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# Field Efficiency of Slurry Applications Involving In-field Transports

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**Summary**

Controlled traffic farming can significantly reduce the soil compaction caused from heavy machinery systems. However, using CTF in material handling operations executed by cooperative machines, the significantly increased in-field transports lead to a lower system's efficiency. Recently, a discrete event model for the simulation of CTF operations executed by cooperating machines has been introduced. The use of this model makes it possible to estimate the extent of reduction of the field efficiency. In this paper, a field experiment involving slurry application under the conventional unconstrained traffic system and the corresponding operation under the CTF system are presented and analyzed.
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***Key word:*** *Controlled traffic, cooperative machines, machinery management.*

## Introduction

In Denmark, a large proportion of the fertilizer used in crop production is based on animal slurry due to the extent of animal production. However, due to the use of heavy machines for the slurry transportation and application, the soil is affected in a negative direction as a result of the increased compaction.

The introduction of Controlled Traffic Farming (CTF) in heavy machinery operation consitutes a countermeasure to soil damage. According to the basic principle of CTF, permanenent parallel wheeltracks (also called tramlines) are established in the field area and used for machine trafficking. The limitation of the trafic to the tramlines provides for a number of benefits such as elimination of soil compaction within the cropped area (Chamen et al., 2003), increase in crop yield and energy savings (McPhee et al., 1995), reduced $CO_2$ outlet and less use of water (Reicosky et al., 1999).

However, drawbacks of CTF have been reported as well, such as the need to acquire specilised machinery, which affects the overall economy (Chamen and Audsley, 1993) and the loss of cropped area due to permanent wheel tracks and expenses due to the creation and maintenance of wheel tracks. Furthermore, the constraints of the paths for traversing the field may reduce field efficiency in the case of cooperative machines as in the slurry application case. CTF does not permit random turnings and may require the machine to drive in empty mode along the traffic path in order to be serviced by a refilling unit.

It has not previously been possible to estimate the actual field efficiency of operations, involving multiple machines in CTF systems. Recently, Bochtis et al., (2009) have proposed a discrete event model that can simulate both CTF as well as Un-Constrained Traffic Farming (UCTF). The model makes it possible to compare CTF and UCTF, for a given operation setup and enables the estimation of the field efficiency with respect to time and travelled distance. In this paper, a field experiment involving slurry application under the UCTF system and the corresponded simulated application under the CTF system are presented and analyzed.

## Materials and methods

This section describes the experimental setup for the field operation and introduces the discrete event model used for the corresponding simulation.

*Experimental Setup*
A Massey Ferguson 4840 tractor, pulling a tank with 14.6 $m^3$ capacity, was used as the refilling unit while a self-propelled Terra-Gator, with 13.5 $m^3$ tank capacity, was used as the application unit.

The recording of the operations activities involved the logging of the position and the application status of the slurry applicator. As data acquisition tool for the slurry applicator, a module comprising a TC65 Siemens Terminal® with a built in modem was connected to the implement computer for data extraction. This terminal encompasses a Java™ software development platform with a wide range of standard interfaces plus GPRS class 12 functionality. Finally, a sensor was mounted on a switch indicating the on/off status of the trailing hoses. The sensor comprised a standard wheel sensor (2 nodded reed sensor), which is activated through a magnet. In this case, it was mounted on the regulating lever, so that the magnet was activated when no slurry was applied. The customized sensor together with the GPS sensor, a Holux GR-213 capable of delivering a NMEA 0183 GGA string via a RS-232-compatible serial port, were connected to the terminal unit for wireless transmitting of data to a dedicated server configuration (Sørensen & Thomsen, 2006). The Basic setup is shown in Fig. 1.

*Simulation Model*
The discrete event model developed by Bochtis et al. (2009) constitutes a simulation model capable for simulating both UCTF and CTF operations taking the coordination of multiple machines into consideration. The model is based on the mathematical formulation of the discrete events regarding the motion of the machines and is implemented using the MATLAB technical programming language. The overall flow of the model is shown in Fig. 2.
The model's input includes information regarding the field area (geometry, obstacles presence and tram-lines configuration), the operation (application rate, coordination strategy) and involved machinery (specifications of the machines).

As an output, the simulation results the segmentation of operation's time and travelled distance for each part of the implemented machine system. Based on this detailed information, the efficiency of the system can be estimated. During validation of the model it has been shown, that the error prediction in terms of the totalled travelled distance was in the order of 1 %. For a thorough description of the specifics of the model, refer to Bochtis et al., (2009).

