Improving Agricultural Operational Efficiency with Wireless Communication

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ABSTRACT

The purpose of the system outlined here is to increase the operational efficiency of multi-vehicle agricultural operations, such as harvest and planting. The system will incorporate hardware and software that communicates to the vehicle operator the status and position of other vehicles and their grain bin fill levels and grain attributes. The system will also provide assistance to the operator to optimize the movement between combines, grain wagons and road transport so that any bottlenecks and time the combines are waiting to be unloaded in the field are minimized. The real-time information provided to the operators of each machine will lead to a much more effective use of resources in the field, thus increasing productivity.

As an example for grain harvest, the system will include communication between multiple combines, tractor/grain carts, transport trucks and the point of harvested grain delivery. Information exchanged between various agricultural equipment will include current location, speed, grain level status, time to bin full levels, scheduled unloading time and location. A new vehicle cab display will be developed that will improve communication of the status information to the driver and will show the location of the vehicles and their scheduled unload points. A survey instrument is also developed to assess the value of the system and identify appropriate parameters for communicating between the various vehicles.

Keywords: WiFi, GPS, Precision agriculture

INTRODUCTION

Major advances in agricultural vehicle technologies in recent years have resulted in much higher work rates and efficiencies on a per vehicle basis. However, very little attention has been paid to systems of vehicles cooperating, for example, during crop planting and during harvesting (Hansen, Hornbaker and Zhang, 2003). In the case of grain harvesting, greater throughput of grain and increased grain bin capacities has lead to greater demands in transferring the grain between machines and moving it out of the field without causing combines to stop to be unloaded. Extra demands are placed on the operator of the grain wagon who is responsible for ensuring that the grain is transferred out of the combine on the go and then unloading the grain onto road transport. Hornbaker and Hansen (2002) have demonstrated the potential for ten percent increase in productivity (ac/hr) with five percent decrease in cost ($/ac) from improved planning and multi-vehicle coordination. This project focuses primarily on grain harvesting and handling systems, but the basic technology should be portable to other cooperative vehicle systems.

One of the factors contributing to lower vehicle productivity with grain handling systems is the difficulty of communicating the status of each vehicle; in particular its location and its grain tank fill status to the other vehicles involved in the grain handling process. Coordination of grain handling activities is done primarily by audio communication with mobile radio units or cell phones. The purpose of this project is to develop a more effective communication system to help the vehicle operators make more informed decisions for inter-vehicle operation and for grain deliveries to the grain elevator.

The overall goal of the project is to develop a decision support system with inter-vehicle real-time data communication for optimizing in-field grain handling by combines, grain wagons, road transport and grain elevator. The system will rely on an inter-vehicle wireless network/communication system, existing yield monitors as well as GPS fitted to combine, grain wagon, and road transport and access to CANBUS status information on the various vehicles. The wireless data communication will also be included between road transport and grain elevators or on-farm storage sites. The system designed to increase grain handling efficiency will also further facilitate the industry's ability to identity track grain from within farm fields to terminal elevator or grain processing facilities.

Through this wireless linkage the system will communicate vehicle status information such as current yield, bushels in the bin, ground speed, location etc. The system will utilize the status information from the various vehicles to compute optimal scheduling and real-time operational plans for the vehicles involved in the agricultural operation. In previous research we have collected real-time information on single and multi-combine harvest operations for multiple crops. These data included one second interval position (from GPS) information for the combine(s), tractor/grain-cart and semi-truck transport engaged in the harvest activities. Using these data, a visualization model has been developed for displaying the actual vehicle movements and quantity status in the field and to the farm or elevator storage sites. We also developed an economic model for estimating the cost of operations under various numbers, size and coordination patterns for the multiple vehicle operations. Further developed has occurred on the mathematical algorithms for estimating current and predicted status and position information for the various vehicles

WIRELESS COMMUNICATION SYSTEM OVERVIEW

The system is being developed on three levels of service: 1) a base level of real-time wireless communication, 2) the base level plus data retention and data storage, and 3) levels one and two plus linkage to agricultural grain and/or chemical tracking system technology. As an example for grain harvest, the system will include communication between multiple combines, tractor/grain cart, multiple transport trucks and the point of harvest grain delivery (see Figure 1).

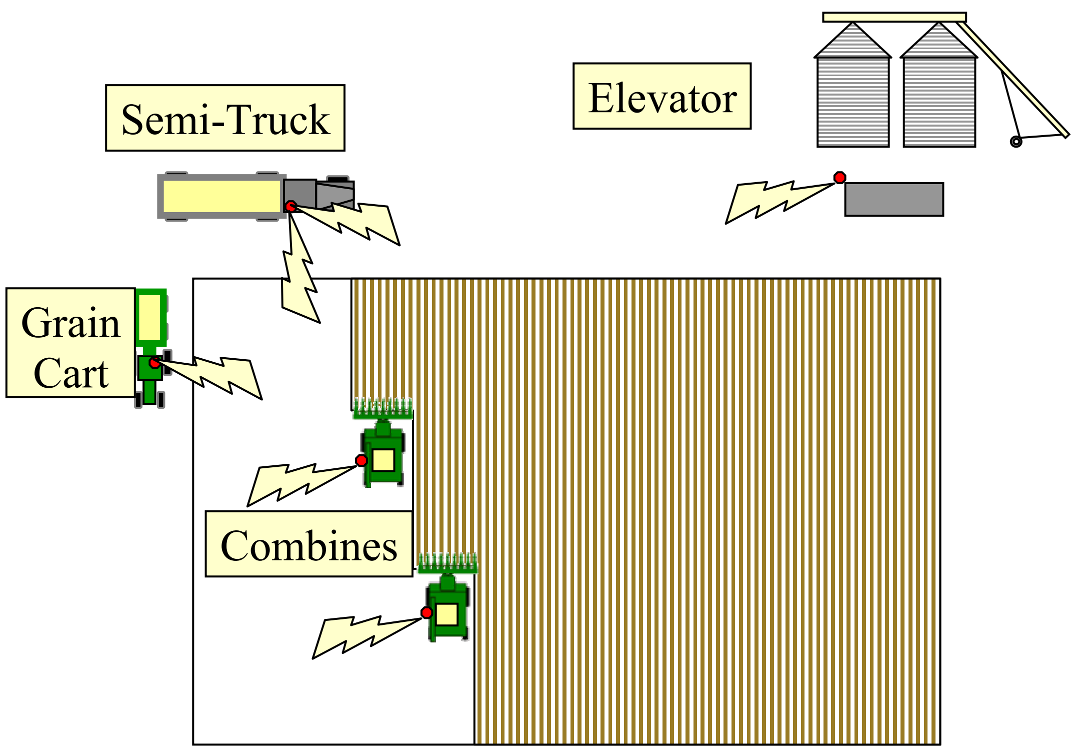

Figure 1. Wireless harvest communication.

