# Documentation, Review, and Assessment of a State of Michigan-funded Engineering Undergraduate Summer Internship for the Development and Implementation of an Energy Usage Planning Tool for a Large Grain Elevator and Grain Storage Facility

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**Documentation, review and assessment of a State of Michigan funded engineering undergraduate summer internship for the development and implementation of an energy usage planning tool for a large grain elevator and grain storage facility**

**Abstract:** This work reviews efforts undertaken with funding from a State of Michigan Energy Office Student Internship grant. The authors document, review and assesse the major aspects of this undergraduate engineering student energy-focused summer internship. These components ranged from the nature of the RFP and, securing the grant, hiring an undergraduate engineering student, the development of the possible energy usage projection tool developed by the summer intern; and finally the energy usage tool itself and the validation of the tool as used by Michigan Agricultural Commodities, Inc. (MAC) personnel.

The student internship efforts capitalizes on previous activities from 2012 through 2014 when Lawrence Technological University had undertaken a major energy audit and energy study with MAC, at their facilities in Marlette, Michigan. In the spring of 2015 the State of Michigan Energy Office offered a competitive Request for Proposal (RFP) to universities within the state for one fully-funded grant for an engineering undergraduate student summer internship. The grant RFP stipulated that the undergraduate engineering student intern work on a project focusing on energy usage and savings specifically in the agriculture industry in the State of Michigan. Fortunately, over the past three years Lawrence Technological University has been undertaking energy usage assessments and audits of a large grain elevator facility in Marlette, Michigan, that is owned and operated by the Michigan Agricultural Commodities (MAC) Corporation. The previous three-year's work undertaken by Lawrence Tech had resulted in significant data collection and had provided an excellent foundation for what to do next to obtain possible energy savings. The process options at the grain facility in Marlette are many, are complex, and each carries with it energy costs that are not always understood. But up to this 2015 State proposed RFP internship, no addition funding resources were available to MAC or Lawrence Tech to finally develop and implement an appropriate energy savings planning tool that could be used by the MAC personnel for accurate projected energy usages for the receiving, routing and storage of gain at their facility.

Such applied engineering internships are of great value to the student and to industry, so a discussion of the lessons learned are provided by the undergraduate engineering student herself, along with a commentary of both the academic and applied engineering knowledge gained by such internships are also presented. This information will be of interest to engineering faculty at other colleges and universities who might wish to successfully pursue other internship opportunities for their engineering students in other areas of interest.

## 1) Introduction:

This work reviews efforts undertaken with funding from a State of Michigan Energy Office Student Internship grant. The student internship efforts describe here capitalizes on previous activities from 2012 through 2014 when Lawrence Technological University had undertaken a major energy audit and energy study with Michigan Agricultural Commodities, Inc. (MAC), at their facilities in Marlette, Michigan. This previous work was funded by the Energy Optimization Pilot Programs at DTE Energy with the intent to assess the use of variable frequency drives for controlling fans and conveyors. These previous efforts have been well documented and presented at earlier ASEE conferences.[1, 2] The previously funded work indicated there was a real need for a useful computational tool for use by MAC personnel that could assist them in grain routing and process decision making that could yield reliable energy usage estimations. The DTE Energy funded project did not, however, provide any funding for the development of such a computational tool.

Fortunately, on March 9, 2015 the Sate of Michigan's Energy Office released a request for proposals (RFP) for the "Michigan Energy Office Student Internship Program" where an energy planning, use and assessment computational tool could be developed. Funds were from the US Department of Energy but administered by the State of Michigan. This internship program offered "grants to accredited colleges and universities in Michigan to support up to three junior and senior undergraduate engineering students to implement innovative but commercially available energy efficient technologies in agribusinesses identified by the Michigan Energy Office."[3] The purpose of the grant was to "provide unique opportunities to students to gain real-world work experience and to implement projects that have measurable reductions in energy usage and costs for Michigan businesses."[3] The grant had worthy funding with a per student intern stipend of up to $7,330, and allowed for a university administration charges of $1,000. A student hourly pay rate was stipulated at $15.27 per hour. Other details regarding the internship can be obtained from the State of Michigan. Note that since the initial issuance of the RFP the Michigan Energy Office was reorganized and is now the "Michigan Agency for Energy", located at 7109 W. Saginaw Highway, Lansing, MI 48917.

