Modeling of Grain Harvest Logistics for Modern In-Field Equipment Complements

S.A. Shearer, **D.J. Wolters**, **P.G. Root**, **A.A. Klopfenstein**, **B.A. Schroeder**, The Ohio State University, Columbus, OH, USA

Abstract

Logistics modelling of combine and grain cart harvest systems was undertaken to better understand opportunities for improving capacities of current equipment complements and answer "what if" questions concerning the impact of new technologies. Results from this modelling work indicate that for traditional North American harvest equipment complements the limiting factor in harvest capacity are the periods of time when the combine traverses headlands between passes. Less obvious is the minor influence of grain cart capacity on overall harvest capacity and field efficiency. The model revealed that for currently available grain carts, the overall impact on harvest capacity is less than 5.0%. However, existing 54.4 metric tons (MT) grain carts should easily accommodate the trend towards larger capacity combines for the near future.

1. Introduction and Background

Agricultural machinery has continued to increase in size and capacity over the past few decades, and if current trends suggest anything it is that machinery size will continue to grow. The increase in equipment size can be attributed to many factors, but the one that appears to be at the forefront is the generalization that 'bigger is better." However, the continual increase in size of agricultural machinery has major implications in areas such as compromised soil structure and overall machine efficiency. The study of in-field logistics of agricultural machinery is a crucial but often overlooked aspect in the machinery size discussion. It is difficult to study the implications of machine size without an analysis of machinery interaction within the field. Therefore, the focus of our efforts were to create a basic machinery logistics model to better understand the implications of increasing machinery size on the overall economics associated with modern, North American, cropping systems.

Previous work in these areas sheds light on some of the factors affecting overall equipment harvest capacities. For example, Hansen et al. [1] studied combine harvesting patterns and focused on headland turns. They concluded that larger cornheads resulted in less time to execute a "loop turn" and less idle time traveling across headlands. Wold et al. [2] developed a logistical simulation for harvest operations and concluded that "the increase in field capacity for the 50.8 MT (2,000 bu.) grain carts over 38.1 MT (1,500 bu.) cart(s) was nil. Busato et al. [3] developed a logistical model to study the economic effect of the number of trucks used during harvest operations. Turning time was used as a simulation parameter, but there was no attempt to investigate the implications of machinery size and equipment compliments on turning time. Reinecke et al. [4] developed a dynamic in-field planning system which determined the optimal paths for a two combine and one grain cart harvest system. Unfortunately, many of the aforementioned factors mentioned in these works have not been addressed in a more comprehensive manner nor for modern and future equipment complements.

2. Objectives

The overall objectives of work summarized in this manuscript were to: 1) develop a logistics model to simulate combine and grain cart system harvest capacity and efficiencies; 2) provide options to ask and answer "what if" questions concerning equipment complements and/or the impact of new technologies; and 3) support visualization of field harvest traffic events and the potential to compromise soil structure.

3. Methodology

Model Assumptions - The developed logistics model simulates in-field operations of a grain harvest complement of equipment along with field parameters (shape, size and yield) and truck load-out location. The model assumes that field operations include: 1) threshing speed and/or capacity limitations; 2) unloading on-the-go; 3) tractor and grain cart movement parallel to the direction of harvest until reaching the headlands; and 4) a fixed truck load-out location. Simulated in-field events are interdependent; for example, the harvester will stop and wait for a grain cart if its grain bin is full, and a grain cart will not be able to move towards the combine until it finishes unloading into the truck parked at the edge of the field.

Algorithm Overview - To simulate in-field events the model calculates a harvest rate based on combine specifications, ground speed and average crop yield. Users can specify a threshing rate to power ratio that serves to limit ground speed. Grain tank capacity and unload rates are added to the model when the user selects the equipment complement. The model assumes a standard harvest path based on field dimensions, and then proceeds to do a grain mass balance based at one-second time steps. When the combine grain tank or grain cart reaches capacity, the program control is transferred to a subroutine that governs the appropraite action – travel to the truck to unload for the grain cart, or stopping harvest and waiting until the grain cart returns for unloading the combine.

Graphical User Interface – A graphical user interface (GUI) was created in the MATLAB environment which allows a user to build and select equipment complements including make, model and number of combines; and make, model and number of grain carts. Users can also select equipment performance parameters including ground speeds, grain tank/cart capacities, unloading rates and threshing power requirements. The location of grain transfer from grain carts to over-the-road-trucks must be specified as well. For simplicity, users can select from a number of preloaded combine and grain cart makes/models, or can build new models based on unique specifications. Existing equipment lists are populated with manufacturer reported specifications. Figure 1 shows the GUI with self-populating fields (in dark gray boxes) along with slider bars that allow deviations from default values.

