, K. (1974): Landwirtschaftliche Transporte und Fördertechnik, VEB Verlag Technik, Berlin

[4] Hörner, R. (2011): DLG-Praxis-Mintor Ackerschlepperreifen: Mehr als nur Gummi in DLG Test Landwirtschaft, DLG Verlag, Frankfurt a. M.

[5] Bundesverband Güterkraftverkehr, Logistik und Entsorgung. http://www.bgl-ev.de/images/daten/verkehr/gueteraufkommen_tabelle.pdf, Zugriff am 4.7.2011

[6] BMELV (2011): Statistisches Jahrbuch über Ernährung, Landwirtschaft und Forsten 2010,Wirtschaftsverlag NW GmbH, Bremerhaven

[7] Bernhardt, H. (2006): Schüttguttransport, Hrsg.: Rationalisierungs-Kuratorium für Landwirtschaft (RKL), Sonderdruck aus der Kartei für Rationalisierung 3.0, S. 393–410

[8] Engelhardt, D. (2002): Transportfahrzeuge im Agrarbereich – Lastkraftwagen – Möglichkeiten und Konzepte, Cuvillier Verlag

[9] Seufert, H. (2002): Fahreigenschaften unterschiedlicher Anhängerbereifung. Landtechnik 57(6), S. 356–357


## Authors


**M. Sc. Sebastian Götz** is member of the scientific staff and **Prof. Dr. Heinz Bernhardt** is Ordinarius and head of the Lehrstuhl für Agrarsystemtechnik, Technischen Universität München, Am Staudengarten 2, 85354 Freising-Weihenstephan, e-mail: sebastian.goetz@wzw.tum.de

**B. Sc. Josef Holzer** and **B. Sc. Johann Winkler** study agricultural science at the TU München.

**Prof. Dr. Dirk Engelhardt** is head of the Institute Logistikmanagement, Steinbeis Universität Berlin.