Pursuing this internship funding was an excellent fit for Lawrence Tech because it could build upon the energy auditing and assessment work the school had conducted in prior years with personnel at MAC facilities in Marlette, Michigan. An added benefit was that little startup knowledge was required by Lawrence Tech due to the well-established connections with the MAC Marlette personnel and extensive process knowledge of MAC Marlette operations.

The primary author of this work, a Lawrence Technological University Mechanical Engineering faculty member, knew the benefits of internship programs for undergraduate engineering students and, therefore, aggressively pursued and submitted a proposal for this Student Internship Program. Lawrence Tech successfully secured funding from the program for the only internship awarded during the 2015 year's program cycle.

This work reviews the process for securing the grant by Lawrence Tech faculty, a description of the work done and the final deliverable of a spreadsheet tool for use by the Michigan Agricultural Commodities, Inc. (MAC) personnel, at their facilities in Marlette, Michigan.

## 2) Background:

The US Department of Labor has six criteria that define an internship. These are listed as follows:[4]

1. The internship, even though it includes actual operation of the facilities of the employer, is similar to training which would be given in an educational environment.
2. The internship experience is for the benefit of the intern.
3. The intern does not displace regular employees, but works under close supervision of existing staff.
4. The employer that provides the training derives no immediate advantage from the activities of the intern; and on occasion its operations may actually be impeded.
5. The intern is not necessarily entitled to a job at the conclusion of the internship.
6. The employer and the intern understand that the intern is not entitled to wages for the time spent in the internship.

Many authors have documented well the various aspects of undergraduate engineering student participation in industry and governmental sponsored internships, so only a few key recent references are cited here. The retention of engineering students to stay enrolled in engineering programs remains a concern, and internships have been shown to help improve student retention by giving students exposure to the nature of future career opportunities.[5] Recent studies have shown the relationships of internships, as well as other employment opportunities, to the hours worked by a student and their impact on grade point average (GPA) compared to student retention.[6] The use of required professional internships for graduation from engineering programs have also been carefully assessed.[7] The specific outcomes with compelling data were also recently presented showing how internships have improved student's personal attitudes towards their future prospects in an engineering career, and have documented the positive financial benefits to an organization.[8] Others have established multi-institutional internship programs for several engineering disciplines to help meet what are perceived as the future challenges in the energy sector.[9] These references each review the many positive impact of engineering internship programs that are sponsored by industry or governmental institutions. Undergraduate engineering internships have intrinsic value, and provide student benefits that go well beyond what is learned in the classroom.

## 3) The Michigan Agricultural Commodities facilities in Marlette, Michigan:

The previous work undertaken by Lawrence Technological University with the Michigan Agricultural Commodities (MAC) and their processes have been extensively documented elsewhere and are only highlighted here to facilitate discussion.[1,2] The MAC facilities in Marlette, Michigan storage facilities has a rail spur that allows out-bound transfer of stored grain directly into rail cars that can then be transported by rail train for distribution to its final destination. Grain delivery by truck/trailer is also common. The Marlette facility has sixteen permanent storage bins in their primary-use storage area for a total storage capacity of 3.754 million bushels (4.693 million $ft^3$) of grain. The facility can also accommodate an added 1.055 million bushels (1.319 million $ft^3$) of temporary pile storage. See Figure 1 below showing an aerial view of the facility looking east. Grain is primarily received from local farmers at the Marlette facility in trailers pulled by trucks or tractors. There are two receiving stations. The first is the front receiving station that allows grain dumps to the “front receiving pit” that transfers grain to the front receiving leg for routing to any of the permanent grain storage bins on the site. The second is the back receiving station (located towards the rear of the facility) where grain can also be dumped into a separate receiving pit that also allows grain to be distributed to all storage bins on site.

