CHEMICAL ENGINEERING TRANSACTIONS
VOL. 58, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Remigio Berruto, Pietro Catania, Mariangela Vallone

ISBN 978-88-95608-52-5; **ISSN** 2283-9216

DOI: 10.3303/CET1758052

Influences and Decision Criteria on Infield-Logistics in German Agricultural Farms

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Efficiency enhancements in future agriculture will be achieved not only by higher machine power or bigger working widths but increasingly by well organized and synchronized production processes. Potential for optimization is particularly provided by machine complexes with several interacting machines.
Infield path planning is one way to make agricultural production more efficient. In this special sector lots of theoretical optimization has been done, mainly based on field geometry. However, field shapes have major influences on infield logistics but they are not the only ones. Moreover, farmers' decisions concerning specific infield strategies depend on farm individual organizational reasons, on machinery equipment used by the particular farmer or on individual features of the considered fields. Considering all these decision criteria for mathematical optimization would make infield route planning more practical. As a result navigation not only to the field but also within the field would be possible.
Decisions on infield logistics often depend on farm specifically influences such as machinery equipment or process organization. Furthermore intuition is of high importance. To ensure that no farm individual information gets lost the study is conducted in the form of expert interviews. It is intended to cover the entire range of German agriculture from rural mixed farms with simple technology to large agricultural cooperatives with thousands of hectares using track guidance and various other electronic assistance systems.
The first interviews already show major differences of various farm types. In case of headland designing on big farms a tramline always surrounds the whole field whereas smaller-scale agricultural farms use adjacent field roads for turnings to keep the main field as large as possible. Further examples for influencing factors on infield logistics are direction-giving obstacles, such as power lines, the cultivation of sugar beets with its particularities concerning removal logistics or the application of organic manure, which especially livestock farmers and biogas producers focus on.
In conclusion infield strategies always are based on interactions of several different influences and decision criteria. Single working steps like tillage, seeding, plant protection or harvest mostly cannot be considered each individually. The entire production process has to be taken into consideration to detect the right infield logistics for a specific field. One long-term objective of this examination is to integrate the obtained influences on infield strategies as decision criteria into an infield navigation tool. In this way path planning could become more practical for farmers and process efficiency could be further increased.

1. Introduction

Increasing process efficiency in future agriculture will not only be achieved by higher engine power or higher machinery working widths but also by optimized techniques as well organized and coordinated working processes (Mederle et al. 2015). The more machines are interacting in a process chain in one single field the higher is their potential for optimization. Hence, infield logistics especially has to be focused on for matching all equipment being part of the process (Bochtis et al., 2007). Bad organization leads to higher shares of dead times during the process and results in rising costs per unit produced (Lin Li et al., 2013).
Currently complicated agricultural processes can be planned and organized with the help of software solutions (Bakhtiari et al., 2013). These analysis and optimizations often are conducted post-harvest and base on experience. Infield strategies base on a wide range of influences and only little of them (e.g. amount of yields)

Please cite this article as: Mederle M., Bernhardt H., 2017, Influences and decision criteria on infield-logistics in german agricultural farms, Chemical Engineering Transactions, 58, 307-312 DOI: 10.3303/CET1758052

are known in advance. Hence optimization tools based on experiences or post-harvest analysis mostly are not really feasible for pre-planning of possible infield routing (Costa et al., 2014).

However, infield path planning will increasingly contribute to make agricultural production processes more efficient in future (Zhou et al., 2015). By now researches concerning agricultural logistics rather focus on navigation on public and field roads until the edge of the field. This is particularly useful for contractors or big farms with changing staff to help finding the fields to be worked (Götz et al., 2014). By contrast, infield logistics is known as area logistics. Farmers could choose an endless number of possible lanes to work their fields but only a certain part of them is realistic and practicable.

Farmers frequently do not implement theoretical optimizations although they know about the parameters and the mathematical assistance tools. The predicting calculations mostly base on field geometry and do not really take into account the reasons for certain farm-specific infield-strategies. There are reasons why farmers do not work their fields as the optimization pretends. These causes partly differ from farm to farm and are often based on experience or intuition. Not every farmer decides the same way in a specific situation (Mederle et al., 2016).

