Hazard Lighting and Marking System for Agricultural Machinery

by

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Abstract:

Current hazard light systems on agricultural equipment may not effectively convey the machine’s extreme size. This lack of awareness by motorists, while the equipment is being transported on the road, leads to collisions with the machinery. By placing additional hazard lighting at specific locations, the hazard lighting and marking system will convey the machine’s extreme size and improve the recognition of the machine to motorists.

This report encompasses the entire product development process from identifying the problem to the creation of an operational and functional prototype that increases recognition of agricultural machinery to motorists. According to the Ohio State Highway patrol, the Clermont County sheriffs department, the primary consumers (farmers), and local motorists, the hazard lighting and marking system for agricultural machinery increased recognition of the machines when compared to the standard hazard lighting available on the equipment. Not only does the product increase recognition, but also follows the standards for flash rate and turn indication for hazard lighting as designated by the American Society of Agricultural Engineers. It accomplishes both of these without increasing the operators input by integrating it into the existing hazard lighting system.

After following the stages of the hazard lighting and marking system, this report concludes with several product enhancements to improve the prototype and ensure the quality of the final product.
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1 Introduction:

1.1 Problem Definition

Like most vehicles, agricultural equipment must have functional caution or hazard lights. When this equipment is in route to a destination, the signals must be in operation while on the road. Due to the enormous size of these machines, the signals may not convey all extreme locations or the extreme size of the machine. This means that the flashers may not be at the farthest point of any part of the equipment. This results in motorists unable to effectively recognize the size of the machine, and slow down to safely pass or wait until the machine reaches its destination. The National Safety Council (NSC) reports that 88 farm vehicles were involved in fatal accidents in the United States in 1998 [1]. This statistic does not include non-fatal accidents. The NSC also reports that in 1998, 700 to 800 people were injured in U.S. traffic accidents involving farm vehicles [1]. People do not realize the size or slow speed of the machinery until it is too late. The flashers that are currently standard equipment are the typical on/off flashing type. Although these lights fall within the laws and guidelines set for these types of equipment, they may not be effective in conveying the equipment's extreme size. Placing additional hazard signals at all extreme locations of the equipment could dramatically increase visibility and could possibly decrease accidents that involve agricultural equipment.

1.2 Solution

When looking at the number of lights as a solution, the effectiveness of this increase in lights can be found on other vehicles. This correlation can be found on motor transport vehicles, particularly tractor-trailers. Tractor-trailers are a type of vehicle that motorists come in contact with on a daily basis. Their extreme size is highly recognizable due to the number and placement of marking lights. It was found that on average, 23 lights were used to convey the extreme size of the motor transport tractor. This does not include the number
of lights on the trailer. This is for a machine that is roughly 8 feet wide, 10-13 feet tall, and that weighs between 6 to 8 tons. In comparison, the Case-International model 9380, four-wheel drive agricultural tractor is 13 feet wide, 13 feet tall, 22 feet long, and weighs 12.5 tons, but only uses 6 hazard lights to convey its extreme size. This comparison shows that agricultural machinery lacks the number of lights to properly convey its extreme size.

A solution to the problem of motorist’s failure to recognize the extreme size of agricultural tractors would be to increase the visibility and awareness of agricultural machines while they are in transport. Increasing the number of hazard lights and placing them at strategic locations that would convey the extreme size of the machinery could accomplish this. In doing this, the extreme size of the machine could be conveyed representing a potential hazard to motorists. This was accomplished by the design and fabrication of a hazard lighting and marking system prototype that attaches to an agricultural tractor and improved the recognition of the tractor to other motorists while in transport on the road.

1.3 Design Objectives

The main objective of the prototype was to improve recognition of the agricultural machinery to other motorists, over standard equipment, while the tractor was being transported on the road. Increased lighting and the addition of reflective marking tape at specific locations were key elements to successfully improve recognition. Other than the main objective, the hazard lighting and marking system also had to conform to two other objectives. The flashing hazard signals must conform to the American Society of Agricultural Engineers (ASAE) standard S279.10 4.1.4 and 4.1.5 for flash rate and turn indication. The hazard lighting and marking system must use standard operator input. This means that the system would not require any additional input from the operator to function properly along with the current hazard lighting system. The integration of the hazard lighting and marking system into the current hazard lighting system would maintain its conformance to the ASAE standard.
1.4 Project Development

In order to meet the design objectives in a timely manner, the design and fabrication of the hazard lighting and marking system was initiated following the development of a detailed schedule. This schedule was a measuring unit used to maintain forward procession of the project. The result of following the project schedule was a fully operational, functional prototype that met the design objectives. This detailed schedule can be seen in Appendix A, to follow the progression of the prototype through the entire design process. Along with the schedule, a preliminary budget was constructed to see how much the system would actually cost. Changes in the scope of the project, led to changes in the budget that are reflected in a revised budget, which can be reviewed in Appendix B. Even though cost was not a driving factor in the design of the prototype, expenditures for materials were held below five hundred dollars.

1.5 Scope of Report

The following sections of this report will include the entire design process that resulted in the hazard lighting and marking system for agricultural machinery. The customer’s input served as a foundation for the selection of the preferred design. The technical analysis of the preferred design ensured a product that would withstand the operating conditions that it was subjected to. Testing and evaluation procedures are given to show that the prototypical hazard lighting and marking system met the design objectives and requirements to be considered successfully complete. Recommendations are given for further development considerations to enhance the quality of the product while maintaining its functionality and operability.
2 Background Information:

2.1 Agricultural Lighting and Marking History

Farm equipment has changed dramatically over the years. New innovations and
designs have changed the tractor from a steel wheeled, steel seated workhorse, to a rubber
tired, ergonomically functional and pleasant to drive piece of equipment. There have also
been advances in the lighting of such pieces of machinery, most occurring within the past 40
years. In 1964, slow moving vehicle symbols (SMV), the orange triangles, were introduced.
Shortly after, flashing lights were added to tractors. In the late 60's, manufacturers started
using turn signals on the machinery. Although by 1998 most tractors had them, it became
mandatory to have turn signals on new equipment. Also in 1998, certain reflective tapes
were initially being used as a source of tractor awareness along with extremity lights that
extend over the tires of the tractor. [2]

2.2 Studies and Current Hazard Lighting

Even though hazard lighting was added to agricultural equipment, the awareness of
these types of machinery may still be lacking to motorist. Tom Bean, a professor and safety
leader at Ohio State University, conducted a study that led to the American Society of
Agricultural Engineers (ASAE) standards to be changed in 1998. “People on a test panel
looked at different configurations of lighting and marking and were asked to identify what
they saw and what they cued in on,” said Bean. “Most people are familiar with typical
lighting packages like you find on cars and trucks, which include turn signals, brake lights
and other things. They cued in on that (vehicle lighting) much faster than any other type of
arrangement.” [2] This suggests that people are relatively unfamiliar with tractor lighting.
“Most automobile drivers are unaccustomed to farm machinery,” writes Wei Zhao, the
agricultural health and safety coordinator for the New Jersey Agricultural Experiment
Station.[3] This unfamiliarity and lack of awareness contributes to vehicle collisions between
motorists and farm equipment on rural roads and highways. Speed is also a factor in this arrangement. Tim W. McAlavy, a writer for Texas A&M Agriculture news, wrote that “Not recognizing slow moving vehicles, or simply not being aware of them until it is too late, is a leading cause of collisions between motorists and farm equipment.”[4] It is easy to misjudge the time that it takes to overcome a slow moving vehicle. This issue of closure time, or the time that it takes one vehicle to overtake another vehicle, can be easily explained. If a vehicle is traveling 45 miles per hour and is being followed by a vehicle traveling at 55 miles per hour, it would take 27 seconds for the second vehicle to close a 400-foot gap that was between them (Figure 1).[5] If the first vehicle happens to be a tractor going 15 miles per hour, it would take less than 7 seconds for the second car to close that same 400-foot gap (Figure 2).[5]

If the awareness of agricultural equipment in transport can be increased, accidents between motorists and tractors can be significantly reduced.

Some examples of the current usage of reflectors and emblems to increase tractor awareness are shown in figures 3, 4, 5, and 6.
Figure 3. Tractor with implement [6]

Figure 4. Tractor, rear view [6]

Figure 5. Combine with reflective tape [6]

Figure 6. Factory optional single strobe [7]
3 Discussion of Design Solutions:

3.1 Design Criteria

Before developing alternatives to be evaluated to find the best solution, a list of design criteria must be created. The project must fulfill these objectives.