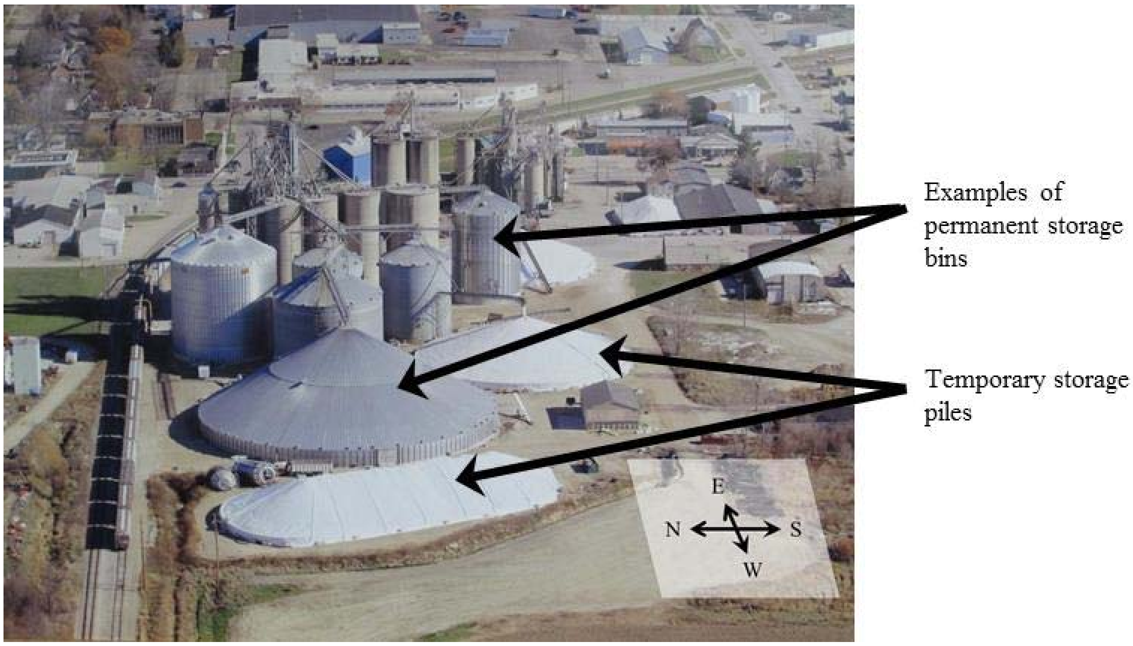


**Figure 1:** An aerial view looking east of the Michigan Agricultural Commodities facilities in Marlette, MI prior to addition of bins 28, 29, 30. Permanent storage bins and temporary storage files are indicated. The rail spur with train cars on it is located on the north side of the facilities (left side of the photo).

Figure 2 below, taken from Google Earth, shows a second aerial view of the Marlette facility. The various storage bins are indicated by number or name. The “Chief”, as labeled in the photo, is a cone-shaped grain storage bin with a capacity of 950,000 bushels. The “Temporary Pile” in the lower left-center of the figure is used for the transient temporary storage of grain for a few weeks or longer, until it can either be sold or transferred into a permanent on-site grain bin. In the summer of 2013 the MAC erected two new permanent grain storage bins and are indicated as #29 and #30 in Figure 2 below with capacities of 225,000 and 310,000 bushels respectively.

If grain evaluation at receiving indicates that the grain is not dry (above 16% to 16.5% moisture by weight) the grain can be routed to a bin for later drying, or it can be sent directly to the grain dryer.