Figures 2 shows further schematics on the short-range within field communications. This type of wireless communication will occur when the two machines are actively transferring grain and within Bluetooth range. The code is under development, which would signal transmitting the communication data when two vehicles are within Bluetooth range. Further grain transfer confirmation data would be transferred at the start and stop (based on CANBUS signal information) of the unloading auger on the combine and grain cart when transferring grain from to the grain cart(s) and truck(s) respectively. Initial tests during wheat harvest in Kansas using two IPAQ pocket PCs showed the ability to transfer up to 1MB files during the on-the-go unload process between the combine and tractor/grain-cart. Actual file size needed for communicating our position, time, fill-status, etc., data will be closer to 2 to 10 KB.

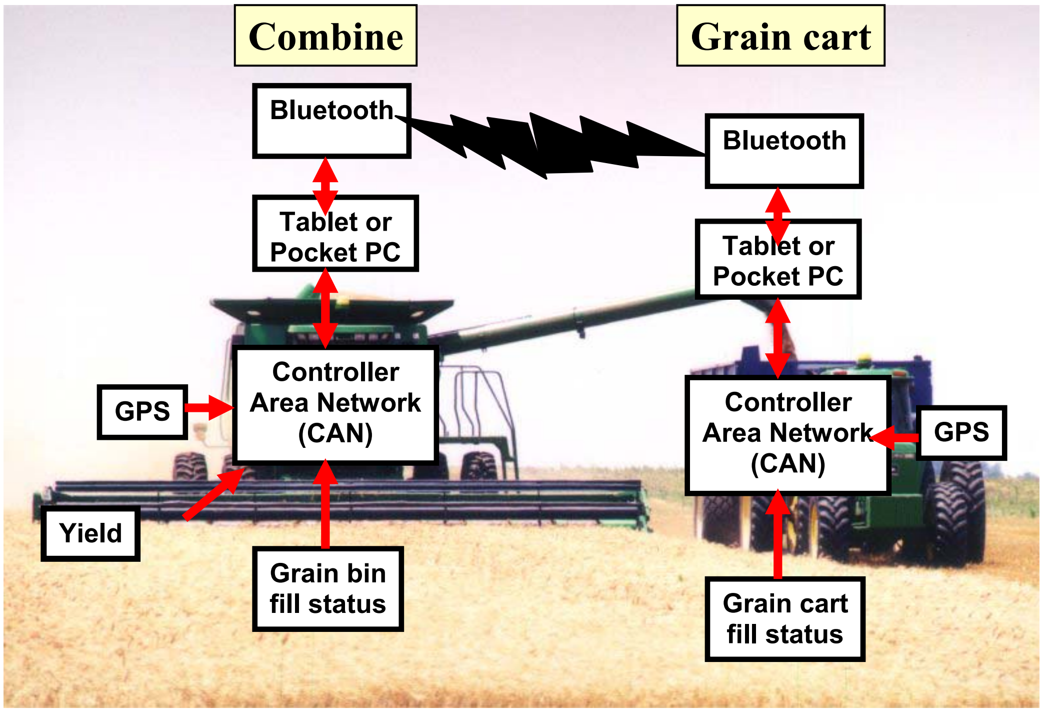

Figure 2. Wireless short-range in-field communication.

Figures 3 and 4 show communication between vehicles or units of medium to longer range. This range will include across the field communication between the multiple combines and tractor/grain-carts as well as communication between the transport truck(s) and storage site and back to the field. Communication of this range may occur via a wireless network with repeater stations if needed, or by time scheduled (30 sec, 1 min, 2 min etc) data packet delivery with cellular phone or similar service.

An overview of communication between the various machines and on-farm storage site is provided in Figure 5 with more details in the later figures. Figure 6 provides the color-coded information for the time and bushel status information used in the later figures. Data for the two combines are depicted in blue and red, the grain single tractor/grain-cart data are in black, and the semi-truck information is green. Information within a rectangular box is the data received from the appropriately colored unit. Time and bushel information, which is not in the rectangular box, is the current status information for that machine. Data in brown are predicted information transmitted from the machine or location.

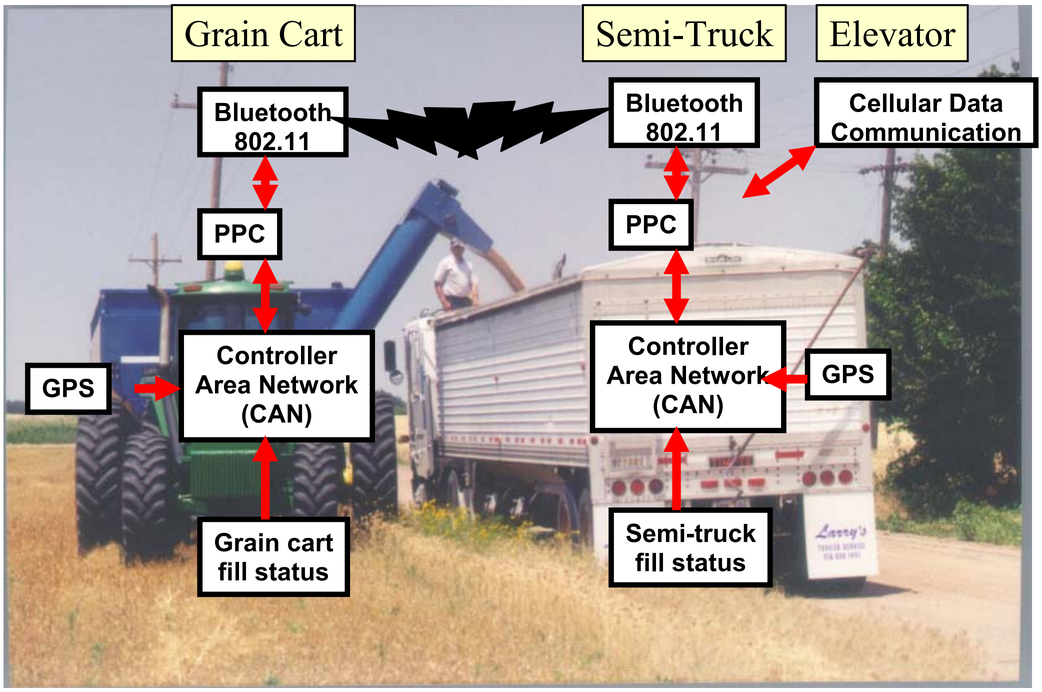

Figure 3. Wireless short-range and medium range communication.

