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Research Paper

Route planning evaluation of a prototype optimised infield route planner for neutral material flow agricultural operations

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The need to decrease unit production costs has led agricultural industries to develop larger and consequently heavier machinery. While this has increased the productivity of single machines, it has also caused significant soil compaction, which may cause reduced crop yield and crop quality. Therefore, mechanisation solutions that have both lower unit costs and reduce the risk of soil compaction are needed. Optimising infield routes will reduce labour costs, fuel consumption and field trafficking intensity, providing important benefits for infield operations. In this paper, a prototype of an optimised infield route planning tool for neutral material flow operations is evaluated. The evaluation parameters focused on distance and traffic intensity reductions, comparing the routes proposed by the tool prototype and the routes followed by a professional operator during mowing operations. The tool requires some minimum inputs: field boundaries, field gates, working width and minimum turning radius, in order to provide an optimised route. Twelve fields were recorded by a Global Positioning System (GPS) during mowing operations and later compared with the routes proposed by the tool. In all fields, the operator's normal route was longer in distance than the route proposed by the tool, being up to 18.4% longer. In total, 9.2 km of infield distance was saved, i.e. 7.5%. The traffic intensity was reduced in all fields, except for two of the smallest fields, where it equalled that of the normal route. Specifically, the traffic intensity was reduced in the working areas, as the tool confined all non-working distance to the headlands.

1. Introduction

The increasing world demand on agricultural products has led the farming industry to increase productivity by diverse solutions from different disciplines, e.g. genetics, agronomy or engineering (Tilman, Cassman, Matson, Naylor, & Polasky, 2002). In the last decades, the engineering focus has been to develop large, powerful, and high-capacity machinery, in order to decrease unit costs. However, this development has

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Nomenclature

GPS	Global Positioning System
ORP	Optimised Infield Route Planner
NMF	Neutral Material Flow
W_w	Working width
R_m	Minimum turning radius
F_g	Field gates position
F_b	Field boundaries position
P_h	Headland paths
P_r	Row paths
P_c	Connection paths

made machinery heavier, and it is consequently creating important subsoil compaction problems, which may result in lower yields and reduced fertiliser efficiency, along with higher water-logging, run-off and erosion problems (Hamza & Anderson, 2005).

Soil degradation is an increasing problem worldwide, mainly caused in modern agriculture by subsoil compaction caused by heavy machinery (Hamza & Anderson, 2005). According to Kroulík, Kumhála, Hůla, and Honzík (2009), p. 95% of the area in a field in conventional agriculture is run over at least once a year, meaning that the problem is generalised throughout the field. Repeated traffic over an area highly increases the risk (Keller, Arvidsson, Dawidowski, & Koolen, 2004). Soil compaction means increased bulk density and homogenisation of the soil, causing decreased aeration and water infiltration and increased penetration resistance, which impedes a proper root development and limits the biological activity of the soil (Głąb, 2014; Horn, Domżżał, Słowińska-Jurkiewicz, & van Ouwerkerk, 1995). Subsoil compaction has long term effects on the soil which are difficult to solve, therefore the most effective practice is to avoid or reduce the compaction as much as possible, rather than apply post-effect solutions, e.g. deep ripping (Laura Alakukku, 1996). Furthermore, soil compaction also has effects on greenhouse gas emissions. For example, Bhandral, Saggar, Bolan, and Hedley (2007) found in grassland soils that the N_2O emissions were between 2 and 14 times higher for a compacted soil than for an uncompacted soil, with the rate for nitrate fertilisation being especially high. These results were corroborated by Uchida, Clough, Kelliher, and Sherlock (2008).

Regardless of compaction problems, farmers need to decrease unit costs in order to adapt to and compete in the globalised modern market system, where apart from the exceptional increases in 2007–08, and 2011, low prices dictate their agenda (EU, 2016; FAO, 2015). There is therefore a need for solutions that can reduce both the unit costs and reduce the risk of soil compaction. Computer based tools can both optimise farming operations, as well as minimise the risks from soil compaction, making the whole system more sustainable. Although computer innovation in farming has been more common for business related activities than specifically for farming (Lewis, 1998), in the last decade the number of computer based tools in precision farming has grown considerably (Kaivosoja, Jackenkroll, Linkolehto, Weis, & Gerhards, 2014). One of these tools is an infield route planner, which optimises the route followed by the machinery. Optimised infield route planning can reduce labour costs and fuel consumption, in addition to reduce field trafficking, which is one of several solutions proposed to reduce soil compaction (Bochtis, Sørensen, Busato, & Berruto, 2013; Hamza & Anderson, 2005). Moreover, infield route planning can be used for controlled traffic farming, which offers farmers an opportunity to not only reduce soil compaction, but also to restore their soils (McHugh, Tullberg, & Freebairn, 2009).

Optimised route planners are already commonly used in Global Positioning System (GPS) based applications in mobiles and computer systems, for personal use, as well as for industrial and logistical uses; however they are still in the development stages for farming applications (Sørensen & Bochtis, 2010). Several studies and projects are working with optimised algorithms and solutions for route planning in precision agriculture, and especially for the emerging development of field robots. Different activities require different approaches, as some activities have capacity constraints and may require aid from support units (Bochtis, Sørensen, & Vougioukas, 2010), e.g. cistern trucks for replenishing fertilisers or pesticides. Furthermore, there may be in-field and inter-field routes that need to be optimised, making route planning in agriculture a challenging task, as there are infield attributes (e.g. working tracks and headland passes), and inter-field configurations (e.g. field gates and road networks) to be considered (Jensen, Bochtis, Sorensen, Blas, & Lykkegaard, 2012). However, none of the above mentioned models have been adapted into functional tools which can be used by a tractor drive to optimise in field operations in real-time.

An optimised Infield Route Planner (ORP) prototype tool is evaluated. The ORP tool is designed for ‘neutral material flow’ (NMF) field operations, i.e. operations where there is no flow of material into or out of the field (e.g. tillage, cultivation, mowing) (Bochtis & Sørensen, 2009). Here, the tool is evaluated by comparing the distance travelled by a professional operator during mowing operations, with the optimised distance proposed by the ORP tool. Optimised route planners can save travelling distance inherent in agricultural operations, reducing consequently unit costs, and compaction risks. Secondarily, the ORP tool is evaluated by comparing the trafficking intensity as derived from the recorded data and the modelled optimised route, in order to assess the potential efficacy of the tool for reducing soil compaction.

2. Material and methods

Applied mathematical modelling provides many possibilities to improve the effectiveness of precision agriculture. In this case, the driving pattern of agricultural machinery in the field is optimised by the application of an ORP prototype tool. The developed ORP tool has been evaluated by comparing the routes followed by an experienced tractor driver during mowing operations and the ones proposed by the ORP. The tool and the conditions are explained below.