The grain drier intakes outside-air at the bottom of the unit, and heats that outside-air using a natural gas burner and blows the heated air into the dryer to dry the grain. Once dried, the grain can then be routed to longer term storage bins, or temporary bins, as needed. For shipping the target moisture must be between 15% and 15.5%. Figure 3 below shows a diagrammatic illustration of the major grain handling operations and storage systems at the Marlette facility.

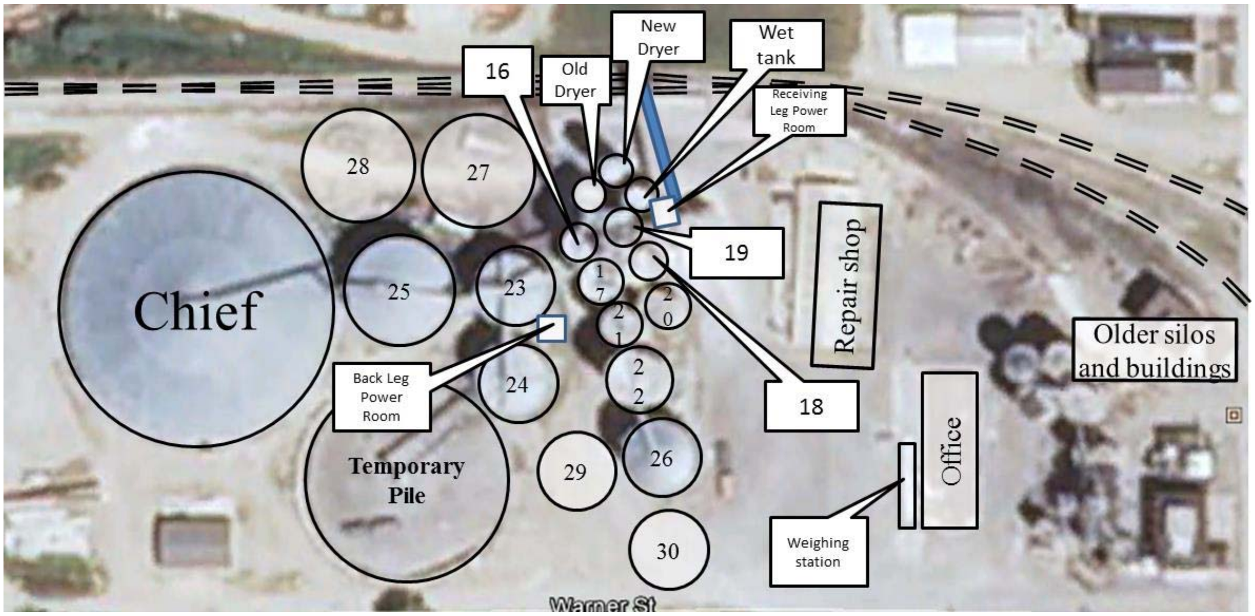

**Figure 2:** A second aerial view, copied from Google Earth, of the Michigan Agricultural Commodities facilities in Marlette, MI. The top of the photo is north. Each permanent bin or facility system is identified by number or name. The dashed line drawn shown in the upper portion the photo shows the position of the rail spur with a split for train car short term holding. The weighing station, facility offices, and older grain storage facility are to the lower right in this image. Bins 29 and 30 are drawn into this photo and postdate the Google Earth image used here.

It is important to note that all grain received at the Marlette facility is handled at least twice, once at receiving for storage, and once again for sale/shipment. In some instances grain can be mixed with similar grain in other on-site bins. This involves yet another handling of the grain. Repeated handling and movement of the grain is undesirable because this can cause damage to the individual kernels of grain, which lowers the dollar-value of the grain.

The predominant electric energy consumption at the Marlette facility is from the operation of electric motors for the operation of fans, legs and drags. All legs and drags electric motors are powered using 480 VAC delta connections.

