Hürter, Steffen; Götz, Sebastian and Bernhardt, Heinz

Comparison of simulated and real tractrix of agricultural machines

Farm roads and tracks have to be regularly updated to help meet the requirements of agricultural machinery that continually increases in size. The machines become wider and longer, with more axles and increasingly complex steering systems. With farm road construction, this leads to special requirements for the layout of curves in particular. In this investigation the tractrix curves of actual farm machinery were recorded and tests were carried out to determine whether they could be simulated by using appropriate software. The result showed a satisfactory degree of precision by the simulation software in determination of tractrix curves for agricultural machinery with complex steering systems.

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Abstract
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The infrastructure of farm buildings and their associated fields features a continuous growth in scale. Adjustments in form and size are necessary to accommodate the required developments in agricultural machinery. These developments are currently strongly regulated in Germany under the requirements of the Road Traffic Licensing Act (StVZO) [1]. Not only roads for general traffic are affected in this respect but also agricultural roads. Driving modern farm machinery on older farm and field access tracks and roads can damage the surfaces, e.g. because of the heavy axle weights. If such a roadway does not follow the required tractrix, manoeuvring round bends can, in the long run, result in destruction of the roadsides [2].

Simulation models are already applied in road building for the planning of junctions [3; 4; 5; 6]. For testing the suitability of tractrix simulation programs for agricultural tractors with attached implements and trailers as well as self-propelled machinery, the real tractrices of the vehicle trains involved were recorded and compared with a simulation.

So that newly built field access roadways are sufficiently dimensioned for modern agricultural machinery the DWA (German Association for Water, Wastewater and Waste) is currently updating the guidelines for rural roadway construction [7].

Material and methods

For a comparison of simulation and reality, performances with typical machinery combinations were analysed under practical conditions:

- a medium sized four-wheel-drive tractor (145 kW) with a five-furrow mounted reversible plough and front-mounted weights,
- a four-wheel-drive tractor (133 kW) and tandem axle, fixed drawbar trailer,
- a four-wheel-drive tractor (133 kW) with two steering-drawbar trailers,
- a six-row sugar beet harvester und
- a medium-sized combine harvester (5.10 m working width) with attached cutterbar trailer.

The tracing out of the tractrices took place in a sufficiently large concrete-floored building. A 90° curve was marked out according to the current requirements for construction of agricultural access roadways, and the driver followed these curves. (**Figure 1**).

Determining the up to eight single curves of the tractrices was not carried out with GNSS technology. This was because of time and cost grounds, as well as the technical difficulties caused by the antennae being positioned too close together. The curves were hereby marked out with different colours of sand and digitalized by tachymeter. The < 2 cm precision error during recording lay within the range experienced in other experiments [8].

For the simulation, the vehicles were depicted as lattice models, based on their respective dimensions and maximum steering locks, in the tractrix program autoTURN. The digitalised real curve was fed into the program and served as comparative example and construction aid. The digitally represented vehicles were moved along the curve route, thus following the simulated tractrix. The digitalised real tractrix and the simulated tractrix were laid over one another and analysed for the results.

For the comparison, the required area for the track manoeuvre, and the space required for machinery overhanging the running gear during manoeuvres, have to be determined. The former, representing the surface of load bearing track required and the latter the manoeuvring free-space outwith the roadway that is needed. Such differentiation of road surface and extra »swing out« space is not necessary in the standard models for road traffic [9; 10].