- Use standard operator input.
- The flashing hazard signals must conform to ASAE standard S279.10 4.1.4 and 4.1.5 for flash rate and turn indication.
- The system must increase recognition of the agricultural machinery to motorists when compared to the available standard equipment.

When evaluating lighting systems, standards to measure against other than the ASAE standards for lighting and marking of agricultural machinery, were difficult to find. When lighting systems of agricultural machinery, that conform to the latest ASAE standards, were compared to other large machinery such as motor transport vehicles, it was found that the agricultural machines were lacking in their hazard lighting that conveys their extreme size. This was also reinforced by the results of a lighting study that was conducted by professor Thomas L. Bean of The Ohio State University for the Association of Equipment Manufacturers (AEM). [8] This study evaluated several lighting systems to determine the best solution. This study was going to be used as a standard to measure the final hazard lighting system against. The evaluation of the study though, relates that the results were inaccurate and the alternatives unable to be properly evaluated to determine the best solution. It states that, “After consultation with statisticians, we concluded that the statistical results for the questions above remain inconclusive. Based upon a review of the raw data, evaluation instrument and panel verbal and written instructions, there was obvious misunderstanding, confusion, and too much subjectivity relative to accurately marking of the instrument (instrumentation error). The necessary statistical assumptions for proper analysis
of the data could not be met. Therefore, it was inappropriate to try to interpret this data with advanced statistical applications.” [8] In this situation, statistical analysis was unable to evaluate the alternatives to achieve any measurable results. The summary of the study concludes that, “Due to the objectives and complex visual nature of the study, financial and other considerations, not all of the universe of alternatives for testing could be included in this study. However, the results of the dynamic on-highway testing provide insight for consideration of future lighting marking standards. It appears that daytime and nighttime visibility, definition, and conspicuity of agricultural machinery, including extremities, may be enhanced using alternative lighting and marking schemes.” [8] After review of this study, it was found that evaluation of lighting and marking systems were somewhat subjective, since the conclusion was that alternative lighting and marking schemes can be used to enhance recognition. Other correlations had to be sought out to determine design criteria to measure against. Due to time constraints, long-term studies were not feasible. As with professor Bean’s study for AEM, proving a hypothesis through advanced statistical analysis would also not be able to be accomplished, because of study set up, testing, analysis time, and the lack of resources currently available to the student. Even though there is not ample time to set up an advanced study, there is sufficient time to show that the solution is valid through the response of different groups of people. The student and advising professor set up an arbitrary standard in order to properly evaluate the hazard lighting system and show that the system was successful in solving the problem stated in the problem definition. The standard consists of the acceptance of increased recognition of the design by law enforcement officials, the primary consumers (farmers) and local people from rural areas that would come in contact with agricultural machinery. People from each of these groups would be asked to evaluate the new hazard lighting and marking system against the standard lighting system. Their evaluation and acceptance of the new hazard lighting and marking system would
validate the solution, therefore proving the project successful in improving recognition of agricultural machinery while in road transport.

3.2 Quality Function Deployment

The Quality Function Deployment method was used to evaluate the customers’ needs. Looking at the customers needs does this. Finding out the customers needs was accomplished by personal interviews with the primary customers of the lighting system. These would be the farmers that own equipment that the system would be mounted on. Results of these interviews are shown in Appendix C. Key wants that the customers expressed were:

- Improved Recognition over standard hazard lighting.
- Durable/Rugged.
- Does not require additional operator input.
- Does not inhibit field visibility.
- Easy to install.
- Easy to maintain.

These customer requirements were placed into a House of Quality. The House of Quality is a decision matrix used to evaluate all the elements that go into the definition of the product. It assigns numerical values to determine the most important characteristics of the product. It is made up of several rooms.

- What’s
- How’s
- What’s vs. How’s
- Why’s
- Why’s vs. What’s
• Technical Importance

The “What’s” are the customers needs determined from observations and the informal interviews. The “How’s” are the engineering characteristics used to satisfy the “What’s”. The “What’s vs. How’s” room is a numerical relationship between the “what” and design characteristics. Three values are assigned here. 9, indicates that there is a strong relationship. 3, indicates there is a moderate relationship. 1 indicates that there is a weak relationship. No number indicates that there is no relationship. The “Why’s” are a competitive assessment and show how current products measure up to the customer requirements. They rank and relate satisfaction and importance. The “Why’s vs. What’s” are the importance rating between the two. The Technical Importance shows the importance of each engineering characteristic in meeting the customer requirements. The completed QFD matrix is shown in Appendix D.

From the QFD matrix, it can be determined which design characteristics are most important in satisfying customer needs. The characteristics are listed in order of importance.

1. Full Boundary Definition
2. Number of Lights
3. Standard Parts
4. Brightness of lights
5. Reflective Material
6. Standard Controls
7. Comparable to factory equipment

3.3 Alternative Designs

Using the design characteristics and the customer needs evaluated by the QFD method, four alternative designs for satisfying the criteria were conceived. Each concept is sketched and shown in Appendix E.
1. **Under frame concept:** A design where the system would be folded or retracted under the frame during field operation.

2. **Straight Bar concept:** Simple straight bar design that is mounted under the frame. No retraction. Always deployed. No moving parts.

3. **Vertical fold up concept:** Design where the system folds up vertically, parallel with the hood sides. Inhibits engine access and is always exposed.

4. **Horizontal fold up concept:** Design where the system folds up horizontally, perpendicular to the hood sides. Inhibits engine access, visibility, and is always exposed.

### 3.4 Selection of preferred design

The four alternative designs were evaluated using the Pugh concept selection method. This method uses a list of features to measure the alternatives against a particular datum. It assigns a +, -, or S for each alternative at each feature. A plus (+) indicates that the alternative is better than the datum for that feature. A minus (−) indicates that the alternative is not as good or worse than the datum for that feature. An “S” indicates that the alternative is the same as the datum for that feature. These assignments are added up to see which alternative is the best selection.
The straight bar concept scored more +’s than the others and was determined to be the preferred design due to its lack of moving parts, durability and increased recognition.

### 3.5 Review of Preferred Design

The concept that was chosen seemed to be the best solution to the problem. After further review though, the straight bar design only partially addressed the problem. In order to successfully address all areas of the problem, additional parts were needed in addition to the straight bar design. The purpose of the hazard lighting system was to convey the extreme size of the machine. Additional mounted parts were added that would house multiple lights at various locations of the machine. The addition of these mounted lights would satisfy the solution to the problem. These mounts would encompass the height, width, and length of the machinery. It was also found that side marking would be beneficial.

A study done by Charles J. Kahane Ph.D., for the National Highway Traffic Safety Association, as an evaluation of side marker lamps for cars, trucks, and buses, reported that:

- Side marker lamps have significantly reduced the number of nighttime angle collisions that occur in the United States. [9]
• The lamps have significantly reduced the number of nonfatal injuries that occur in nighttime angle collisions, because they reduce the severity of accidents and/or prevent them entirely. [9]

• Side marker lamps are a cost-effective safety device. [9]

These findings have been incorporated into the straight bar design by the addition of side mounted hazard lights to address all aspects of the vehicle.

3.6 Analysis of Preferred Design

The size of the light bar and its components were chosen due to the light size and reflective marking (conspicuity) tape size. Steel tubing that was large enough to house the lights was chosen. This tubing was then analyzed to determine if it would withstand fatigue stresses due to the constant motion of the machine. Other bracket material for the lighting additions was also selected this way. It was then analyzed for each mounting configuration that it would be used in. Even though the size of the material could be chosen this way, the welds and bolt size for the light bar system had to be designed to withstand the fatigue stresses. Fatigue and unknown loadings were the main factors that needed to be addressed for this prototype. The product had to withstand the constant motions that would occur as the equipment was being used for daily work, and either withstand or react to unknown loadings in a manner that was not detrimental to the product. For the design for fatigue loading, the modified endurance strength and soderberg criterion for fluctuating stress methods were used. [10] Using these methods ensured that the members would not fail, even when subjected to an infinite number of repetitive loadings. For unknown loadings, certain members were designed to breakaway, so they would not sustain any damage. The analysis of the system is covered in Appendix F. A500-B rectangular tubing was chosen for any tubing parts that were to be fabricated. For sheet metal parts, ANSI 1020 sheet metal was used. For the brackets that hold the lower light bar to the frame, A-36 carbon steel angle
iron was used. The lights for the hazard lighting system consist of Light Emitting Diodes (LED) fabricated in several different lighting sizes. These will be purchased from a vendor. Also, the mounting and wiring hardware for these lights will be purchased. Mounting hardware for the actual light system consists of various SAE-Grade 5 material bolts, nuts and washers. The actual mounting hardware used is shown in the bill of materials portion of the detailed drawings in Appendix G. Detail drawings of all parts are shown in Appendix G. Also shown in the Appendix are the vendor data sheets for the lighting materials (Appendix H).
4 Fabrication and Assembly:

4.1 Fabrication, Assembly, and Mounting

The fabrication of the hazard lighting and marking system was accomplished at the Stahl Farms shop facility. The tools associated with this task were provided. A chop saw, an arc welder, cutting torch, grinder, drill press, magnetic drill, and various hole saws were used in the fabrication of the prototype. It was then painted with a primer coat and a topcoat.