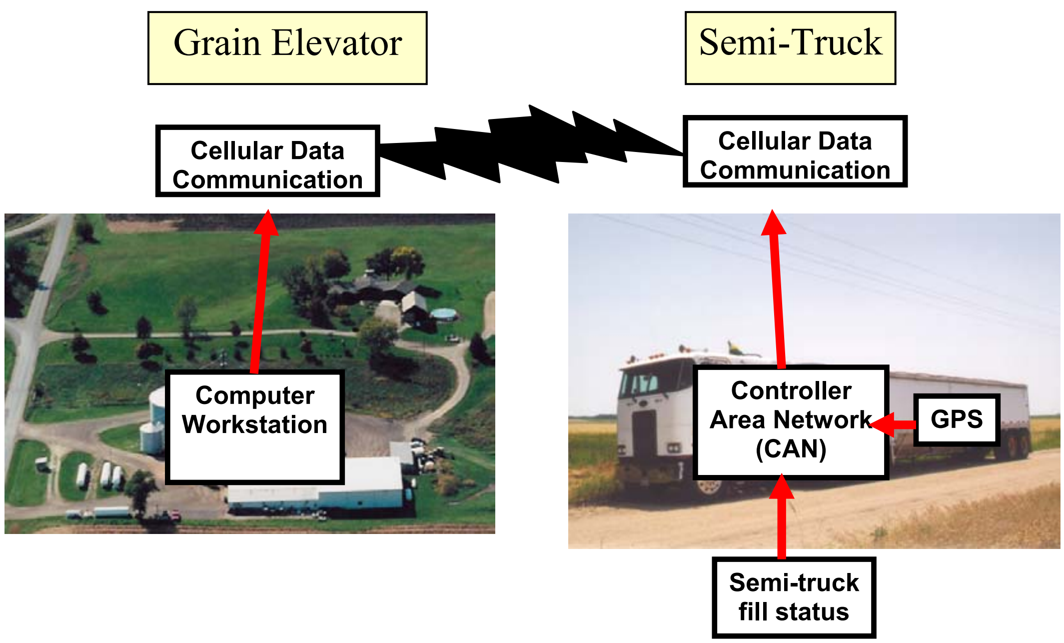

Figure 4. Wireless medium range (across field to farm) communication.

SYSTEM USAGE EXAMPLE

To illustrate the communication information Figure 7 shows the initial information for the two combines and tractor/grain-cart at time zero. In this depiction the blue combine is heading south with 218 bushels on-board and transmitting information that its bin will be full in 4.36 minutes. The red combine is at the south end of the field (0.5 miles) heading north with 327 bushels on-board and just beginning to unload into the grain-cart. The tractor/grain-cart is receiving the information that the blue combine will be full in 4.36 minutes.

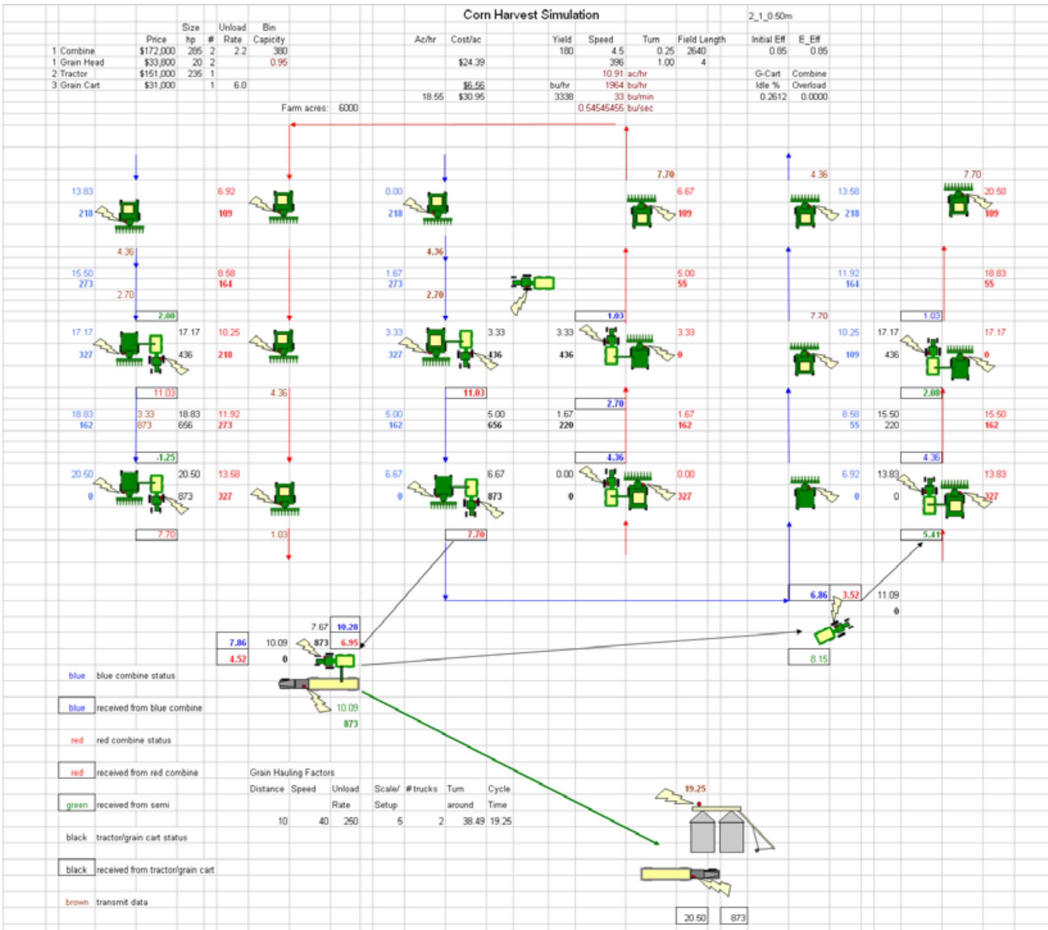

Figure 5. Depiction of wireless data communication during grain harvest operation.