Results

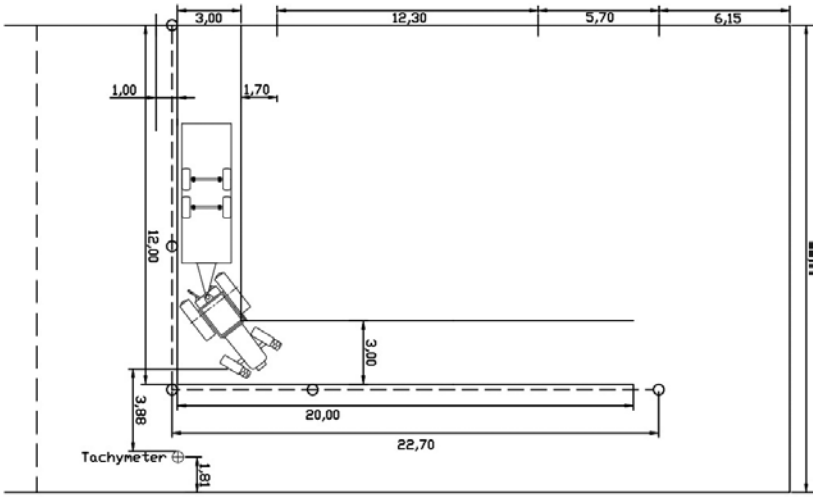
Results from practical trials

Figure 2 shows the recorded tractrix elements for a twin axle sugar beet harvester with simultaneous articulated steering and axle pivot steering. The red and the black lines of the first and second axle show the limits of the area covered by the drive train of the harvester whereas the blue and the yellow lines depict the front and rear extremities of the machine and thus the area required outwith the track.

The curve intersection line was used as comparative measurement of the tractrices, being based on the length of the bisectors from point of intersection of both outer edges of the road through to the inner tractrix line. These curve intersections measured 2.67 m for the tractor with plough, 7.72 m for tractor with tandem trailer, 8.41 m for the agricultural trailer combination, 6.69 m for the beet harvester and 7.40 m for the combine harvester.

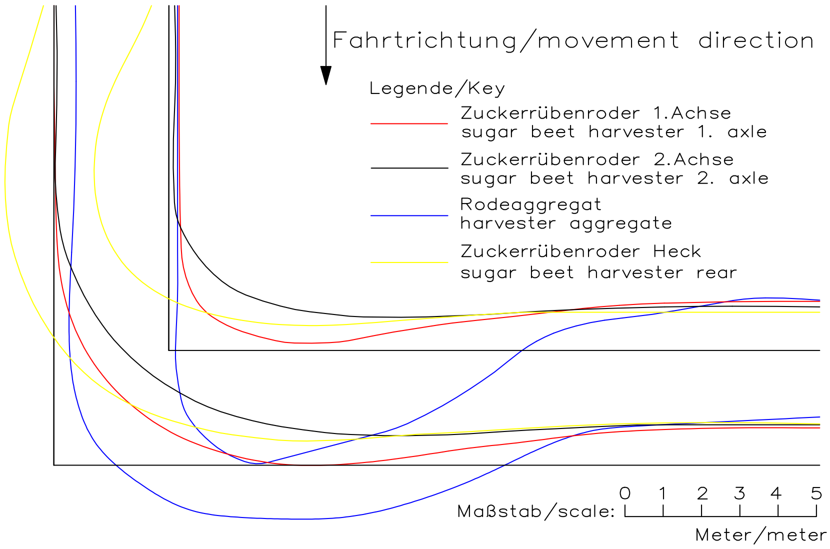
In recording the tractrices, the track followed by the running gear, as well as the total area required for the manoeuvre, were represented. The difference between the roadway required and the total manoeuvring area was determined and represented, e. g. for the combine harvester, 3.21 % (**Figure 3**) and 21.25 % for the beet harvester.