The color designation is as follows:

<table>
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<th>PART</th>
<th>COLOR</th>
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<tbody>
<tr>
<td>Front Turn Indicators</td>
<td>Black</td>
</tr>
<tr>
<td>Front Light Bar</td>
<td>Black</td>
</tr>
<tr>
<td>Side Turn Indicators</td>
<td>Red</td>
</tr>
<tr>
<td>Top Light Bar</td>
<td>Black</td>
</tr>
</tbody>
</table>

Also, plastic end caps can be placed on the ends of the top light bar to keep debris away from the lights. This was not done in the prototype stage due to cost, but will be a recommendation.

After completion, the prototype was mounted on the supplied tractor. Due to the extreme size of some of the components, a floor jack had to be utilized to raise portions of the assembly in preparation for mounting on the machine.
4.2 **Light Assembly and Wiring**

The assembly of the LED lights is shown in Figure 8.

![Figure 8. LED Assembly](image)

The grommet encases the light and then fits into the hole in the light bar. The pigtail (wiring) then attaches to the rear of the LED light. The wiring was accomplished before the lights were assembled in the housing components. The wiring schematic is shown in Figure 9.

![Figure 9. Overhead Wiring Schematic](image)

This shows how each light set was wired into the system. There is a common ground in the overhead console; so grounding is not shown on all sets. Wires 45A and 45B are the designated by the equipment manufacturer as the wiring for the right hand side front
and rear hazard signals. 45A is for the right front and 45B is for the right rear. Wires 46A and 46B are designated by the equipment manufacturer as the wiring for the left hand side front and rear hazard signals. 46A is for the left front and 46B is for the left rear. The front and the back designations are not as important as the left and right. This is due to the turn indication. The top light bar and the side turn indicator for the left side were wired into 46B. The left set of the front light bar and the left front turn indicator were wired into 46A. The top light bar and side turn indicator for the right side were wired into 45B. The right set of the front light bar and the right front turn indicator were wired into 45A. An additional terminal is located at the rear of the tractor. This did not have to be used. The wires were routed in a manner so that they would not come in contact with anything that would be detrimental to the system. The wire routing is shown on the following page in Figure 10.
The hazard lighting and marking system was integrated into the existing hazard lighting that is currently available on the equipment. The operator uses the standard switch to activate it. There were no additional switches needed for the increased hazard lighting. The fabrication, assembly, mounting and wiring were all accomplished within the time specified in the project schedule. The final mounted product can be seen in Appendix I.
5 Schedule and Budget:

5.1 Schedule

The complete schedule is shown in Appendix A. A completion schedule is also shown in this appendix. This schedule differs from the original proposed schedule due to the amount of variability present at the proposal stage. In compliance with the completion schedule, this prototypical lighting system was attached and tested on a Case-International model 9380 four wheel drive tractor, but could easily be adapted to other four-wheel drive tractors. Fabrication and assembly was accomplished by the student and took place at a shop provided by Stahl Farms. Testing proceeded after assembly and is taking place throughout the spring planting season. If weather does not permit, testing will be done indoors at the same facility provided for fabrication and assembly.

5.2 Budget

The proposed and final budget is shown in Appendix B. The final budget was changed from the original proposed budget due to the change in solution to the problem. Initially, the proposal was for a retractable hazard lighting system that would retract under the frame when not in use. After reviewing the needs of the customer and using the Quality Function Deployment method to evaluate these needs, it was found that the scope of the project would have to change in order to satisfy these needs and create a valid solution to the problem. The proposed budget totaled $479.00. This was probably a low estimate due to the variability at the proposal stage. The final budget was even lower than expected and now totals $420.86.
6 Testing and Evaluation:

6.1 Testing and Product Evaluation

With the fabrication, assembly, mounting, and wiring of the hazard lighting and marking system completed, the prototype could now be tested to see if it solved the lack of recognition problem that motorists were having of agricultural machinery. As previously stated, the new standard was going to be used to determine increased recognition. This new standard devised consists of the acceptance of improved recognition of the prototype compared to standard equipment, by Law enforcement officials, the primary consumers (farmers) and local people from rural areas that would come in contact with agricultural machinery. They were given a roadway demonstration of the hazard lighting and marking system, and asked to evaluate it via a survey whose main focus was regarding increased recognition. The survey questions and results can be found in Appendix J. The survey was structured for the participants to answer five statements in one of four ways. Strongly agree, agree, disagree, and strongly disagree. The eighteen respondents participating in the study included representatives from the Ohio state highway patrol, Clermont county sheriffs department, farmers and rural motorists. According to the response of the conducted survey, the hazard lighting and marking system for agricultural machinery, overwhelmingly increased recognition of the machine when compared to standard equipment.
7 Conclusions:

The hazard lighting and marking system for agricultural machinery that is detailed in this report addresses the problem of motorists’ failure to recognize the extreme size of the machine and its potential hazard. The import benefit of the system is its full boundary definition of the machine. The system conveys the machines extreme size and its potential hazard to motorists. Similar systems have been very successful in conveying size. Motor transport vehicles utilize a similar concept to convey just how large tractor-trailers are. The new hazard lighting system carries over this concept to the agricultural industry. The improved recognition over standard hazard lighting is an important aspect not only in concerns of safety, but also in the marketing of the product. Its ease of installation, use, and maintenance are also key points that enhance the qualities of the hazard lighting and marking system.

The designer of the hazard lighting and marking system for agricultural machinery feels that this system would sell well in the agricultural marketplace due to its ability to provide improved recognition over the standard hazard lighting system. This improved recognition would convey to motorists that the agricultural equipment represents a potential hazard, and that this hazard can be avoided.
8 Product Enhancements:

As with the fabrication, and assembly of any design, changes can be made that would enhance the product. One of the key enhancements found during the fabrication of the HLMS was to change the mounting style of the lights from grommet mounted, which requires the machining of large diameter holes, to surface mounted lights, which only requires minimal drilling. The results of this change would be a reduction in machining time due to less material removal, a decrease in wiring since the light is grounded at the mount, and the elimination of light movement within the mount, that otherwise would lead to possible wire separation. It should also be noted that the breakaway hinge on the top light bar would need to be redesigned to create a better product. A different return mechanism other than the spring should be used. Rubber placed at the contact points would also be beneficial to absorb the impact loads associated with the return. Finally, to ensure a quality product, end caps could be placed in the ends of the rectangular tubing to keep any debris, or insects from entering and creating problems with the lights, or wire mounting.
9 References:

5. Privette III C.V., Rx for Ag Safety & Health. CU Safe (Clemson University), 2001. 3(Number 7).
10. Appendices
Appendix A
“Schedule”
<table>
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Completion Schedule

Revised 1/29/02

Figure 8.2 “Completion Schedule”
Appendix B
“Budget”
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<td>Stahl Farms</td>
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<td>Mounting Hardware</td>
<td>Stahl Farms</td>
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<td>Material Stock</td>
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<td>Lights and Hardware</td>
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<td>purchase</td>
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<td>Spring Hinges</td>
<td>McMaster Carr Supply Co.</td>
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Figure 9.1 “Proposal Budget”

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<td>Case IH tractor Model 9380</td>
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<td>Springs</td>
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<td>Paint</td>
<td>Shumard Hardware</td>
<td>3.99 * 5</td>
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<td>Eye bolts</td>
<td>Shumard Hardware</td>
<td>.59 * 4</td>
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<td>Yellow reflective tape 15ft</td>
<td>Wolfers</td>
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<td>Red/White tape 8.5ft</td>
<td>Wolfers</td>
<td>1.22/ft</td>
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<td>60 ft 10 gage wire</td>
<td>Stahl Farms (Donated)</td>
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<td>Quick connectors male</td>
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<td>Quick connectors female</td>
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<td>¼”-20 x 1-1/4” hex bolt.</td>
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<td>3/8”-16 x 3-1/2” hex bolt.</td>
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<td>3/8” lock washer.</td>
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<td><strong>TOTAL PRICE:</strong></td>
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<td><strong>$420.84</strong></td>
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Figure 9.2 “Final Budget”
Appendix C