2. Material and methods

Main part of the research is a survey of numerous German farmers in the shape of an expert interview. The variety of German agriculture is very broad as there are different structures in the north and east of the country compared to the south. Arable farming in the north and east is rather large-scaled and farms are more and more often organized as agricultural companies whereas in the south family farms with mainly smaller sizes dominate the structure. Various types of farms are expected to have different preconditions concerning field shapes and sizes or machinery equipment and technologies used for cultivating their fields. All these factors are said to have influence on different infield scenarios.

In the run-up to this survey various studies based on Global Navigation Satellite System (GNSS) lanes have predicted that influencing factors on infield strategies strongly depend on farm specific parameters. So the survey structure is rather qualitative than quantitative in order not to lose valuable farm individual information. However, regarding the evaluation of the study it is important to be able to compare all the statements of the different farmers. Therefore all the conversations are carried out based on a certain interview guideline.

2.1 Guideline of the questionnaire

The introducing part of every interview is about general questions on the particular farm such as farm size, technical equipment or available workers. Based on this information it is possible to range the farms.

The second section covers general questions on infield strategies and is intended to focus on reasons for certain infield patterns as well as to answer questions concerning specific field arrangements or area divisions. Examples might be as follows:

Do you work your fields always the same way or is this depending on the cultivated crop?

What parameters do you focus on when you consider on your infield logistics?

Do you zone your fields in certain subdivisions or are you always trying to work biggest fields possible?

The following section of the guideline deals with issues concerning headland, patches and tramlines. The central question in this part is the particular way of headland designing as well as the question of working in special patches or not.

Further chapters of the interview concern about operation steps as tillage, seeding, plant protection as fertilizing or spraying as well as grain harvest. Livestock or biogas farmers are additionally asked about slurry or organic manure application affairs.

The last chapter is mainly reserved to larger scaled grain farms where certain operation steps such as tillage or particularly grain harvest are carried out by more than one machine of the same type at the same time. Especially when working in such complexes the reasons for special infield strategies are extremely interesting and reasonable to analyze.

2.2 Already interviewed farmers

Table 1 shows 12 farmers of different parts in Germany with various agricultural preconditions already having participated in the first step of the study.

These farms have been classified in 3 different categories depending on their amount of arable land in hectare. 3 of the participants farm less than 100 ha but all these 3 also do livestock farming. One of them cultivates sugar beets whereas no one uses GPS technology. Half of the already interviewed farmers belong to the second group of 100-500 ha arable land. Almost all of them grow sugar beets and two thirds use RTK assistance systems. 3 participants farm more than 500 ha. This range is from 640 to 1200 ha. All these 3 use RTK technology but only 2 are cultivating sugar beets.

Table 1. Already interviewed farmers

Farm size	Total number	Livestock farming	Sugar beet cultivation	Use of GPS technology
[ha]	**[n]**	**[n]**	**[n]**	**[n]**
< 100	3	3	1	0
100-500	6	0	5	4
> 500	3	1	2	3
Total	**12**	**4**	**8**	**7**

3. Results and discussion

First results of the evaluation show that influences on infield logistics can be categorized in two different groups. There are so-called "hard" factors which are not at all or only hardly changeable, such as field shapes, field sizes or field access points. Of course the geometry of a field strongly affects the working direction of this specific field but it is not the only influencing parameter. "Soft" factors can be changed quite easily because they strongly depend on organization and structure of a particular farm. Examples therefore are e.g. labor force or utilized mechanical equipment.

3.1 Application of organic manure

Different farm types consider different influences when talking about infield strategies. Figure 1 shows an example regarding the application of organic manure.