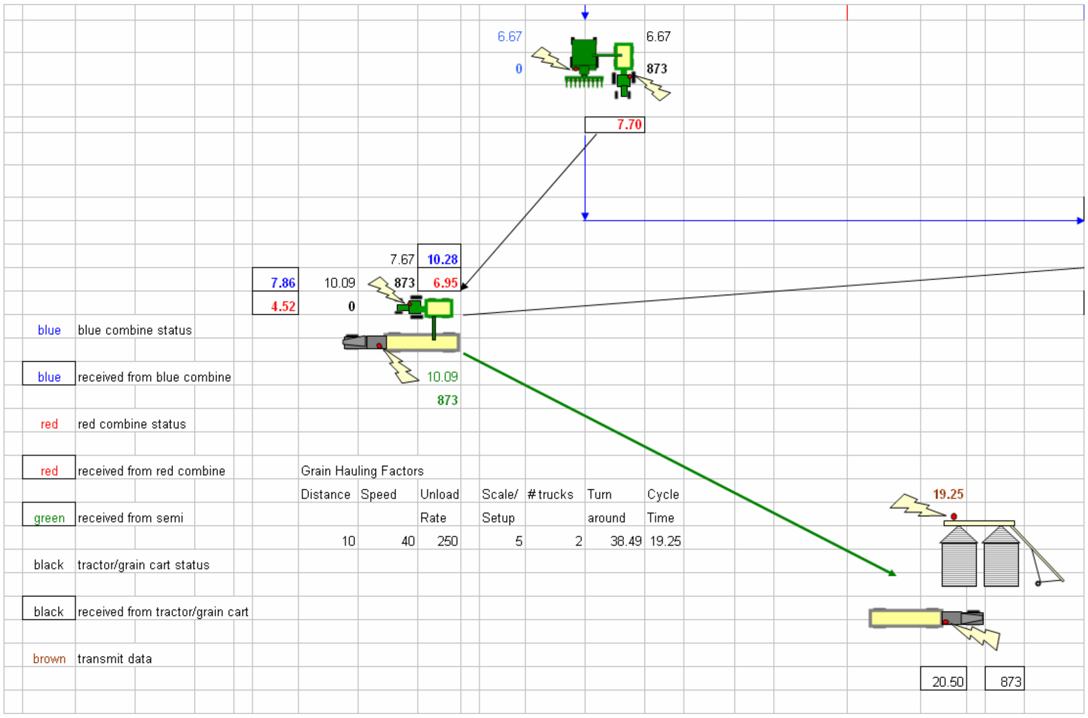

Figure 6. Communication of selected combine, grain-cart, transport and farm storage time and quantity data.

Figure 7 further illustrates the operation 3.33 minutes later after the combines have traveled 0.25 miles and the red combine has completed the unload process. The grain-cart now has 436 bushels on-board and begins unloading the blue combine, which has a current bin status of 327 bushels. The grain cart is also receiving information from the red combine indicating it will be full in 11.03 minutes.

As an example, the estimated time to bin full status of the combine is:

$$TTF_{ij} = \frac{ct - l_{ij}}{(s_{m-1}w/8.25)/(y_{m-1}/60)}$$

where TTF_{ij} is the current predicted time to full at a location whose latitude and longitude are i and j, respectively, c is combine bin capacity, t is percentage of combine bin capacity target, l_{ij} is combine's load level at the position ij, s_{m-1} is an average speed for load $m-1$, w is the combine harvest width in feet, and y_{m-1} is the current average yield for load $m-1$.

Further models are developed for communicating the estimate fill, unload and arrival times of the other vehicles as well as predicted location information which will be display in a later figure.