“Customer Interview Data”
Customer Interview Data:

Casual Interviews were conducted with area farmers concerning the lighting of their equipment. Recently, new lighting laws went into affect in Ohio, concerning the lighting of agricultural machinery. Each felt that abiding by the new laws was sufficient. The sufficiency though was more in abiding by the law, than the safety of the equipment while it is in transport on the road. Even though several of the farmers had been involved in accidents, lighting sufficiency was not questioned, but whether accordance with the law was present. To the farmers, following the rules meant that they were following the safest measures. Otherwise, why would there be rules or laws to abide by? It was then explained that the present hazard lighting could be an insufficient method to convey the tractors extreme size and that it wasn’t the safest method. Correlations with other industries such as the motor transport vehicle industry were shown and the insufficiencies in the current hazard lighting became more apparent. The proposal for the hazard lighting system was explained to the farmers. They were then asked what they felt was important and if an alternative were available on the market, what would prompt them to consider purchasing it. Several aspects were recurrent among the owners and operators of the equipment. They were:

- If laws were changed and they had to purchase it.
- It wouldn’t take long, and wouldn’t take someone with outstanding capabilities to install it.
- Had to be inexpensive or within reason as far as materials involved.
- It would have to be better than what they already had.
- They should be able to get parts for it easily.
- Once installed, it should last a long time.
- Once installed, they wouldn’t have to do anything extra to make it work.
- It wouldn’t get in the way.

These aspects were used in forming the customers’ needs in use of the Quality Function Deployment method to find a viable solution to the problem.
Appendix D

“QFD Matrix”
**QFD Matrix**

**warn motorists**

<table>
<thead>
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<td>Full Boundary Definition</td>
<td>Reflective Material</td>
<td>Bright Lights</td>
<td>Number of Lights</td>
<td>Comparable to Factory Equipment</td>
<td>Standard Controls</td>
<td>Standard Parts</td>
<td>Importance to Customer</td>
<td>Planned Hazard Lighting System</td>
<td>Improvement Ratio</td>
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<td>1. Improved Recognition</td>
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Figure 10 “QFD Matrix”
Appendix E

“Alternative Design Concepts”
Figure 11.1 “Under Frame Concept” Figure 11.2 “Straight Bar Concept”

Figure 11.3 “Vertical Fold Up Concept” Figure 11.4 “Horizontal Fold Up Concept”
Appendix F

“Analysis of Hazard Lighting and Marking System”
The size of the components of the hazard lighting and marking system were chosen to accommodate the lights and markings that they would be housing. The modified endurance strength of the material was then calculated. The components were then analyzed using the Finite Element Analysis method and free body diagram analysis. This was accomplished with the solving capabilities of I-DEAS software, the same design software used to model the components. The stress that these components encountered was then compared to the modified endurance strength. The modified endurance strength was used for fatigue of the components. A design factor of 4 was used in the design of any components for “ductile materials with uncertainty about some combination of material properties, loads, or stress analysis, particularly under shock or impact loading.” [10]
Front Bar Analysis:

Weight/ft = 10.5 lb/ft
(156/12)\times 10.5 = 136.5 lb
Bracket = (500+136.5)/2 = 318.25
60.5\times [250 + (52.9825/2)] = 16726.36
(15.3125/2)\times 17.5 = 133.98

\sigma = \frac{MC}{I} \quad C=2

I + (3)\times 4^3/12 - (2.5)\times (3.5)^3/12 = 7.068
\sigma = \frac{16726.36(2)}{7.068} = 4733 \text{ psi}
This is the maximum stress that occurs in the member.

The modified endurance strength is:
A500-B tubing:

\begin{align*}
S_y &= 46000 \text{ psi} \\
S_{sy} &= 0.5S_y = 0.5(46000) = 23000 \text{ psi} \\
S_n &= 19000 \text{ psi} \\
S'_{sn} &= S_n(C_m)(C_n)(C_{st})(C_R) = S_n(1)(1)(1)(0.75) = 14250 \text{ psi} \\
S''_{sn} &= 0.5S'_{sn} = 0.5(14550) = 7125 \text{ psi}
\end{align*}

The stress in the member is well below the modified endurance strength for that material. This is good due to the unknown loading that may occur on the light bar due to its location.
Weld Design – modified endurance strength:

E60 Arc Welding Electrode
Tensile Stress = 69000 psi
Yield Stress = 62364 psi

Fatigue Loading of Welds:

\[ S_y = \text{Yield Strength} \]
\[ S_{sy} = \text{Yield Strength in Shear} \]
\[ S_n = \text{Endurance Strength} \]
\[ S_{sn} = \text{Endurance Strength of the material under actual conditions} \]
\[ S'_{sn} = \text{Endurance Strength in Shear under actual conditions}. \]

\[ C_s = \text{size factor} \]
\[ C_m = \text{material factor} \]
\[ C_{st} = \text{stress factor} \]
\[ C_R = \text{reliability factor} \]
\[ F_m = \text{force max} \]
\[ F_A = \text{force average} \]
\[ A = \text{area of the weld} \]
\[ N = \text{design factor (4)} \]

* all design factors obtained from *Machine Elements in Mechanical Design* [10]

\[ S_{sy} = 0.5S_y = 0.5(62000) = 31000 \text{psi} \]
\[ S_{sn}' = S_n(C_s)(C_m)(C_{st})(C_R) = 17000(1)(1)(1)(0.75) = 12750 \text{psi} \]
\[ S'_{sn} = 0.5S_{sn}' = 0.5(12750) = 6375 \text{ psi} \]

\[ A = N[(F_m/S_{sn})+(F_A/S'_{sn})] \text{ for fluctuating shear stresses} \]
\[ F_m = (F_{\text{MAX}} + F_{\text{MIN}}) = 296 + 46 = 342 \text{ (296 is the force exerted if someone stood on the bar.} \]
\[ \text{46 is the weight of the half the bar since there are two brackets)} \]
\[ F_A = (F_{\text{MAX}} - F_{\text{MIN}}) = 296 - 46 = 250 \]
\[ A = [(342/31000) + (250/6375)] = .200\text{in}^2 \]
Minimum weld size for electrode = .188in leg

\[ .200\text{in}^2/.188\text{in}_{\text{leg}} = 1.06 \text{ in leg. 1.0 should be sufficient} \]

Bolt Design – for fatigue loading:

A1020 cold drawn:
\[ S_y = 51000 \text{psi} \]
\[ S_{sy} = 0.5S_y = 0.5(51000) = 25500 \text{psi} \]
\[ S_n = 20000 \text{psi} \]
\[ S_{sn}' = S_n(C_s)(C_m)(C_{st})(C_R) = S_n(0.97)(1)(1)(0.75) = 14550 \text{psi} \]
\[ S'_{sn} = 0.5S_{sn}' = 0.5(14550) = 7275 \text{psi} \]
\[ A = 4[(342/25500) + (250/7275)] = .191\text{in}^2 \]

Required D:
\[ D = \sqrt{(4A/\pi)} = \sqrt{(4(.191)/\pi)} = .493 \text{in diameter. Use .5in diameter bolt.} \]
Analysis of Top Light Bar:

Free Body Diagram for Top Light Bar at Hinge

Finding the resultant force at C:

\[-5(17.25) + F_c(1.75) = 0 \]
\[-86.25 \text{ in lbs} + 1.75(F_c) = 0 \]
\[1.75F_c = 86.25 \text{ in lbs} \]
\[F_c = 49 \text{ lbs} \]

\[\Sigma \text{bolt} = F/A = 49 \text{ lbs} / .05\text{in}^2 = 980 \text{ psi} \text{ (for .25” diameter bolt)} \]
Applying the Soderberg Criterion for Fluctuating Stresses:

Grade 5 bolt = 92000 \( \sigma_y \)
Therefore \( S_n = 25000 \) psi
\[ S'_a = S_n(C_s)(C_m)(C_t)(C_r) = 25000(1)(.8)(.8)(.75) = 12000 \]
N=4 (Design Factor)

When applying the Soderberg Criterion, the design factor is not only applied to the material for the graph above, but also applied to the loading that occurs.