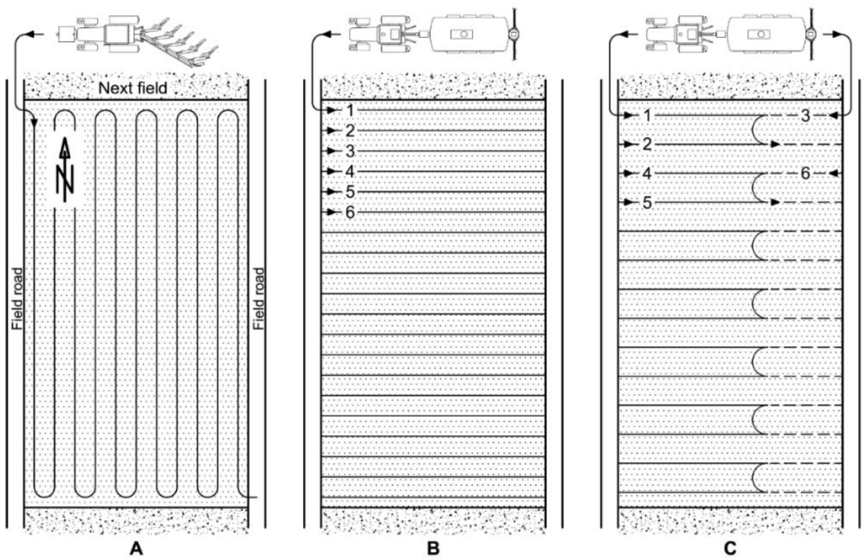

Figure 1: Different infield-strategies depending on various operations or farm types

The pictured field is surrounded by neighbor fields north and south as well as by field roads east and west. Only focusing on the field geometry arable farmers would choose the north-south lane (Scenario A) to achieve long distances and high process times in terms of tillage, seeding or plant protection. They are not reliant on the application of organic manure and do all their fertilization with mineral fertilizer. Due to the higher nutrient concentration of mineral fertilizer less volume is required to be transported which ends up in less dead distances within the field compared to the application of organic manure.

Nevertheless, in some cases even non-livestock farmers answer to take the shorter east-west lane when talking about sugar beet cultivation. Reasons therefore are the positioning of the beet clamp along the field roads to ensure smooth removal logistics by trucks and keeping the ways for the sugar beet harvester as short as possible in order to protect the soil from unnecessary compaction.

Scenario B and C represent particular cases where not only the field geometry is considered. Processes requiring supply-logistics, e. g. slurry application, make farmers deciding differently. Livestock farmers indicate to make use of the field roads for direct entrance and exit of the field without any unnecessary dead ways within the field. The agricultural public path network now surely has influence on the infield-strategy and farmers will also arrange the tramline system in east-west-direction. Good professional practice indicates that

every working step from tillage until seeding as well as plant protection is conducted in the same direction. Tramline systems play a significant role in German arable farming because conventional agriculture mostly is practiced with high intensity. In these tramlines farmers go up to 5-8 times with the sprayer or fertilizer spreader for plant maintenance.
The difference between scenario B and C is the working width of the slurry tank. In B it is operated with a smaller width to be able to cover the whole west-east-distance. This scenario is fitting either for smaller-scaled farms with closer tramline pitches or even for bigger farms when spreading manure on the stubble field. After harvest it is not mandatory to keep in the tramlines, so that the infield patterns can be easily adapted to other priorities. Scenario C is to illustrate slurry application in growing plant stocks with defined tramlines of up to 36 meters pitches. Particularly in case of bigger distances one manure tank is not enough for covering the whole field length. Reduction of the working width is no option because too many plants would be irreversibly damaged. To face this problem there are two possibilities: either reducing the application rate what makes the fertilizer management to be changed or to take three tanks for two tramlines (Scenario C).