Once the grain has been routed to its initial storage destination within the MAC Marlette facility it can be routed to three other on-site destinations. These are 1) to the dryer if it is initially received with moisture above 16%; 2) to a longer-term storage bin, if dry; 3) if additional foreign materials are present then it can be blended with other similar grain with lower foreign material levels to meet sale specifications. The final disposition of all grains at the MAC Marlette facility is to be sold to external customers. As previously mentioned, minimal handling and movement of grain is desired. Excessive grain handling movement transport can have two financial impacts. First, each grain movement activity can crack or fracture the grain. Such damage is undesirable because it negatively impacts the quality of the grain and, thusly, lowers the value of the grain. Second, additional grain movement requires electric power use to energize motors for drags and legs resulting in added processing costs.

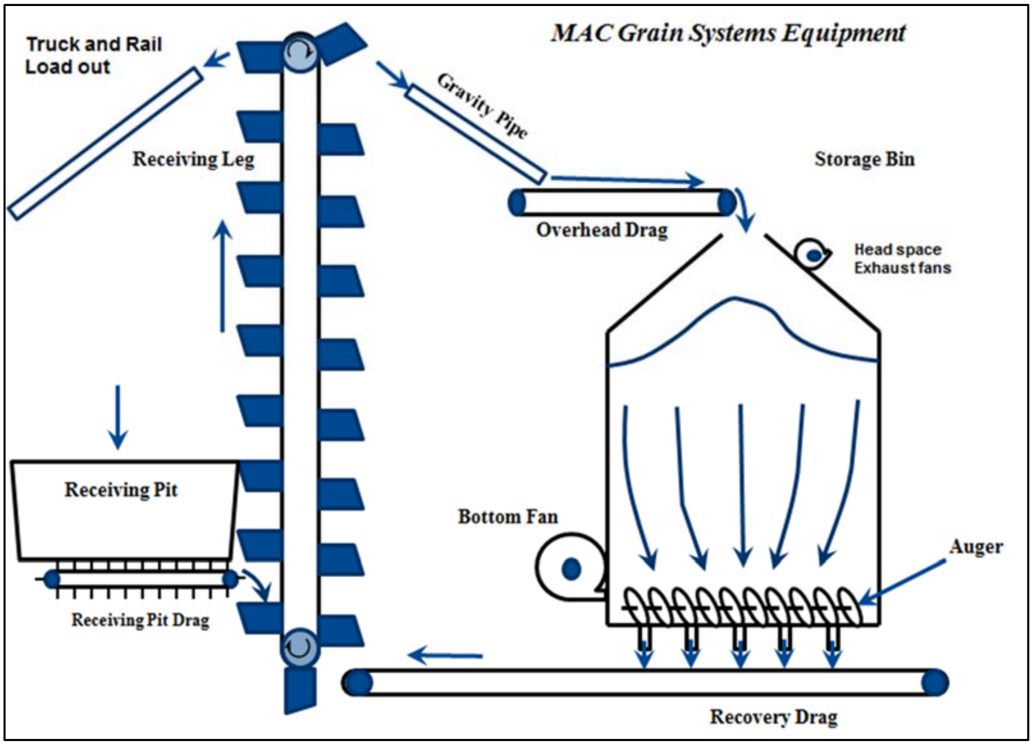


**Figure 3:** This diagram shows the major equipment components used at the MAC Marlette facility.

The fundamental challenge for energy savings for the Marlette facility operations was that there was no formal working tool to use for energy decision making, energy based grain routing planning and best practices for energy savings/process assessment. The only method available to the operations manager at the Marlette facilities was based on best-estimate, or more likely a “best-guess”, approach. The energy auditing and assessment work done under the DTE Energy grant indicated a very strong need for such a decision support tool. The process energy decision and assessment tool, therefore, became a logical objective for Lawrence Technological University’s application for the State of Michigan Student Internship grant.