980psi x 4 = 3920psi for a .25” bolt. Utilizing the graph above, the 3640psi stress that is placed on the bolt is in between the safe zone and the failure zone. It falls out side of the design stress line. Therefore, a larger bolt will have to be used.

\[ \sigma_{bolt} = \frac{F}{A} = 49 \text{ lbs/}.11\text{in}^2 = 445 \text{ psi} \text{ (for .375” diameter bolt)} \]
445psi x 4 = 1780psi

This value falls below the design stress line into the safe zone. The bolt sized used will be 3/8 (.375”).
Analysis of other components:

The front turn indicator was loaded as shown. The actual weight of the lights is unknown. For analyzation purposes, the lights were given a weight of .5 lbs. The .5 lbs was distributed evenly around the hole that holds the light. This was done for each consecutive hole. So the total loading on the member is 1 lb. This will be carried through the analyzing of the other components. The stress that the member sees due to the loading will then be compared to the modified endurance strength of the material to see if failure will occur as a result of fatigue loading.
The maximum stress that the member encounters is 183psi. This stress occurs at the bolt holes. The modified endurance strength of the material is:

ANSI 1020 Sheet metal:

\[ S_y = 51000 \text{psi} \]
\[ S_{sy} = 0.5S_y = 0.5(51000) = 25500 \text{psi} \]
\[ S_n = 20000 \text{psi} \]
\[ S'_n = S_n(C_m)(C_a)(C_R) = S_n(0.97)(1)(1)(0.75) = 14550 \text{psi} \]
\[ S'_n = 0.5S'_n = 0.5(14550) = 7275 \text{psi} \]

The stress in the member of 183psi is well below the modified endurance strength of 7275psi. This member should not fail under cyclic loading for an infinite number of cycles.
The side turn indicator was loaded as shown. Again, for analyzation purposes, the lights were given a weight of .5 lbs. The .5 lbs was distributed evenly around the hole that holds the light. This was done for each consecutive hole. So the total loading on the member is 3 lb. The stress that the member sees due to the loading will then be compared to the modified endurance strength of the material to see if failure will occur as a result of fatigue loading.
The maximum stress that the member encounters is 100psi. This stress occurs at the bolt holes. The modified endurance strength of the material is:

**ANSI 1020 Sheet metal:**

\[ S_y = 51000 \text{psi} \]
\[ S_{sy} = 0.5S_y = 0.5(51000) = 25500 \text{psi} \]
\[ S_n = 20000 \text{psi} \]
\[ S'_n = S_n(C_s)(C_m)(C_{st})(C_R) = S_n(0.97)(1)(1)(0.75) = 14550 \text{psi} \]
\[ S'_{sn} = 0.5S'_n = 0.5(14550) = 7275 \text{psi} \]

The stress in the member of 100psi is well below the modified endurance strength of 7275psi. This member should not fail under cyclic loading for an infinite number of cycles.
Wiring of the LED Lights:

Considerations had to be taken to ensure that the lighting would not exceed the circuit breakers of the hazard lighting that is on the 9380 model Case-International tractor. The tractor operates on a 12 volt system. The lights chosen for the project also operate on this voltage. A review of the electrical system showed that there are actually two circuit breakers that are used for the hazard lighting. They are a 20 amp and 30 amp set of circuit breakers. Light data from the manufacturer showed that the LED lights used for the project draw only .33 amps each. The total number of lights that will be used is 32. The total amps that they will draw is:

\[32 \times 0.33 = 10.56 \text{amps}\]

This is well below the amperage rating for the first circuit breaker. This primary breaker will be used. If problems arise, the second breaker will be used in conjunction with the first breaker. A sample wiring schematic of the hazard lighting and marking system is shown below:
Reflective Tape Placement:

In order to increase the visibility of the equipment, additional marking tape was placed on the components of the hazard lighting and marking system. To satisfy the standards for actual color and placement, yellow marking tape was placed in the front on the front light bar and top light bar, and on the rear, the alternating red/white marking tape was placed on the top light bar. The placement of the tape is shown below.
Appendix G
“Detailed Drawings”
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<td>1</td>
<td>2</td>
<td>FRONT TURN INDICATOR</td>
<td>ANSI 1020 16 GUAGE SHEET METAL</td>
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<td>2</td>
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<td>SIDE TURN INDICATOR</td>
<td>ANSI 1020 16 GUAGE SHEET METAL</td>
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<td>3</td>
<td>1</td>
<td>FRONT LIGHT BAR</td>
<td>A500-B RECTANGULAR TUBING</td>
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<td>4</td>
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<td>TOP LIGHT BAR</td>
<td>A500-B RECTANGULAR TUBING</td>
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<td>5</td>
<td>2</td>
<td>BRACKET</td>
<td>A-36 CARBON STEEL ANGLE IRON</td>
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<td>6</td>
<td>6</td>
<td>2.5&quot; ROUND SEALED LED LIGHT</td>
<td>TLED-2H 6C 13 DIODES 2 PRONG PIGTAIL</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>1&quot; X 4&quot; RECTANGULAR LED</td>
<td>TLED-1X4 6I 12 DIODES</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>RUBBER GROMMET</td>
<td>TGR0-2HRQ 2.5&quot; OPEN BACK RUBBER GROMMET</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>1&quot; X 4&quot; MOUNTING BASE</td>
<td>TBAS 1X4 GRAY MOUNTING BRACKET</td>
</tr>
<tr>
<td>10</td>
<td>24</td>
<td>2&quot; ROUND SEALED LED LIGHT</td>
<td>TLED-2 6C 9 DIODES 2 PRONG PIGTAIL</td>
</tr>
<tr>
<td>11</td>
<td>24</td>
<td>RUBBER GROMMET</td>
<td>TGR0-2HRQ 2&quot; OPEN BACK RUBBER GROMMET</td>
</tr>
<tr>
<td>12</td>
<td>2</td>
<td>1/2&quot;-13 X 2-1/2&quot; HEX BOLT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>13</td>
<td>16</td>
<td>1/4&quot;-20 X 1-1/4&quot; HEX BOLT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>3/8&quot;-16 X 3-1/2&quot; HEX BOLT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>1/2&quot;-13 RH HEX NUT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>1/4&quot;-20 RH HEX NUT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>1/2&quot; X .869&quot; X 1/8&quot; LOCK WASHER</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>18</td>
<td>16</td>
<td>1/4&quot; X .260&quot; X 1/16&quot; LOCK WASHER</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>19</td>
<td>6</td>
<td>3/8&quot; X 16 RH HEX NUT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
<td>3/8&quot; X .385 X 1/16 LOCK WASHER</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>21</td>
<td>4</td>
<td>3/8&quot; X 2&quot; EYE BOLT</td>
<td>SAE-GRADE 5</td>
</tr>
<tr>
<td>22</td>
<td>6</td>
<td>3/8&quot; X 1/16 FLAT WASHER</td>
<td>SAE-GRADE 5</td>
</tr>
</tbody>
</table>

2-ISOMETRIC

DRAWN BY: JONATHAN HAYNES
DATE: 2-20-02
DWG NO.: LS-9
TITLE: LIGHT SYSTEM ASSEMBLY
QUANTITY REQD: 1
Appendix H
“Vendor Data Sheets”
<table>
<thead>
<tr>
<th>Description</th>
<th>Price</th>
<th>Replacement</th>
<th>Qty</th>
<th>Add</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2 1/2” Round Sealed LED Light</strong>&lt;br&gt;13 DIODES&lt;br&gt;Fits standard 2 prong pigtail&lt;br&gt;10 Year Warranty</td>
<td>$6.49</td>
<td>Truck-Lite 10250R/10250Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2” Round Sealed LED Light</strong>&lt;br&gt;9 DIODES&lt;br&gt;Fits standard 2 prong pigtail&lt;br&gt;10 Year Warranty</td>
<td>$6.49</td>
<td>Truck-Lite 10250R/10251Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1”x4” Rectangular LED Light</strong>&lt;br&gt;12 DIODES&lt;br&gt;Fits standard 1”x4” base&lt;br&gt;10 Year Warranty</td>
<td>$6.49</td>
<td>Truck-Lite 35200R/35200Y</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MOUNTING BASES</strong>&lt;br&gt;1704 Style Mounting Bracket includes 1 lead wire</td>
<td>$1.55</td>
<td>Truck-Lite 19721</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2” Open Back Rubber Grommet</strong></td>
<td>$0.65</td>
<td>Truck-Lite 30700</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2 1/2” Open Back Rubber Grommet</strong></td>
<td>$0.65</td>
<td>Truck-Lite 10700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix I

“Final Product”
Appendix J

“Product Evaluation Results”
**Product Evaluation:**

To prove that the prototypical hazard lighting and marking system solved the recognition problem that motorists have of agricultural machinery while in transport, a standard was devised for product evaluation. This standard consists of the approval of recognition over standard equipment by Law enforcement officials, the primary consumers (farmers), and local motorists that would come in contact with this type of machinery. Not only does the prototype have to increase recognition, but must also use standard operator input, and the flashing hazard signals must conform to ASAE standard S279.10 4.1.4 and 5.1.5 for flash rate and turn indication (see Appendix K). To show that the product increases recognition, the groups of people asked to evaluate the prototype were given a demonstration and then asked to fill out a survey whose main focus was regarding increased recognition. The demonstration consisted of a road test where the group was first shown the standard equipment from head on, from the side, and from the rear of the tractor. Immediately following, they were presented with a tractor that was equipped with the hazard lighting and marking system. After the demonstration, each group had the opportunity to view the components up close and ask any questions regarding the prototype. They were then asked to fill out the survey to evaluate what they saw. The survey is shown on the following page.
Hazard Lighting Survey

Please answer the following questions to the best of your ability.