3.2 Cultivation of sugar beets

Sugar beet cultivation has very high influence on infield logistics. Firstly, the supply quota pretends the amount of cultivated fields. No farm is allowed to deliver more than this contractually committed quantity of sugar beets. In some cases this circumstance even ends up in field separations in order not to exceed the quota.
The specific row crop system also shows some particularities. With the way of sowing the farmer already determines the direction of the following working steps for plant protection and especially for harvesting. By contrast when cultivating grain crops the harvest can theoretically be conducted in other directions than sowing for realizing longer distances as far as possible. It is not recommendable to make tramlines across the beet rows because of damaging beets.
In sugar beet cultivation the harvesting system plays a significant role and is influenced by several aspects. Harvest usually takes place in autumn from September until December with high probability of wet conditions that will inevitably result in soil compaction. Nevertheless farmers often are interested in late harvesting because otherwise the sugar content of the beets might be too little. This fact additionally intensifies the already mentioned problems of wet conditions and soil compaction. Thus some farmers prefer as little machines as possible in the field. This kind of harvesting system is called single-phase harvest and typical for smaller-structured agriculture. The sugar beet harvester does the work completely on its own without any additional unloading trailers although mass yields to be transported are quite high compared to other cultures.
Additionally the positioning of the beet clamp requires some considerations because the removal logistics is mainly carried out by trucks that are not able to use field roads of bad quality. Therefore it should be positioned parallel along public roads or at least well developed field roads. The main working direction of the field should be vertical to the beet clamp. Thus ineffective dead distances of the harvesting machine with full tank and without harvesting can be kept low.
There are farmers that explicitly want to work without multiphase logistic systems in the field because of soil protection. In special cases they deliberately turn their fields 90° and accept shorter field lengths than possible so that the harvester does not have to cover more dead distances than unconditionally necessary with full beet tank. Consequently more time for turning and unloading while standing gets necessary what mandatorily prolongs the whole harvesting process and decreases efficiency. On the other hand one single machine with one single operator can get the harvest done, so less machinery and less manpower is required. Other farmers rather focus on process times of the expensive harvest machine at the expense of more vehicles being in the field.
Especially sugar beets strongly affect the way farmers arrange the tramline system of their fields because the decision-maker always has to make compromises. Field lengths are wanted to be as long as possible to have both high process efficiency and less time needed for turnings. On the other hand dead distances with full bunker lead to soil compaction and decreasing yields. The positioning of the beet clamp, a major influence, additionally pretends the main working direction. Furthermore the type of harvest organization, e.g. single-phase harvest, has to be adjusted and considered when planning infield strategies for a specific field.

3.3 Different ways of headland designing

Concerning the headland designing farmers have particular interests which have to be considered individually for each field. Especially smaller-scaled farms tend to keep the headland as small as possible because otherwise the share of headland compared to the field body in total would be even higher than anyway. Additionally, small fields usually do not have high field lengths, so these are not unnecessarily wanted to be even shortened. Furthermore small structured agricultural landscape usually provides a well-established and close network of field roads almost every field is directly connected to. In order to protect the headland from soil compaction farmers try to turn their machinery equipment off-site the field on a paved road or in an adjacent fortified area.

By contrast farmers with more arable land and bigger machinery respectively prefer a tramline surrounding the whole field for not having to leave the farmland while working. Firstly, this is due to bigger working widths of the implements. Specifically in case of spraying a boom of up to 36 m has to be flipped considerably more often because of any obstacles, like trees or power poles, than a smaller one.
Another reason for this kind of headland designing is the usage of different machinery types. Trailed or saddled implements for higher working widths at tillage or seeding require different ways of turning manoeuvers with the need of larger headlands. Mostly headland sizes are adjusted to the farm individual machinery that carries out the following work, e.g. the working width of the sprayer. Furthermore keeping machinery within the field helps the farmer to avoid dirty public or field roads and thus higher acceptance of the society. Finally, in many cases there is no possibility at all to leave the field for turnings because it is surrounded by natural boundaries like hedges, woods or ditches.
In case of sugar beet cultivation a feasible solution for field lengths being too long would be a special headland designing. Mostly, the limiting factor of a sugar beet harvester is its bunker capacity. Enlarging the headland would be one possibility to cover the whole distance from one edge of the field to the other and back with one bunker. In this way dead distances could be avoided.
For grain crops as barley, wheat or canola, it would not be mandatory to arrange the tramlines in a special way because the problem not being able to cover the whole distance with one grain tank of the combine is not that severe. Secondly, compared to sugar beet harvesters combines do not mandatorily have to take the same routes or working directions as the sowing machine pretends. Tramlines could be arranged the longest way possible for high process efficiencies in plant protection measures with little turning times. This is definitely useful because in intensive conventional agriculture the mechanical equipment has to pass the plant stock up to 8 times for fertilizing or spraying whereas harvest could be done across the tramlines as far as necessary.
The headland is an essential part of the field because every machine uses it quite frequently especially for turnings. The worse the conditions during working in the field the higher is the danger of soil compaction and consequently decreasing yields in this part of the field. In addition the headland is often used for temporary storage of harvest goods, mainly sugar beets, or fertilizers like manure or lime. All these influences require special measures as frequent deep tillage to keep the soil damage as low as possible.