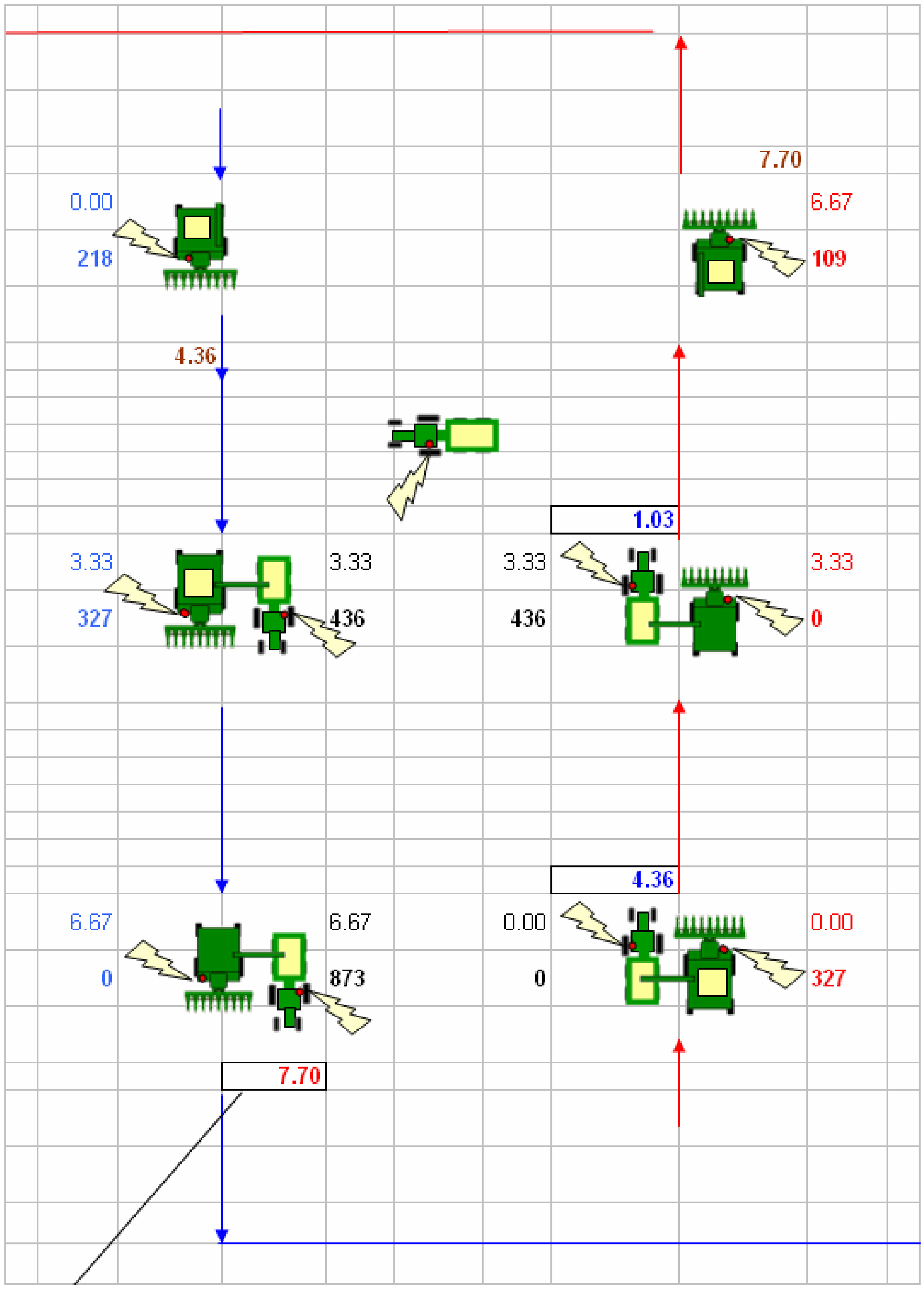

Figure 7. Combine and tractor/grain-cart communication.

At 6.67 minutes with 873 bushels on-board the grain-cart and the red combine indicate its bin will be at capacity in 7.70 minutes. The tractor/grain-cart now proceeds to the semi-truck (figure 8). The grain-cart arrives at the truck at the 7.67 minute mark with 873 bushels. Unloading is completed at 10.09 minutes at which time the blue combine is indicating its full status in 7.86 minutes and the red combine in 4.52 minutes. The tractor/grain-cart then returns to the field to unload the red combine, the semi-truck departs for the on-farm storage site and then the next cycle in the harvest process begins.

An example of the vehicle cab display is depicted in Figure 9. The display will not only improve communication of the status information, but also show the location (through GIS mapping of the field, current locations and predicted locations) of the vehicles and the scheduled unload points for the vehicles. This is an example of a map based unit as it might appear in the tractor/grain-cart unit. At this specific point in time it is indicating that the red combine (C1) is unloading into the grain-cart. The square boxes indicate the current position of the combines (C1 and C2), the semi-truck transport (T) and the tractor/grain-cart (G). The projected position of the combines when they will need to unload the next time is indicated by the circle (C1 and C2). The information on the right hand panel depicts part of the data that could be displayed in the tractor/grain-cart indicating the current status of the second combine, grain-cart fill status and the semi-truck status. Similar units would be in place in the other vehicles with options on the right hand panel for selecting the vehicle and particular data to display.

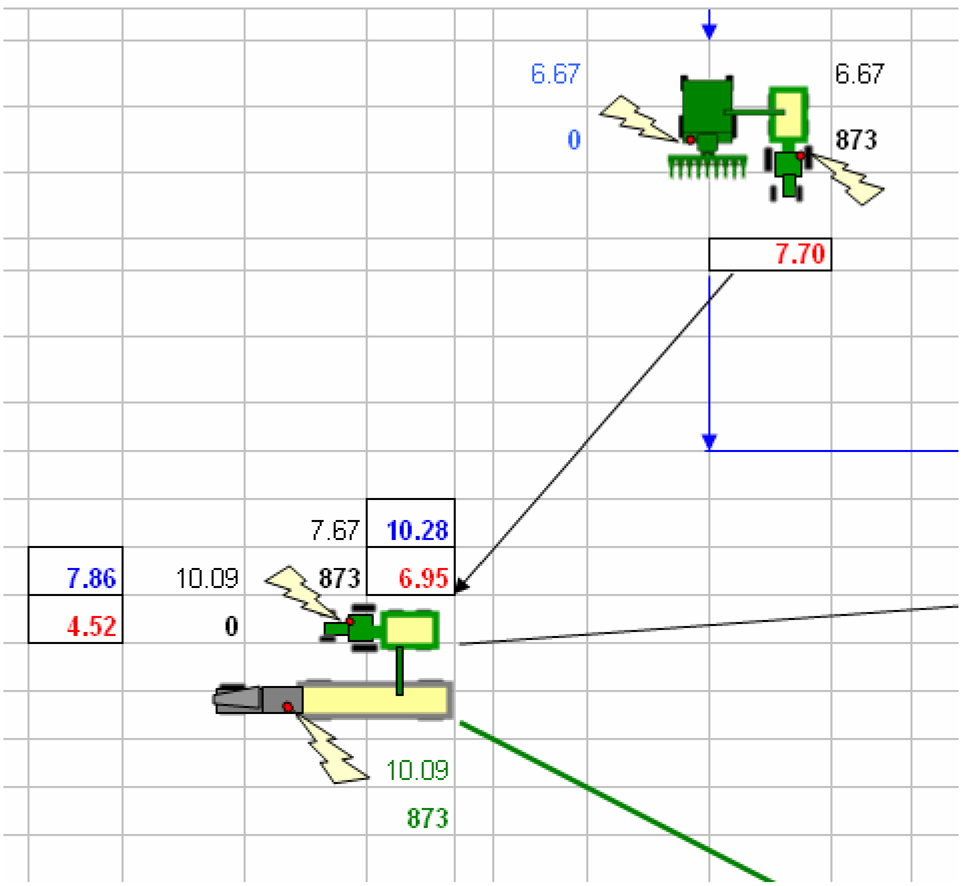

Figure 8. Tractor/grain-cart and semi-truck communication.

Similar models could be depicted for agricultural planting, tillage and chemical applications. However, the harvest activity is the most complicated with a larger number and diversity of vehicle types involved in the operations. The second level of service by this wireless system will include the wireless link to data storage. For the harvest example, data can be passed from combine to grain cart to transport truck and then to data storage at the on-farm storage or elevator location. Likewise the third level of service can include communicating the grain and/or chemical tracking and attribute information via the wireless system between the agricultural vehicles and to the on-farm or central data warehouse/storage location.