1. Does perception of size indicate a greater hazard?
   □ Strongly agree □ Agree □ Disagree □ Strongly disagree

2. The Hazard Lighting and Marking System increases recognition of tractor size compared to standard hazard lighting.
   □ Strongly agree □ Agree □ Disagree □ Strongly disagree

3. The Hazard Lighting and Marking System clearly indicates the extreme height and width of the machine.
   □ Strongly agree □ Agree □ Disagree □ Strongly disagree

4. When approaching a tractor on a roadway at night, the Hazard Lighting and Marking System indicates the true size of the machine.
   □ Strongly agree □ Agree □ Disagree □ Strongly disagree

5. Knowing that flashing amber lights represent a potential hazard, the Hazard Lighting and Marking System conveys a greater hazard potential over standard hazard lighting.
   □ Strongly agree □ Agree □ Disagree □ Strongly disagree

Overall Impression of the Hazard Lighting and Marking System:

Final questions:

Gender: □ Male □ Female  Age: ___________

Occupation: _____________________________________________

What area best describes your residence?
   □ Urban □ Suburban □ Rural
The results of the survey were as follows:

### Survey Question Results

There were a few respondents that answered either disagree, or strongly disagree. A breakdown of each statement will give reasoning why any respondents would answer this way.

**Statement 1:** Does perception of size indicate a greater hazard?
Of the respondents, 39% strongly agrees, 38% agreed, and 23% disagreed. Those respondents that disagreed were then asked to expand on that answer. Their consensus was that if they knew how large that something was, or if something was bigger, it did not necessarily represent a hazard, because that hazard could be avoided altogether.

Statement 2: The Hazard Lighting and Marking System increases recognition of tractor size compared to standard hazard lighting.

All of the respondents either strongly agreed or agreed.

Statement 3: The Hazard Lighting and Marking System clearly indicates the extreme height and width of the machine.

All of the respondents either strongly agreed or agreed.
Statement 4: When approaching a tractor on a roadway at night, the Hazard Lighting and Marking System indicates the true size of the machine.

All of the respondents either strongly agreed or agreed.

Statement 5: Knowing that flashing amber lights represent a potential hazard, the Hazard Lighting and Marking System conveys a greater hazard potential over standard hazard lighting.

In response to this statement, 43% of the respondents strongly agreed, 30% agreed, 19% disagreed, and 8% strongly disagreed. Those that disagreed were asked to expound on their reasoning. Their consensus again was that if they knew the size of the approaching vehicle, regardless of size, they did not feel it was a greater hazard, but one that can be avoided. The majority of the respondents that answered this way were actual equipment owners and operators, and were the most familiar with this type of machinery.
After reviewing and evaluating the surveys, it was found that the hazard lighting and marking system for agricultural machinery increased recognition of the machines when compared to standard equipment. The respondents were also asked to give their overall impression of the hazard lighting and marking system. Their reactions were:

- Very impressed. Did a good job of increasing depth perception for on-coming traffic. Enables the on-coming driver to better determine closing speed of the tractor.
- The Hazard lighting system made a great increase in recognition, depth, and rate of speed for closure.
- In my opinion, the marking system greatly improves the visibility of the tractor. As soon as headlights hit the reflective marking it becomes apparent what is approaching or what you are approaching. The additional lighting helps also. The reflective marking amazes me as to how much more visible it becomes.
- Quick to recognize. Quick to determine something large is on the move.
- When comparing the standard lighting system with the enhanced, the enhanced clearly shows dimension and depth and causes one to take notice and use more caution.
- Very well designed and implemented. Real world use and benefit a huge plus.
- Impressed.
- The hazard lighting system certainly greatly improves the recognition of the large machines and maximizes its safe operation.
- I think your lighting setup is safer for night travel.

Firm basis has been given to show that the hazard lighting and marking system increases recognition over standard equipment. The system must also conform to ASAE standards for flash rate and turn indication, and must not increase operator input. To meet these additional design objectives, the system was wired into the existing hazard lighting system. When the operator activates the hazard lights for road travel, the hazard lighting and marking system is also activated. The turn indication and rate are the same as the original equipment. This prototype was successful in meeting all of the design objectives set forth.
Appendix K
“Standards”
Lighting and Marking of Agricultural Equipment on Highways

1 Purpose
This Standard provides specifications for lighting and marking of agricultural equipment whenever such equipment is operating or is traveling on a highway.

2 Normative references
The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Standards organizations maintain registers of currently valid standards.

ANSI/ASAE S276.5 NOV57, Slow-Moving Vehicle Identification Emblem
ASAE S330.1 DEC97, Classifications and Definitions of Agricultural Equipment
SAE J560, Seven-Conductor Electrical Connector for Truck-Trailer Jumpers Cables
SAE J575, Test Methods and Equipment for Lighting Devices and Components for Use on Vehicles Less Than 2722 mm in Overall Width
SAE J585, Tail Lamps (Rear Position Lamps) for Use on Motor Vehicles Less Than 2722 mm in Overall Width
SAE J588, Turn Signal Lamps for Use on Motor Vehicles Less Than 2722 mm in Overall Width
SAE J484, Reflectorized Reflectors
SAE J755, Flashing Warning Lamps for Agricultural Equipment
SAE J594, Tail Lamps (Rear Position Lamps) for Use on Vehicles 2722 mm or More in Overall Width
SAE J2361, Stop Lamps and Rear- and Rear-Turn Signal Lamps for Use on Motor Vehicles 2722 mm or More in Overall Width
ASTM D-1014-95, Practice for Conducting Exterior Exposure Tests of Paints on Steel
ASTM D-4566-96, Specification for Retroreflective Sheeting for Traffic Control
ASTM E-501-95, Practice for Color Measurement of Fluorescent Specimen
ASTM E-308-96, Practice for Comparing the Colors of Objects by Using the CIE System
FMVSS 108, Vehicle Lighting and Marking Standard

3 Definitions and material specifications
3.1 Agricultural equipment. Refer to ASAE S300 for definitions of agricultural equipment.
3.2 Highway. A highway is defined as the entire width between the boundary lines of every publicly maintained, any part thereof open to the use of the public for purposes of vehicular travel (Uniform Vehicle Code).
3.3 Reflector. A reflector is defined as a reflector reflector meeting FMVSS 108 Dot C or retroreflective material as defined in 3.5. Reflector size shall be 50 mm (2 in) wide by 115 mm (4.5 in) long for machines 2 m (6.7 ft) or less in width, and 50 mm (2 in) wide by 230 mm (9 in) long for machines wider than 2 m (6.7 ft).
3.4 Lamp location. Dimensions in this Standard, unless specified otherwise, are based on measurements to the nearest edge of the lens. (Reflectorcovered.