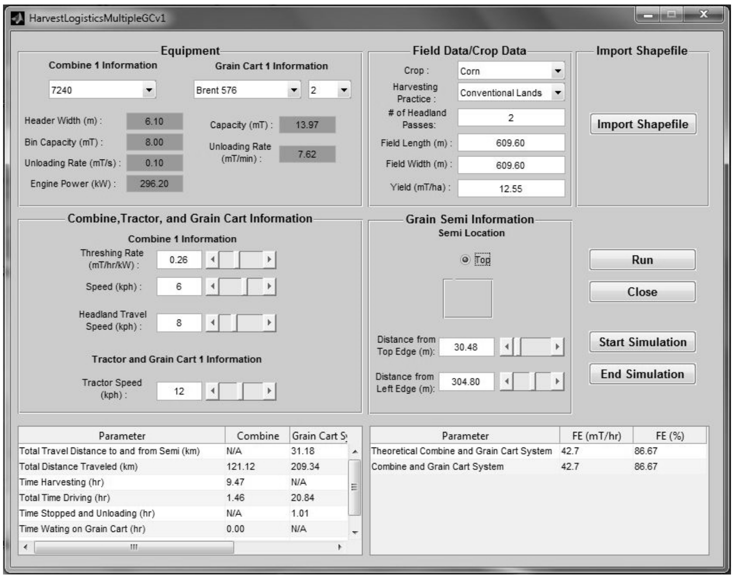

Fig. 1: Logistics GUI for building and/or customizing harvest equipment complements.

The current list of combines shown in Table 1, includes six current 2015 Case IH model combines, which range from Class 5 to Class 9. Also included are projections for Class 10 through 13 machines based on an analysis of existing trends in engine power, grain tank capacity, unloading auger capacities and header sizes. Table 2 summarizes 10, current model, Brent wheeled grain carts ranging in capacity from 15.0 to 54.4 mT.

Table 1: Base and Projected Combine Paramters for Logistics Model.

Class	Year	Engine Size (kW)	Boost (kW)	Unload Cap. (mT/min)	Tank Size (mT)	Base GVW (kN)	Head (rows)	GVW (kN)
5	2015	355	413	0.0635	6.4	159	6	240
6	2015	467	551	0.0813	7.6	158	8	258
7	2015	503	593	0.0813	7.6	159	8	259
7	2015	540	628	0.1016	8.0	198	8	302
8	2015	644	744	0.1016	10.4	198	12	338
9	2015	738	838	0.1143	10.4	206	16	346
10	-	823	947	0.1270	11.4	240	16	401
11	-	917	1055	0.1397	12.7	243	16	415
12	-	1012	1164	0.1524	14.0	245	24	454
13	-	1106	1271	0.1651	15.2	247	24	469

Table 2: Base Grain Cart Parameters for Logistics Model.

Brent Model	Undercarraige	Empty Weight (MT)	Unload Rate (MT/min)	Capacity (MT)	GVW - Corn (kN)	GVW - Beans (kn)
576	Wheels	2.9	8.2	15.0	166	176
678	Wheels	3.7	10.9	17.1	193	204
782	Wheels	4.0	12.2	20.4	226	239
882	Wheels	5.2	13.6	22.9	260	275
1082	Wheels	5.6	13.6	27.2	304	322
1196	Wheels	7.2	23.1	29.9	345	365
1200	Wheels	9.3	17.0	32.7	390	411
1396	Wheels	8.6	23.1	35.4	408	431
1596	Wheels	11.4	27.2	40.8	486	512
2096	Wheels	14.8	27.2	54.4	644	679

4. Results and Discussion

To highlight the value of the logistics model, multiple scenarios were simulated including equipment complements with Class 7, 9, 10 and 12 combines and multiple grain carts, and complements with two Class 7 combines and two grain carts.

The bar plot in Figure 2 shows the modeled harvest capacity (mT/h) and field efficiency (%) for a Class 9 combine with a 16 row corn head, and five different capacity grain carts. Base harvest capacity for the Class 9 combine is shown by the horizontal gray line while maximum theoretical field efficiency is shown by the horizontal black line. Either limit assumes the combine never stops to wait on the grain cart. The modeled harvest pattern assumes the combine harvests a field while working in parallel lands where the combine must travel across the headland to begin the next pass. The graph illustrates that increasing grain cart capacity had a positive effect on both harvest capacity (HC) and field efficiency (FE) with the Brent 1596 (40.8 mT capacity). No difference in either HC or FE are observed as the cart capacity is increased to 54.4 mT (Brent 2096).