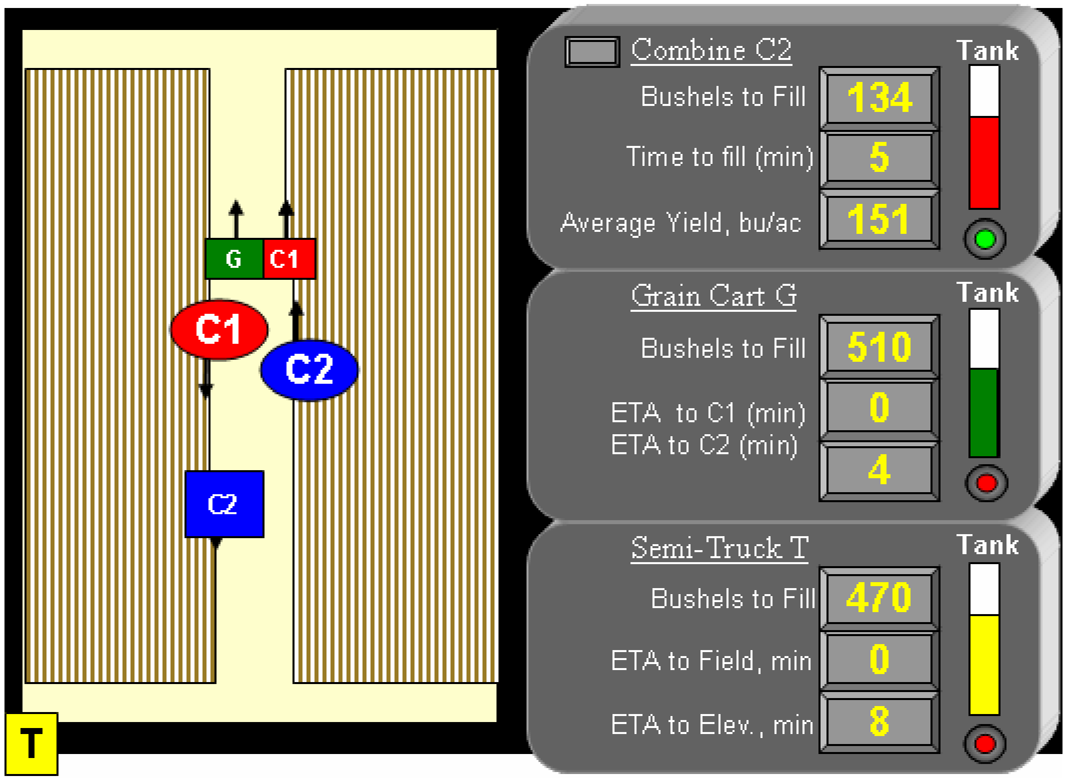

Figure 9. Example of tractor/grain-cart vehicle display.

SURVEY PROCESS AND RESULTS

To help assess the value of such a system to producers, a small preliminary survey was presented to approximately 20 individual farmers in central to western Illinois. The farmers were asked to rate various parameters that might be displayed by the system. A full copy of the preliminary survey is attached to this report.

The preliminary survey was split according to the equipment for which the parameters would be displayed. Farmers were given lists of parameters that could be displayed to operators of grain carts, combines, trucks or semis, and to operators at elevators or on-farm storage locations. The farmers were then asked to use a 1-5 scale to rate each parameter for each location with a 1 suggesting that the parameter would be irrelevant, 2 not-useful, 3 neutral, 4 important, and 5 very important information. For example, the farmers were asked to use the scale to rank the importance of displaying grain cart total bushels and percentage filled to the operator of the grain cart. Note that several of the parameters, including total semi weight and grain moisture, are repeated for several of the equipment options, as a parameter may be more useful to an operator of one piece of equipment than it would be to another.

After rating each parameter on a 1-5 scale of importance, the farmers were asked to choose five parameters for each equipment option that they would view as having the greatest economic value. These value were given an average relative rating based on the number of times and order in which the farmer selected them as important for their economic value.

Finally, the farmers were asked to provide some general information about their farming operations. Information on farm size, combines used, grain cart and truck capacities, storage locations, and storage type were gathered. This information could be used to assess the values of different parameters to different types of farm operations.

Farm Information

The farmers surveyed were well educated and were highly respected in the Champaign County area in Illinois. The operations are considered to be fairly progressive. Farm sizes ranged from 800 to 10000 acres with the average farm size at approximately 3800 acres. Most of the farms utilized on-farm storage facilities. Several of the farms split their grain storage between on-farm storage sites and elevator sites. Distances from farms to storage facilities ranged from under 5 to over 20 miles, but most distances fell within the 5 to 10 mile range.

Equipment used on the farms varied. Total bushel capacity for grain carts and other trucks or wagons on the farms ranged from 900 to 3400 bushel with an average of approximately 2100 bushel. In general the total capacity was split, with about half of the capacity available in grain carts and half available in trucks or other wagons. The number of semis used on the farms ranged from 0 to 7, but most operations were using 1 or 2 semis. Combines also varied with most operations utilizing 25 foot grain table widths and 8 row corn heads.

Survey Results

On average, the farmers surveyed rated almost all of the parameters as 3 or above on the 1-5 scale of overall importance for all four equipment options considered. A rating of 3 suggested that the farmer was neutral on the value of displaying a particular parameter. Only two parameters; other combine(s) speeds displayed to the combine operator, and combine speed displayed to the semi operator; had an average rating of less than 3, with ratings of 2.9 and 2.6 respectively. The rest of the parameters averaged above 3, suggesting that on average, the farmers surveyed saw at least some value in displaying the parameters to the operator. The following charts display the average ratings of overall importance as well as the average ratings of economic value for each of the parameters for each equipment option.

Figure 10 shows average ratings of importance for parameters that might be displayed to a grain cart operator. As illustrated in Figure 10, total semi weight, and the amount of grain in the grain cart were considered the most important parameters to be displayed to the grain cart operator, with average ratings of 4.6 and 4.4 respectively. All of the parameters had average ratings of over 3.5. This also illustrates the high level of overall importance placed on all of the parameters. These results suggest that those surveyed perceive a significant value in displaying the listed parameters to the grain cart operator.