3.5 Retroreflective material
3.5.1 Visibility. The material shall be visible at night from all distances between 153 and 30 m (500 and 100 ft) when directly in front of a lawful vehicle low beam headlamp.
3.5.2 Construction. Retroreflective sheathing shall consist of a smooth, flat, transparent exterior film with retroreflective elements embedded or suspended beneath the film so as to form a non-exposed retroreflective optical system.
3.5.3 Performance requirements. Retroreflective sheathing shall meet requirements of ASTM D-4566 for type V sheathing, except that the photometric requirements shall meet the minimum photometric performance requirements specified in table 1. The sheathing shall meet the color specification limits in table 2.
3.5.4 Exterior durability. Samples mounted on backing material specified in this Standard shall be exposed to the sun for a minimum test period of 24 months outside in south Florida at an angle of 45° to horizontal facing upward and south, per ASTM D-1014. After exterior durability testing, the material shall show no cracking, crazing, blistering, loss of adhesion, or dimensional change, and shall meet the requirements in tables 1 and 2 when measured at 5.5 observation angle, and 4° entrance angle in accordance with ASTM D-4566 section 8.3.
3.5.5 Corrosion resistance. Material shall be tested per SAE J557 and show no corrosion or edge fading and shall meet requirements in table 1 measured at 0.5° observation angle, and 4° entrance angle in accordance with ASTM D-4566 section 8.3.

<table>
<thead>
<tr>
<th>Observation angle, °</th>
<th>Entrance angle, °</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Yellow</td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>4</td>
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<td>5.2</td>
<td>20</td>
<td>60</td>
</tr>
<tr>
<td>5.2</td>
<td>45</td>
<td>15</td>
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<tr>
<td>5.2</td>
<td>4</td>
<td>15</td>
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<td>5.5</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>5.5</td>
<td>46</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 13.1 Standard S279.10 [11]
Table 2 - Color specification limits (daytime)

<table>
<thead>
<tr>
<th>Color</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0.013</td>
<td>0.027</td>
<td>0.088</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.046</td>
<td>0.112</td>
<td>0.227</td>
</tr>
</tbody>
</table>

Table 3 - Fluorescent values

<table>
<thead>
<tr>
<th>Color</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0.013</td>
<td>0.027</td>
<td>0.088</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.046</td>
<td>0.112</td>
<td>0.227</td>
</tr>
</tbody>
</table>

3.6.8 Adhesion. Backing materials shall meet adhesive systems as specified in ASTM D-4698.

3.6 Fluorescent materials

3.6.1 Visibility. The materials shall be visible in the daytime as a red-orange fluorescent strip from all distances between 133 and 39 m (435 and 128 ft).

3.6.2 Dimensional requirements. The fluorescent material shall be 50 mm (2 in.) wide by 230 mm (9 in.) long.

3.6.3 Performance requirements. The red-orange color purity, luminance, and peak reflectance of the fluorescent material shall be within the values shown in Table 3 below and after the durability test.

3.6.4 Exterior durability. Samples shall be exposed to the sun for a minimum test period of 24 months outside in south Florida at an angle of 45° to horizontal facing seaward and south, per ASTM D-1014. After the durability test, the material shall show no cracking, crazing, blistering, loss of adhesion, or dimensional change, and shall meet the requirements set forth in this Standard.

3.6.5 Color measurement. The spectrophotometric color values of the fluorescent material shall be determined by using a colorimeter spectrophotometer conforming to the requirements of ASTM E-969. Luminance shall be compared to that of a NIST (National Institute of Standards and Technology) defined perfect reflecting diffuse (PDD) for CIE (Color Institute) illuminant D65. Because the fluorescent identification material can be expected to be viewed with an angular subtend at < 4° at the eye, it is recommended that the CIE X, Y, Z values be calculated using the CIE E651 (2°) standard observer and CIE illuminant D65. The CIE chromaticity coordinates, x and y, shall be calculated as given below and defined in section 7.3 of ASTM E-308.

\[ x = \frac{X}{X + Y + Z}, \quad \frac{Y}{Y + Z}, \quad \frac{Z}{Z + Y + Z} \]

For example, given CIE x = 0.37, y = 0.66, and z = 0.2116 for a 2° observer conditions, luminance factor \( \lambda = 0.087 \) and chromaticity values \( x = 0.33 \) and 0.3271. The dominant wavelength and purity shall be determined using x and y from CIE diagrams. The values of \( y \) shall be the luminance factor recorded as percent (luminance, %). From the spectral reflectance data, the maximum reflectance shall be no lower than the values shown in Table 3.

3.6.6 Adhesion. Backing materials shall be applied with a pressure sensitive adhesive having a minimum adhesive value of 1147 g (50 oz) per 25 mm (1 in) width. Adhesive test shall be performed as specified in PSFC-1.

3.7 Width. The width is defined as the widest measurement of the equipment in the highway transport configuration.

4 Lighting and marking requirements

4.1 Lighting and marking of tractors and self-propelled machines shall be as follows:

ASAE STANDARDS 1996

Figure 13.2 Standard S279.10 [11]
4.1.7 On machines over 3.7 m (12 ft) wide, conspicuity material shall be provided which is visible from the front and rear of the unit.

4.1.7.1 The conspicuity material visible to the rear shall be red retroreflective material as defined in 3.3 and nonreflective red-orange fluorescent material as defined in 3.6. The retroreflective and fluorescent material shall be as horizontal as practicable and in line as practicable. The horizontal distance between any retroreflective material shall not exceed 1.8 m (6 ft). The horizontal distance between any fluorescent material shall not exceed 1.8 m (6 ft). The retroreflective and fluorescent material on the slow-moving vehicle identification emblem, SMV, may be included to meet these requirements. The outer edge of the retroreflective material shall be within 400 mm (16 in.) of the left and right extremities of the machine and as evenly spaced as practicable. The outer edge of the fluorescent material shall be within 635 mm (25 in.) of the left and right extremities of the machine and as evenly spaced as practicable.

4.1.7.2 The conspicuity material visible to the front shall be at least two yellow reflectors as defined in 3.3. The reflectors shall be within 400 mm (16 in.) of the left and right extremities of the machine.

4.1.8 One SMV (slow-moving vehicle) identification emblem as described in ANSI/ASAE S279.8.

4.1.9 One seven-terminal receptacle conforming to SAE J560 mounted on the machine and located as shown in Figure 2. Tractors and self-propelled machines not primarily used with agricultural implements described in 4.3.1 and 4.3.2 are excluded. (Examples are small garden and compact utility tractors, self-propelled windrowers, and high clearance sprayers.)

4.1.9.1 As a minimum, the receptacle terminal numbers 1, 3, 5, and 8 (ground, flashing and turn signals, and tail lamps), shall be wired for service.

4.1.9.2 The circuit designations for the breakaway connector defined in 4.1.9 are:

---

### Tractor receptacle

<table>
<thead>
<tr>
<th>Conductor identification</th>
<th>Wire color</th>
<th>Terminal number</th>
<th>Circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whi</td>
<td>White</td>
<td>1</td>
<td>Ground</td>
</tr>
<tr>
<td>Blk</td>
<td>Black</td>
<td>2</td>
<td>Worklights</td>
</tr>
<tr>
<td>Yel</td>
<td>Yellow</td>
<td>3</td>
<td>Left-hand flashing and turn indicators</td>
</tr>
<tr>
<td>Red</td>
<td>Red</td>
<td>4</td>
<td>Auxiliary</td>
</tr>
<tr>
<td>Grn</td>
<td>Green</td>
<td>5</td>
<td>Right-hand flashing and turn indicators</td>
</tr>
<tr>
<td>Brn</td>
<td>Brown</td>
<td>6</td>
<td>Tail lamps</td>
</tr>
<tr>
<td>Blu</td>
<td>Blue</td>
<td>7</td>
<td>Auxiliary</td>
</tr>
</tbody>
</table>

See clause A.4 on implement bus breakaway connector.

4.2 Marking of non-self-propelled equipment

4.2.1 Marking of equipment that obscures SMV emblem. Equipment that obscures the SMV emblem on the propelling machine shall be equipped with one SMV emblem as described in ANSI/ASAE S279.

4.2.2 Marking for equipment width

4.2.2.1 Equipment extending more than 1.2 m (4 ft) to the left of the center of the propelling machine shall have at least one amber or yellow reflector visible to the front and positioned to indicate, as nearly as practicable, the extreme left projection of the equipment.

4.2.2.2 Equipment extending more than 1.2 m (4 ft) to the right or left of the centerline of the propelling machine shall have at least two red reflectors visible to the rear and mounted to indicate, as nearly as practicable, the extreme left and extreme right projections.

---

Figure 13.3 Standard S279.10 [11]
Figure 13.4 Standard S279.10 [11]

4.2.2.3 Equipment more than 3.7 m (12 ft) wide or extending more than 1.8 m (6 ft) to the right or left of the center and mounted and/or lowered to the rear of the propelling machine shall have conspicuity material per 4.2.2.1 and 4.2.2.3.2 as applicable.