Fig. 1



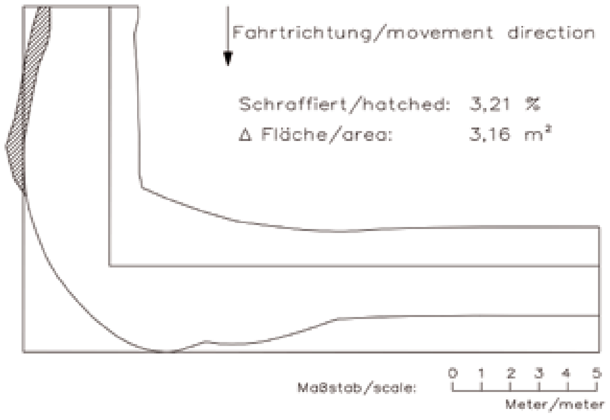
Experimental setup

Fig. 2



Tractrix of a sugar beet harvester

Fig. 3

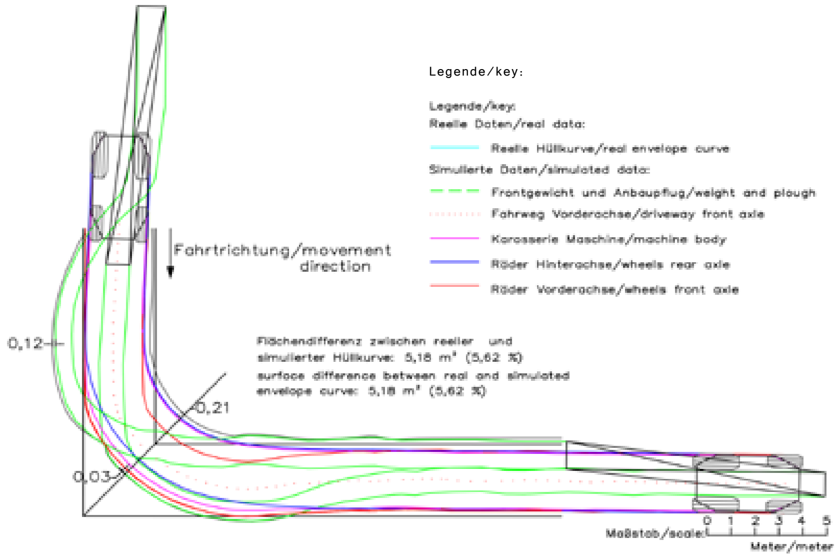


Comparison of overcoated and overdriven areas of a combine

Simulation of tractrices and comparison of the measured curves

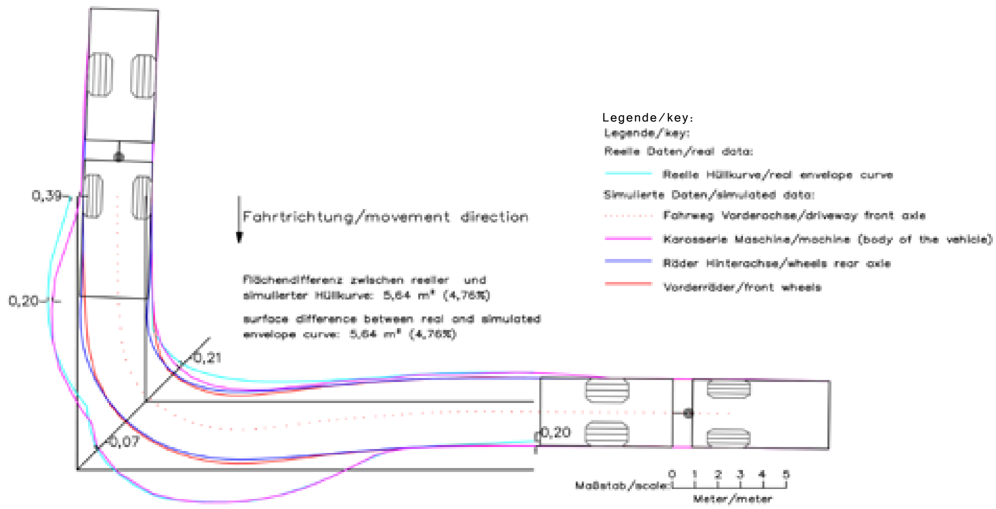
For simulation of the vehicles, the required vehicle parameter data were inserted in the prepared vehicle model. Subsequently they were positioned in the real envelope curves and driven through the curve just as the real vehicles were. Through the identical curve drives, the precision of the simulation can be determined. The simulated vehicles had the same curve behaviour as their real counterparts, covering the same running gear tracks and overhang areas in almost the same way as the vehicles in reality. However, differences were recorded. For instance the four-wheel-drive tractor with reversible plough and front-mounted weights showed a difference of 5.62 % (**Figure 4**), the largest difference recorded in the trial. It is no problem for the software to simulate the mounted implements. The simulation was very precise for tractor and trailer so that the results for such combinations come very near to those for vehicle