Figure 3 shows theoretical values and simulation results of a harvest equipment complement that includes two combines (Case IH 7230) with eight row corn heads and two, 27.2 MT grain carts. While the harvest capacity of the single combine system shown in Figure 2 is greater for all grain cart sizes, the field efficiency for the two combine system is more than 10.0 % greater with FEs of 87.0% versus 75.5%. Not only does the two combine and two grain cart equipment complement have a higher FE, but its theoretical and actual FE values differ by only 0.7%, versus 3.0% for the single combine and single grain cart equipment complement. This comparison is summarized in Table 3. Single combine and grain cart systems for Class 7, 10, and 12 combines were simulated using the same grain cart sizes presented in Table 2. The graph in Figure 4 shows the harvest capacities for the harvest systems versus grain cart capacity. From this graph it is apparent that even when grain cart capacity is more than tripled, it marginally impacts system harvest capacity.

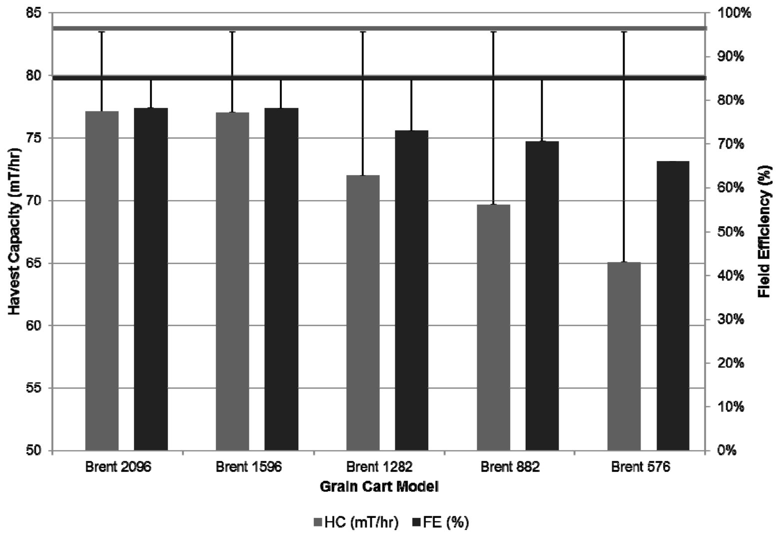

Fig. 2: Simulation summary for Case IH 9240 combine with 12.2 m small grain head and multiple models of a single grain cart.

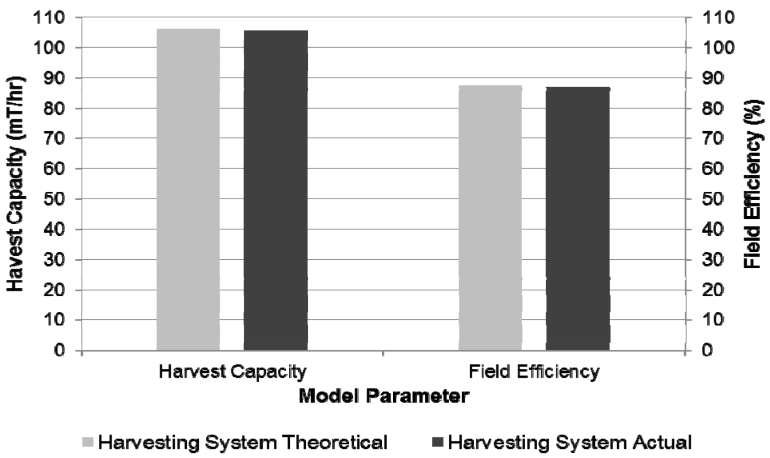

Fig. 3: Model simulations results for and two combines (Case IH 7240) with 6.1 m small grain headers and two grain carts (Brent 1196).

Table 3: Comparision of Combine and Grain Cart System Complements.