4.2.2.3.1 Equipment to the rear of the propelling machine shall have visible to the rear rod retroreflective material as defined in 3.3 and non-reflective red-orange fluorescent material as defined in 3.6. The reflective and fluorescent material shall be as horizontal as practicable and in line as practicable. The horizontal distance between any reflective material shall not exceed 1.8 m (6 ft). The horizontal distance between any fluorescent material shall not exceed 1.8 m (6 ft). The retroreflective and fluorescent material on the SAEI may be required to meet these requirements. The outer edge of the retroreflective material shall be within 400 mm (16 in.) of the left and right extremities of the equipment and as evenly spaced as practicable. The outer edge of the fluorescent material shall be within 435 mm (17 in.) of the left and right extremities of the machine and as evenly spaced as practicable.

4.2.2.3.2 The conspicuous material-visible to the front shall be at least two yellow reflectors as defined in 3.3. The outer edge of the reflector shall be within 400 mm (16 in.) of the left and right extremities of the equipment.

4.2.2.4 Equipment more than 3.7 m (12 ft) wide or extending more than 1.8 m (6 ft) to the right or left of center and mounted to the front of the propelling machine shall have conspicuity material per 4.2.2.4.1 and 4.2.2.4.2.

4.2.2.4.1 Equipment to the front of the propelling vehicle shall have visible to the front at least two yellow reflectors as defined in 3.3. They shall be within 400 mm (16 in.) of the left and right extremities of the equipment.

4.2.2.4.2 The rear of the equipment shall have visible to the rear red retroreflective material as defined in 3.3 and non-reflective red-orange fluorescent material as defined in 3.6. The retroreflective and fluorescent material shall be as horizontal as practicable and in line as practicable. The horizontal distance between any retroreflective materials shall not exceed 1.8 m (6 ft). The horizontal distance between any fluorescent materials shall not exceed 1.8 m (6 ft). The outer edge of the retroreflective material shall be within 400 mm (16 in.) of the left and right extremities of the machine and as evenly spaced as practicable. The outer edge of the fluorescent material shall be within 435 mm (17 in.) of the left and right extremities of the machine and as evenly spaced as practicable. No conspicuity material is necessary on the rear of the equipment for a horizontal distance of 1.2 m (4 ft) on either side of the propelling machine centerline.

4.2.3 Marking for equipment length

4.2.3.1 Equipment extending more than 1.2 m (4 ft) to the rear of the high point of the propelling machine shall have at least two red reflectors visible to the rear and mounted to machine, as neatly as practicable, the extreme left and extreme right projectors.

4.2.3.2 Equipment extending more than 5 m (16.4 ft) to the rear of the high point shall be equipped with one SAEI marker per ANSI/SAE S276 and shall have amber or yellow reflectors visible from the left and right sides. The reflectors shall be spaced at intervals of 5 m (16.4 ft) maximum on both sides measuring from the rear top pitch point. The rear most reflector shall be positioned as far rearward as practicable.

4.3 Lighting of non-self-propelled equipment

4.3.1 Marking of equipment that obscures vehicle illumination

4.3.1.1 Equipment that obscures the effective illumination of any flashing warning lamp, tail lamp, or emergency lamp on the propelling machine shall have lighting as described in 4.3.1.1.4, 4.3.1.1.2, and 4.3.1.1.3. Only those lamps obscured need to be provided.

4.3.1.1.1 If the tail lamps on the propelling machine are obscured, at least two red tail lamps conforming to SAE J504 mounted on the rearmost of the machine and positioned between 0.8 and 1.5 m (2.6 and 4.9 ft) from the left and right side of the machine center and between 0.3 and 0.9 m (1.0 and 3.0 ft) high. On machines less than 3 m (9.7 ft) in overall width, tail lamps conforming to SAE J505 may be used and positioned as widely spaced as practicable and between 0.3 m (1.0 ft) and 0.9 m (3.0 ft) high.
4.3.1.2 If the rear flashing warning lamps are obscured, at least two amber flashing warning lamps conforming to SAE J374 visible from the rear shall be provided. If the front flashing warning lamps are obscured, at least two amber flashing warning lamps conforming to SAE J374 visible from the front shall be provided. The lamps shall be symmetrically mounted and as widely spaced laterally as practicable, preferably mounted between 1 and 3 m (3.3 and 10 ft) in height, but may be mounted between 0.6 m (2 ft) and 3.7 m (12 ft) if required by machine design, and shall flash in unison with warning lamps described in 4.1.4. On non-symmetrical equipment extending only to the left or right, such as moldboard plows or windrowers, one flashing warning lamp shall be provided spaced laterally to within 400 mm (16 in.) of the angle desired.

4.3.1.3 If the rear turn indicators on the propelling machine are obscured, rear turn indicators shall be provided on the equipment consistent with 4.3.5. If the front turn indicators on the propelling machine are obscured, front turn indicators shall be provided.

4.3.2 Lighting for equipment width

4.3.2.1 Equipment that is more than 3.7 m (12 ft) wide or extends more than 1.8 m (6 ft) to the left or right of the centerline and beyond the left or right extremity of the propelling machine shall have lighting as described in 4.3.2.1.1, 4.3.2.1.2 and 4.3.2.1.3.

4.3.2.1.1 At least two amber flashing warning lamps conforming to SAE J374 visible from front and rear shall be provided. The lamps shall be spaced to within 400 mm (16 in.) of the lateral extremities of the machine, preferably mounted between 1 and 3 m (3.3 and 10 ft) in height, but may be mounted between 0.6 m (2 ft) and 3.7 m (12 ft) if required by machine design, and shall flash in unison with warning lamps described in 4.1.4. On non-symmetrical equipment extending only to the left or right, such as moldboard plows or windrowers, one flashing warning lamp shall be provided spaced laterally to within 400 mm (16 in.) of the angle desired.

4.3.2.1.2 Two red tail lamps conforming to SAE J2548 symmetrically mounted to the rear of the machine and positioned between 0.6 m (2 ft) and 1.5 m (5 ft) to the left and right of the machine center. On equipment that is less than 1.2 m (4 ft) wide at the rear most part of the equipment, only one red tail lamp is required (e.g., grain cart). The rear tail lamps shall be mounted as close to the rear as practicable and between 1 m (3.3 ft), and 3 m (10 ft) high.

4.3.2.1.3 Turn indicators shall be provided on the equipment consistent with 4.1.5.

4.3.3 Lighting for equipment length

4.3.3.1 Equipment that extends more than 7.6 m (25 ft) in the rear of the high point shall have lighting as described in 4.3.2.1.1, 4.3.2.1.2, and 4.3.2.1.3.

4.3.4 A seven-terminal plug conforming to SAE J550 shall be provided for operating remote flashing warning lamps, turn indicators, and tail lamps. The plug location and cable length shall be compatible with the location of the seven-terminal receptacle on the tractor or self-propelled machine (see 4.1.9) as shown in figure 2. The circuit designation shall be consistent with 4.1.5.2. See 4.2 on implement bus breakaway connector.

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**Annex A**

*Informative*

**Future Provisions**

NCTF - Future provisions are intended to provide last minute conformances. The intent is to review them annually.

A.1 (Proposed 4.3.10) An implement bus breakaway connector as specified in ISO 11783-2 and light control messages as defined in ISO 11783-7.

Figure 13.5 Standard S279.10 [11]
Appendix L

“Authorization of Equipment Usage”
Authorization of Equipment Usage:

This notice is for the authorization of Jonathan Haynes to use the available equipment and utilities or supplies owned by Stahl Farms in order to successfully complete his senior project requirements. He is knowledgeable of shop time allotment and will schedule usage appropriately. Any changes or exceptions will be discussed and implemented within a timely manner to insure efficiency during the entire project cycle. Mode of transport of certain equipment will also be made available if the need so arises.

Charles F. Stahl

Owner/Operator
Appendix M
“Proof of Design Statement”
To: Reduce accidents between motorists and agricultural equipment

A: Durable hazard lighting and marking system for improved recognition, does not inhibit normal field operation, and uses standard operator input.

Will Be: Designed, built, and tested on a 9380 Case-International 4-wheel-drive tractor.

Performance Confirmed By: The advising MET professor, the functional operation of the hazard lighting system, and the conformance to the arbitrary standard set forth by the proposing student and the advising professor.
Appendix N
“Bibliography”
Bibliography:

5. Privette III C.V., Rx for Ag Safety & Health. CU Safe (Clemson University), 2001. 3(Number 7).