**4) The Michigan Energy Office Student Internship Program:**

In the spring of 2015 the Michigan Energy Office (MEO) offered grants to accredited colleges and universities in Michigan to support up to three junior or senior undergraduate engineering students to implement energy efficient technologies in agribusinesses. Any Michigan university with an accredited undergraduate engineering college in mechanical, chemical, electrical, civil, environmental or agricultural engineering qualified for the program. The purpose of this grant was “to provide unique opportunities to students to gain real-world work experience and to implement projects that have measurable reductions in energy usage and costs for Michigan businesses.”[3] Applicant(s) had to provide a detailed itemized budget with an explanation to describe each budget category. All applicants were encouraged to provide at least 20% match of the total requested of the State of Michigan’s share of the funds. Universities were allotted per student intern administration charges of $1,000. Each allotted student intern stipend was $7,330. All funds had to be expended by September 7, 2015.

The grant required a clear Problem Statement focusing on how Michigan agribusinesses could save money under the proposed project. Work effort had develop and improve engineering talent by providing students experience with design, implementation, and evaluation of energy efficiency projects. The internship had to help workforce training, enable agribusinesses to reduce energy use and operating cost, to improve the energy efficiency of the state, and to reduce the rate of growth of energy demand. A well-constructed project plan outlining the general aspects of the project with a project timeline was also required.

**5) Proposal Submission, Acceptance and Project Initiation:**

The Lawrence Tech proposal focused on how future possible work could be built upon the previous efforts undertaken between Lawrence Tech, MAC and DTE Energy. It was thought that the effort could lead to developing additional energy assessment activities using the “Load Watch” energy monitoring software that was previously installed at the MAC Marlette facility before the start of the internship. Load Watch is a continuous energy monitoring, recording and reporting software available from DTE Energy to its industry customers. It tracks bulk electric utility power use at a customer’s facility. The electric power-use data can be accessed on-line and reviewed to assess how overall electric power use is impacted throughout the day. At the time of writing the internship proposal there were thousands of hours of data accumulated for the MAC Marlette facility. These data were not organized, reviewed or analyzed. It was believed that these stored data in Load Watch, and future Load Watch energy data, could yield an understanding of possible energy savings opportunities. These opportunities could possibly also be shared with other agricultural business.

The Lawrence Tech proposal therefore defined work activities around the use of Load Watch. The submitted proposal then had four areas of focus:
1) Organize Existing Load Watch Data: Have the intern review the overall energy usage data from the MAC facilities generated by Load Watch and set up a basic organizational structure for these data that then lend it to assessment and analysis.

2) Create Energy Usage Data Reports: Have the intern collecting feedback from MAC management regarding useful information about energy consumption and energy management and then generating useful energy usage reports.

3) Assist In Data Collection for Experimental Testing and Operations: Have the intern collect and reviewing data for special energy assessment studies and experiments at the MAC facilities for the specific purpose of understanding energy usage of specific processes.

4) Documenting the efforts: This is needed to assure the efforts can continue after the internship comes to a close.

A work plan was also required defining weekly activities for the student intern and the project progress up to its conclusion in early September 2015. The details regarding these weekly activities can be obtained from the authors, if requested.

Once the full proposal was written the internal approval process at Lawrence Tech was very quick. Provost approval and signature were obtained in one day. The proposal was submitted to the State of Michigan the same day all documents were internally signed. Lawrence Tech received notice of the grant award on May 15, 2015.