Equipment Combination	HC (mT/hr)	FE (%)
Single Combine Base Harvest Capacity	93.8	78.5
Single Combine and Single Grain Cart	90.2	75.5
Two Combine Base Harvest Capacity	106.3	87.7
Two Combines and Two Grain Carts	105.5	87.0

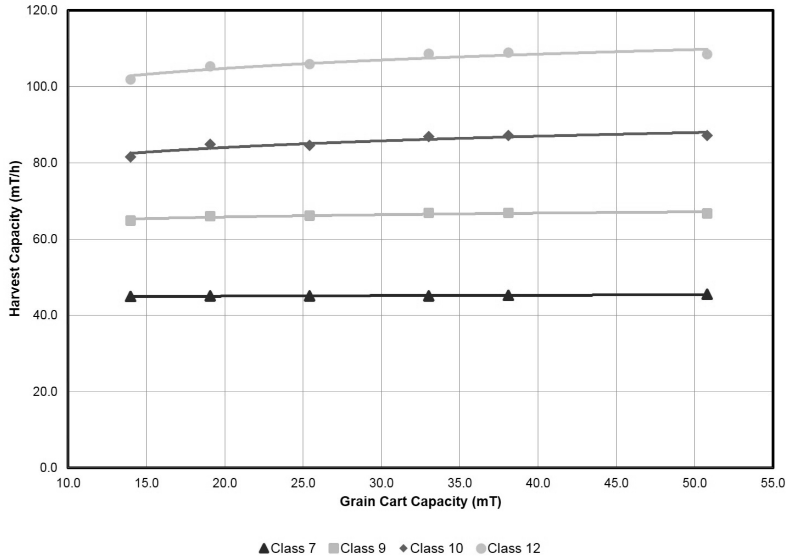

Fig. 4: System harvest capacity versus grain cart capacity for equipment complements with Class 7, 9, 10 and 12 combines.

With regard to equipment size and overall equipment complement harvest capacity, there are tradeoffs to be considered. Obviously, the potential for compromising soil structure are much geater for a 54.4 MT grain cart in comparison to a 15.0 MT cart. An example of how the harvets logistics model can be used to develop a better understanding for the impact of grain cart size on soil structure is best exhibited in Figure 5. The left portion (a) of the figure is representative of the mass of the 15.0 MT grain cart as it chases the combine while unloading on the go. The widths of the lines represent the loaded mass of the grain cart as it traffics the field. In contrast, the lines in right portion of the figure (b) are for the 54.4 MT grain cart providing a stark contract to the 15.0 MT cart traffic events. The trade-off in this case was a few percent in overall harvest capacity gained from increasing the grain cart capacity four fold.

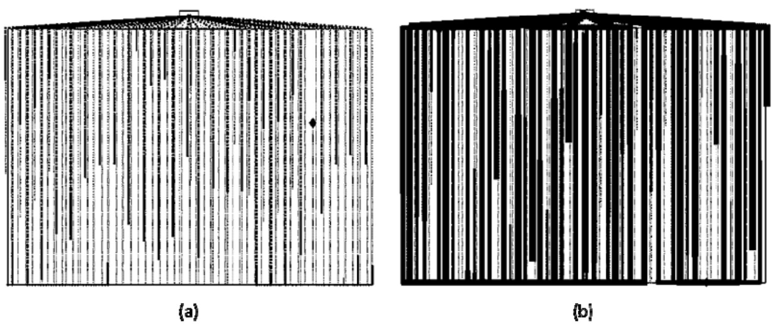

Fig. 5: Equipmenty paths for a) 15.0 MT and b) 54.4 MT grain carts where line width is proportional to loaded cart mass for unload on-the-go opertaions.

5. Summary

From the modelling work conducted, it is clear that for traditional North American harvest equipment complements, manufacturers and end-users must recognize the primary limiting factor in overall harvest capacity is the period of time when the combine is traversing headlands when harvesting field in "lands." That is opening up the field in select locations and then working in parallel passes such that it is possible to unload on-the-go. In other words, laying out harvest patterns, which ensure the combine, can unload into the grain cart while harvesting – harvested passes are always to the left of the working pass. Less obvious to equipment designers and end-users is the minor influence of grain cart capacity on overall system harvest capacity and field efficiency. The model revealed that for currently available equipment, the overall impact on grain cart size on system harvest capacity is less than 5.0%. Of course, this assumes that grain is being transferred from the grain cart to waiting trucks in close proximity to the edge of the field. It should be noted that while the focus is often on grain cart weights, loaded Class 10 and higher combines become increasingly problematic. However, existing 54.4 MT capacity grain carts should easily accommodate the trend towards larger capacity combines for the foreseeable future.

6. References

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