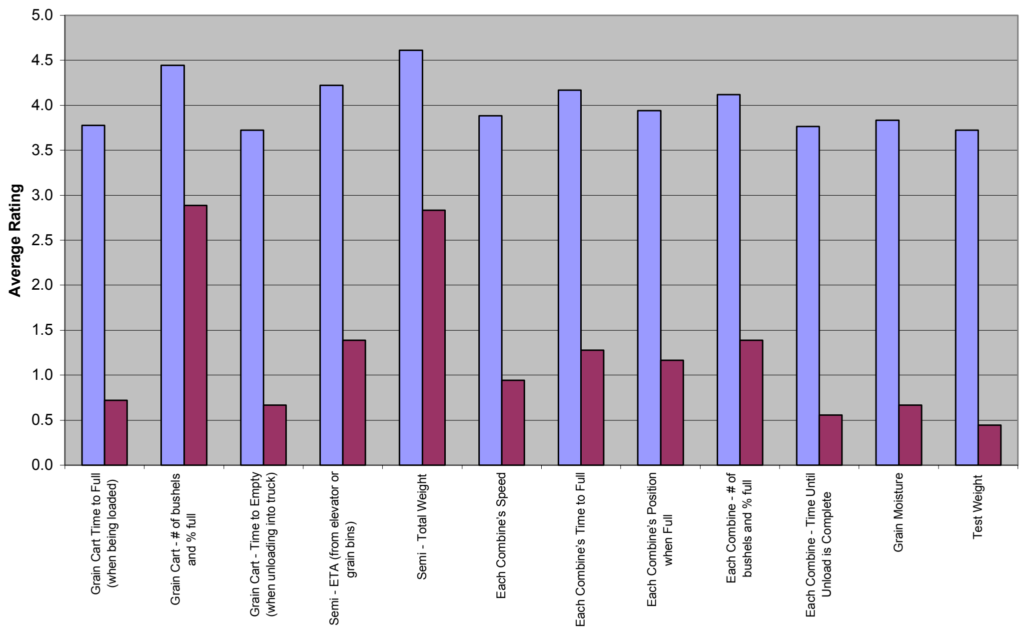

Figure 10. Average importance of parameters displayed to the grain cart operator & average relative economic value.

Figure 10 also displays results for the rankings of the five most economically valuable parameters displayed to the grain cart operator. A corrected average was developed to rank the parameters according to economic value. If a parameter was ranked in the top 5 on a survey, that parameter was assigned its respective rank. All parameters that were not in the top 5 were then given a ranking of 6. This process was repeated for each of the surveys, and the rankings for each parameter were averaged. The averages were then subtracted from 6 so that the highest resulting measure would indicate the parameter ranked on average as the most important. From Figure 10, it is apparent that total semi weight and the amount of grain in the grain cart were considered the most economically valuable parameters to be displayed to the grain cart operator. The remaining parameters ranked well below those two in terms of economic value. It should be noted that the average rankings of overall importance do not exactly correspond to the average rankings of economic value. The rankings are definitely positively correlated, but do not match exactly.

Figure 11 shows average ratings of overall importance for parameters that might be displayed to the combine operator. The farmers surveyed rated total weight of the semi, amount of grain in the grain cart, and the estimated time of arrival (ETA) for the semi from the storage location as the most important parameters to the combine operator. As with the parameters displayed to the grain cart operator, most of the parameters listed for the combine operator rated in the mid 3 to mid 4 range. Only other combine(s) speed rated below a three, signifying that that parameter is considered on average as not extremely important. Again, results suggest that the farmers perceive a significant value in most of the parameters that the harvest support tool would display to the equipment operator.

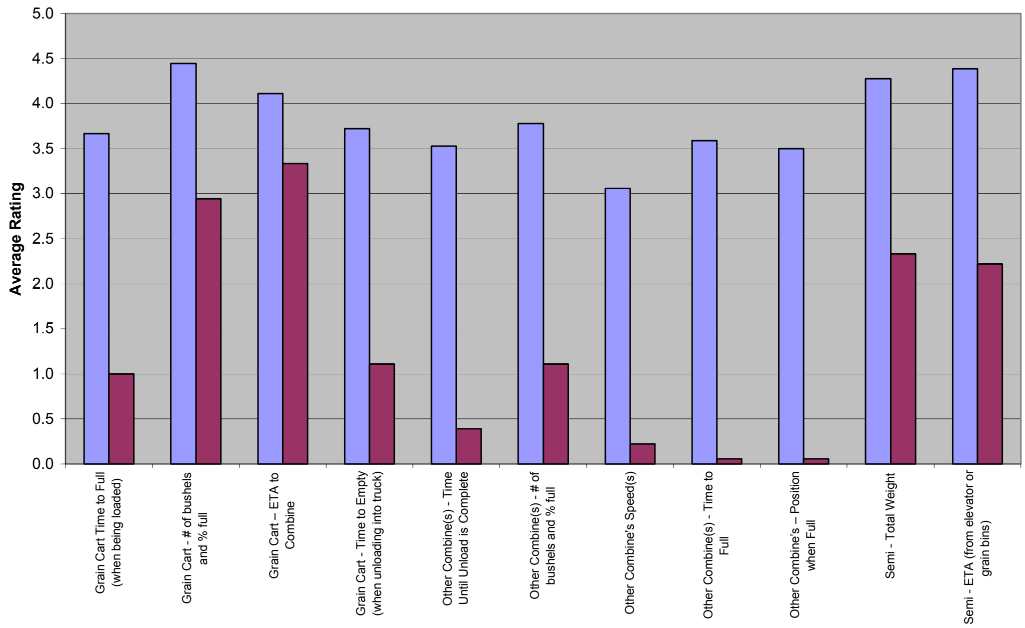

Figure 11. Average importance of parameters displayed to the combine operator & average relative economic value.

It is apparent from Figure 11 that ETA of the grain cart to the combine, amount of grain in the grain cart, ETA of the semi from the storage location, and total semi weight were considered to be the most economically valuable parameters that would be displayed to the combine operator. All other parameters rated well below those four in terms of economic value. Again, the rankings of overall importance and rankings of economic value are highly correlated, but do not match exactly, as made evident by the ETA of the grain cart to the combine parameter, which ranked 4th in overall importance, but first in economic value.

Figure 12 illustrates the average ratings of overall importance for parameters that might be displayed to the semi operator. Again, almost all parameters rate on average above 3, indicating perceived importance in almost all of the suggested parameters. Only combine speed at 2.7 had an average rating below 3. Total semi weight was considered as the most important parameter. On average semi weight rated 4.8 out of 5.0 indicating that the farmers surveyed considered that parameter to be very important. ETA of the semi from the storage location, amount of grain in the grain cart, and grain moisture were the next most important parameters, all with ratings of 4.2, considerably lower than the average rating for total semi weight.