3.4 Common agricultural structure

One of the major influences on infield logistics is the common agricultural structure in which the respective farm is located. It strongly affects farmers' decisions of subdividing fields regarding their ownership structure and farm individual crop rotation. According to Engelhardt (2004) the average field size in Eastern Germany is 49 ha. In comparison a field of 20 ha is quite small anyway. In North or Eastern Germany probably no farmer would even think about separating the field in different subdivisions because the general opinion is 'the bigger a field the more efficient work can be done'. Unnecessary subunits only would cause more time for avoidable turning or machine set-up. Quite the contrary, farmers even change fields and in consequence do not farm their own or their rented land in order to enlarge units.
Looking to the southern part of Germany, e.g. Bavaria, the situation is completely different. As shown in figure 2 owning a field of about 20 ha does not mandatorily mean to work it as one single unit.

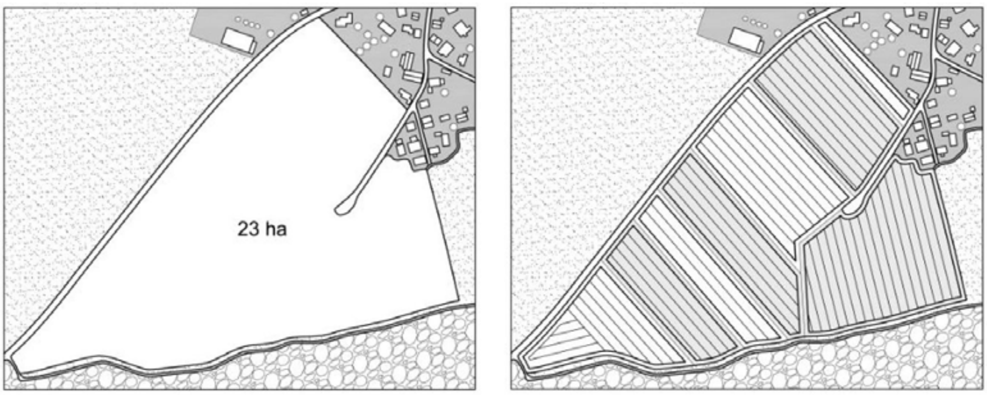

Figure 2: Influence of general agricultural structure on field subdivisions

This field of 23 ha is in possession of a typical family farm with arable land of 65 ha in total. Thus it is one third of the entire farm land. For spreading the risk as well as for adapting this field to the structure of his other field sizes the farmer separates the field into different subunits of about 2-4 ha.

A further reason for the subdivision is once more the cultivation of sugar beets. Only few farmers in Bavaria are in possession of supply quota that complies with 23 ha of acreage. Thus fields are subdivided and sugar beets only are cultivated on sites of good soil quality.
Other farmers even split fields of only 3 ha because of relatively small machinery equipment. They rather focus on site-specific farming than on maximum area or production efficiency.

4. Conclusions

Generally influencing factors on infield logistics can be categorized in “hard” and “soft” factors. Field geometry, the terrain of the landscape as well as the common structure of the particular rural area are some of the biggest influences which are hardly changeable. More difficult to detect are influences that are caused by farm specific organizational reasons or by technical issues.
Farms with differing orientations and focuses respectively consider an equal issue in different ways because of varying preferences. Arable farmers focus on high field lengths with high shares of process times whereas livestock or biogas farmers rather focus on the application of oarganic manure with the influencing network of roads and paths through the landscape. Sugar beet cultivation plays a significant role when thinking about infield strategies due to high mass yields as well as the particularities of the row crop system.
Depending on the common agricultural structure and farm specific organization all influences might differ from farm to farm. In addition they always have to be considered field individually.
Summarizing infield logistics and the system due to which tramlines are arranged in a specific field strongly depend on common agricultural structures, on types of machinery equipment used on the examined farm as well as on the kind of production the farm is set up for. Infield Logistics cannot be optimized for each single working step but it always represents a compromise of all sorts of influences being mentioned above.

Acknowledgments

The Chair of Agricultural Systems Engineering kindly thanks all farmers for their participation in the survey.

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