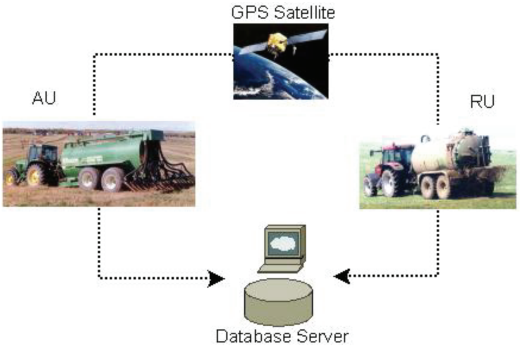


*Figure 1: The overall experimental setup.*

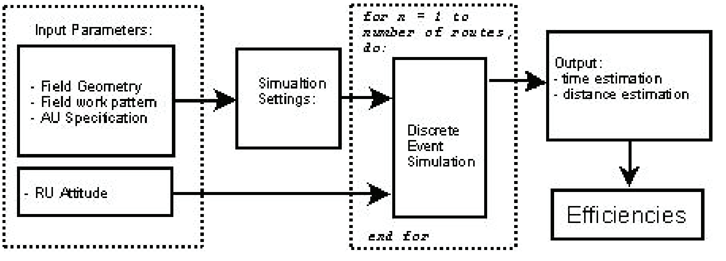


*Figure 2: The overall flow of the discrete event simulation model.*

## Results

*Experimental UCTF*

The GPS recordings of the UCTF experiment operation are illustrated in Fig. 3. The experiment was carried out by a manually driven tractor with auto-steering, equipped as described above.

*Simulated CTF*

The mean values of the operational measured parameters during the experimental UCTF field operation were used as part of the simulator's input in order for the simulation to be as realistic as possible. These parameters are given in Table 1. The field geometry as well as the tramlines' localizations was specified by the GPS recordings from the UCTF experiment.

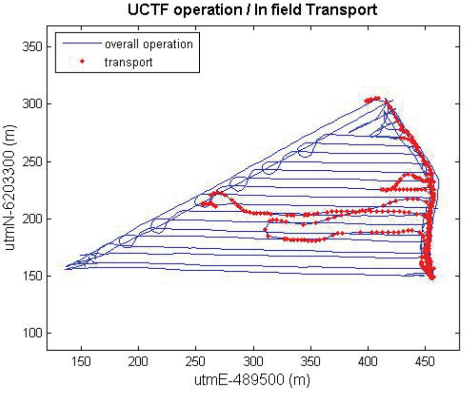


*Figure 3. GPS recordings for experimental UCTF operation*

*Table 1: Parameters from actual operations used by the simulation model*

| | |
|---|---|
| Mean effective distance | 603.55 m |
| Mean operating Speed | 3.10 m/s |
| Mean headland turning speed | 2.02 m/s |
| Mean transport speed / empty tanker | 3.21 m/s |
| Mean transport speed / full loaded | 1.53 m/s |
| Mean transport speed / partial loaded | 2.08 m/s |
| Mean loading time | 379 s |

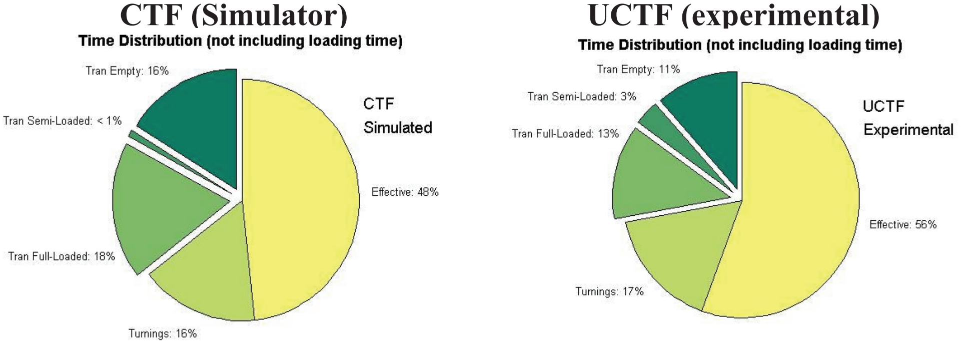


*Figure 4. Pie charts showing the distributions of time, for CTF and UCTF respectively.*

## Discussion and Conclusions

A comparison of the results from the UCTF experiment and the CTF simulation shows that the efficiency is slightly lower for the CTF (Fig 4, Table 2). The decrease of the efficiency in the CTF case is due to in-field transport. As it has been shown by the CTF simulation, the idle non-working travel distance can increase significantly when the refilling unit is not located in the direction that the machine is travelling when the tank empties, because the machine must execute an 180$^o$ turn upon reaching the headland and drive back along the track towards the opposite headland to refill the tank. In addition, there are cases where the machine has to travel over a part of a track without applying slurry, in order to reach the position where the previous application was terminated. As a result, implementing CTF for this kind of material handling operations can affect field efficiency by significantly increasing non-productive in-field transport. This causes decisions regarding the operation of the machinery system to become critical. However, it is expected that in-field transports can be reduced by optimizing the coordination of machines, e.g. through coordinated route plan optimization. Thus the efficiency can be improved, and at the same time the benefits of CTF can be maintained.

*Table 2 : Table showing comparison of time.*

| | | | CTF (simulated) | UCTF (experimental) |
|---|---|---|---|---|
| Time: | | | | |
| Total Operating time | | | 5,482.59 s | 5,092 s |
| Non productive time | Turnings | | 459.69 s | 406 s |
| | Transport | Full | 520.48 s | 320 s |
| | | Partial | 26.42 s | 84 s |
| | | Empty | 456.03 s | 281 s |
| Efficiency: | | | | |
| Field Efficiency | Inclusive loading | | 24.93 % | 26.53 % |
| | Exclusive loading | | 48.31 % | 56.53 % |

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