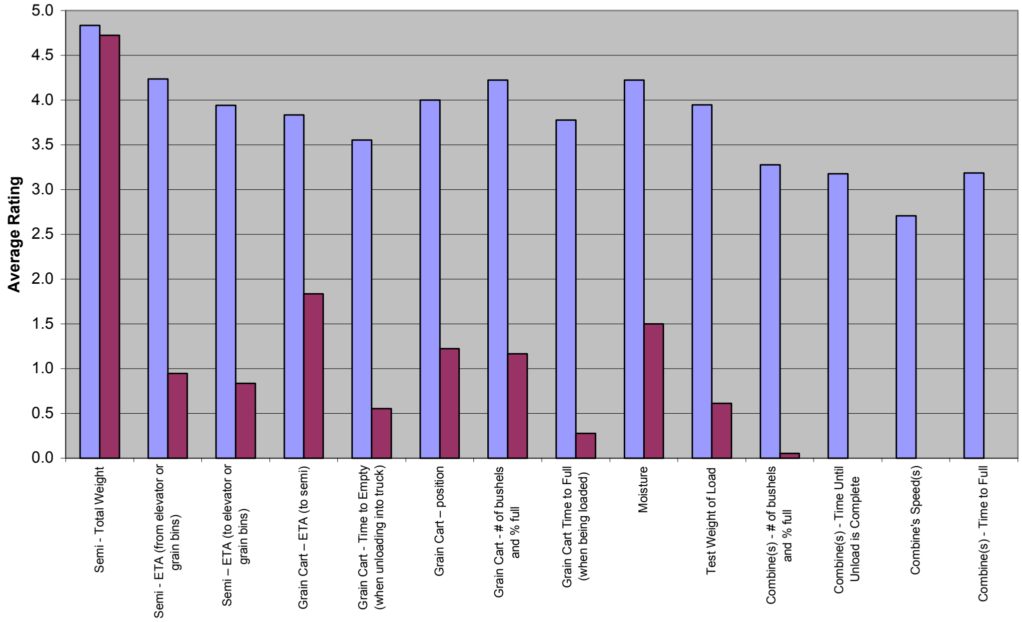

Figure 12. Average importance of parameters displayed to the semi operator & average relative economic value.

Total semi weight also ranks first as the most economically valuable parameter to be displayed to the semi operator. All but one survey farmer ranked total semi weight first in terms of economic value. The remaining parameters were similar to each other in their economic value rankings. All were significantly lower than total semi weight. ETA of the grain cart to the semi was the only other parameter that rated substantially higher than the others.

Finally, Figure 13 shows average rankings of overall importance for parameters that might be displayed to an operator at the elevator or on-farm storage site. Consistent with the other equipment options, all parameters listed for the storage site show average importance ratings above 3, signifying that the farmers surveyed did perceive the parameters as being useful to the operator at the storage site. Eight of the eleven parameters had an average rating above 4. Again, total semi weight rated highest for overall importance, with grain moisture, and field number also rating highly.

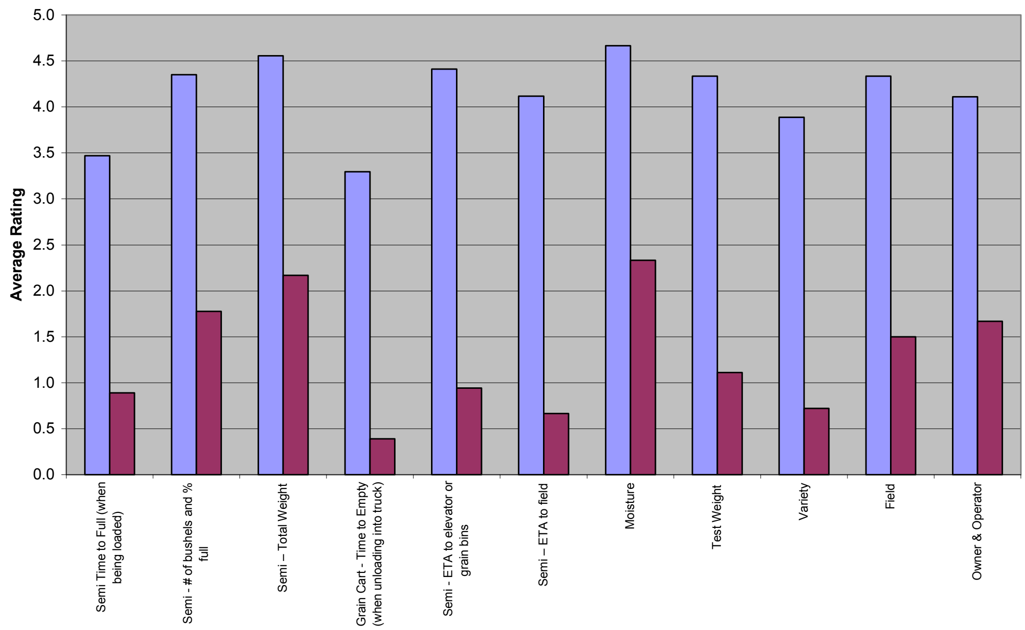

Fig. 13. Average importance of parameters displayed to the operator at storage location & average relative economic value.

Grain moisture ranked highest in terms of economic value among the eleven parameters listed, as seen in Chart 4. Total semi weight, owner and operator, amount of grain in the semi, and field number also ranked highly. Remaining parameters were relatively similar in their economic value rankings, all well below the five listed.

CONCLUSIONS

It is apparent that the farmers surveyed do perceive some value in the development of a real time in-field harvest decision support system. As previously stated, harvest time is a critical period for all farm operations. A real time in-field harvest decision support system may be the next step in improving harvest efficiency. The results of this preliminary survey indicate that most farmers would find some value in such a system, and also provide some guidance as to areas where the system could be improved. The results definitely warrant further inspection into the use of such a system. At this point much of the overall communication protocols have been developed. Moreover, some preliminary testing was conducted in Kansas during the 2004 wheat harvest. The first full prototype will be tested this fall on a couple of farm sites in Illinois during the corn and soybean harvest.

REFERENCES

Hansen, A.C., R.H. Hornbaker and Q. Zhang, 2003. Monitoring and analysis of in-field grain handling operations. Proc. Intl. Conference on Crop Harvesting and Processing. Louisville, KY, 8pp.

Hornbaker, R.H. and A.C. Hansen, 2002. Operational optimization of grain harvest equipment. Poster paper, Agricultural Equipment Technology Conference, Kansas City, MO.