Fig. 4



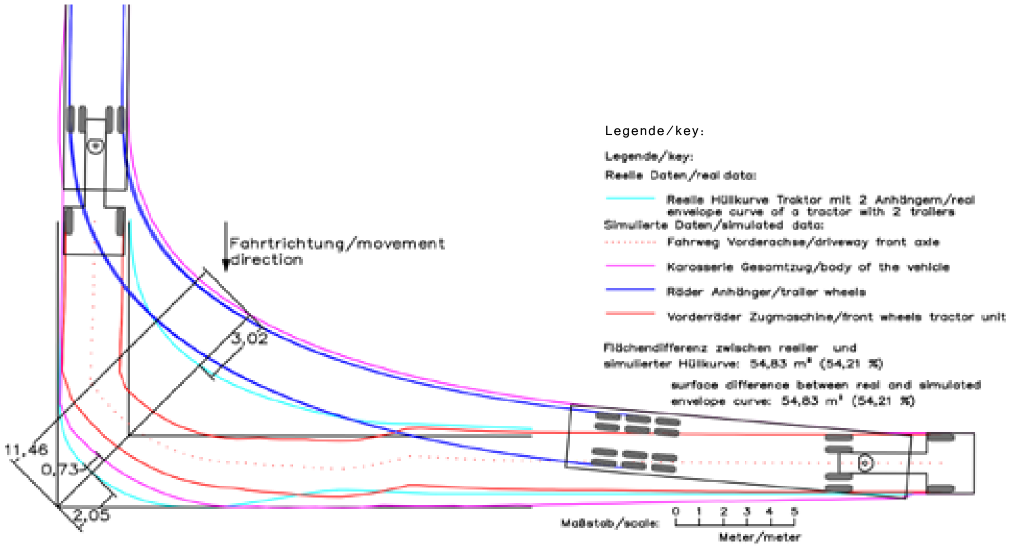
Simulation of a four wheel tractor with plough

Fig. 5



Tractrix simulation of a sugar beet harvester

Fig. 6



Tractrix simulation, comparison of a truck and a tractor with two trailer

trains already implemented in models for trucks. Comparing the simulation and reality for four-wheel-drive tractors with tandem rigid drawbar trailers resulted in a difference of only 2.69 %. For the four-wheel-drive tractor with two steering-drawbar trailers, the difference was 3.89 %. These values are sufficiently precise for application in future road construction planning. In fact, the influence of different drivers on areas covered making such turns gave much larger variations than those found between practical trial and simulation program results.

For the self-propelled machines such as sugar beet harvester and combine with cutterbar trailer, the construction of the vehicle model is a little more complicated. The sugar beet harvester model was constructed with input from two vehicles in order to simulate the combination of articulated steering and axle pivot steering. The deviation here represented 4.76 % (**Figure 5**). It became apparent when comparing the curves that the backend of the beet harvester swung out a little earlier in reality compared with the simulation. This was because, at the time of the trial, the simulation could not take account of the four-wheel steering and articulated steering working interdependently.

The difficulty with the combine harvester construction was how to represent its rear axle steering system. For this reason, the simulation was represented by a vehicle reversing with a trailer. The deviation between simulation and reality was 5.16 %, and therefore much the same as the other machines in general.

In order to establish the area requirement for turns with agricultural vehicles in relationship to other transport vehicles, a tractrix for an articulated truck was simulated and compared with the largest tractrix in the trial - that for the four-wheel-drive tractor with two steering-drawbar trailers. The result showed the widely held assumption that farm machinery had a greater problem manoeuvring on standard road designs is not supportable. The length of bisector with agriculture vehicle trains is 8.41 m and with articulated trucks 11.46 m (**Figure 6**). Even the free space required outwith the track for the agricultural train fitted within the curve required for the running gear track of the articulated truck.

Conclusions

The comparisons of simulated and real tractrices show that simulation software can depict tractrices for agricultural machinery with sufficient accuracy. In the planning of field access roads the area requirement for manoeuvring by the overhanging parts of machinery or attached implements can be simulated so that the location and size of this extra space, as well as that for the running gear tracks, can be determined. In this way provision can be made beforehand for sufficiently dimensioned load-bearing roadways and the right amount of additional free room for vehicle combination overhangs.

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Authors

Steffen Hürter is student at the Technical University (TU) Munich and investigated this subject as part of the work for his Bachelor degree.
Sebastian Götz was a member of the scientific staff and tutor.
Prof. Dr. Heinz Bernhardt is full professor in the chair for Agricultural Systems Technology of the TU Munich, Am Staudengarten 2, 85354 Freising. e-mail: Heinz.Bernhardt@wzw.tum.de

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