Once the grant was approved action immediately focused on hiring a student. This was a challenge. The 2015 spring semester (including finals week) at Lawrence Tech ended Friday May 9th of 2015. Most students were gone for the summer break by the time of grant awarding. The PI of the grant, and co-author of this work, contacted the Director of Lawrence Tech's Office of Career Services, Peg Pierce, prior to grant award notice for possible student candidates. By May 5th student candidate resumes were received, reviewed and interviewed within a few days. Timing was critical as the grant required work to begin at time of award. The winning student candidate was Louise Brasil, an exchange student at Lawrence Technological University. Louise was sponsored by the Science Without Borders Program (SWBP), a large-scale nationwide scholarship program primarily funded by the Brazilian federal government. The SWBP program seeks to strengthen and expand the initiatives of science and technology, innovation and competitiveness through international mobility of undergraduate and graduate students and researchers. At her home institution, Universidade Estadual do Rio Grande do Sul, in Brazil, Louise is an Energy Engineering major. For Louise to get through the hiring process, even with her holding a J-1 visa, it was necessary to get approval from the Science Without Borders Program. In addition, to work at Lawrence Tech, she needed to secure a Social Security Number, which was expedited. All approvals and Social Security requirements were completed in one working week.

**6) Project Work Activities:**

It was critical that the student intern quickly learn and understand the working operations of the Marlette facilities. The MAC Marlette facility has many possible ways to accomplish the same task. This means that different drags and legs (and their different motors) can be used at different times, thus varying the energy use. The choice about which routing path or process used is not a simple decision, and depends on many variables such as the equipment availability and maintenance, variety of grain being moved (corn, wheat, or soybeans; dry or wet), and even the weather. Learning all of this was indeed challenging for the intern, but with the support given by the MAC members this was accomplished in a few weeks.

From the beginning it was understood that Load Watch would never be able to provide all the needed processes energy usage data. But the original plan to use the already installed DTE Energy provided online software Load Watch at the Marlette facility to the level intended had to be dropped early in the process. This was because Load Watch data could only show the bulk overall real-time electric usage, as well as those previously stored data. It was not, however, helpful in understanding the usage of specific equipment operated in the processes, especially if multiple systems were in operation at the same time. So, ultimately, Load Watch was only employed as a tool for cross-checking energy usage data when specific systems or equipment were running, or other equipment either in an ON/OFF mode or, and only when tracking the bulk electricity usage was needed.

The MAC Marlette operations staff needed an additional working tool in order to help them plan, monitor, and predict energy consumption depending upon the type of grain, the method it was received, processed (such as drying), routed to a specific bin number, or blended with other grans to meet a composition specified by a given customer. This working tool had to be very easy for MAC personnel to use, to modify or update, and to deliver easy-to-understand reports. The MAC personnel were all familiar with MicroSoft Excel®, and had used it extensively for other financial and process data analysis, so Excel® became the software of choice for the energy usage working tool. But because of the many process paths for grain at the Marlette facility it was simply not possible to set up unique paths for computations in the spreadsheet. This rendered it a complex process to make the spreadsheet useful.

The goals of the spreadsheet were to give MAC operations a decision making tool that covers 1) the most energy efficient method of routing the grain/commodities to eventual on-site bin storage after receiving; 2) the energy impact of aerating the grain in on-site storage bins and silos (it turns out that aeration is the major electric energy user at the facilities; 3) the most energy efficient method of grain removal from the storage bins and how best to route the grain to either the rail loader, or the truck loader.

For the spreadsheet to properly compute and deliver the needed outputs for energy estimations, several MAC system operational data were required. These included all process motor nameplate data (horsepower rating, input voltage and amps). Drags and legs bushels/hour ratings were also collected. Several meetings with the MAC staff were needed to understand and map all processes and electric power equipment. This step was essential because fully understanding their business decision making process was the only way of providing good solutions to quantify their energy usage needs and projections. These values where then checked and confirmed to assure all Spreadsheet data were accurate.

To make the calculations and estimate the fan power requirements, parameters related to airflow through the typical grains stored at the facility, and static pressure measurements with different amounts of grain inside bins were also necessary. Key references were also consulted.[10-13] Some data, however, were not available in existing literature. Therefore, the MAC staff helped in gathering the baseline data for the required calculations.

Another challenge was that Lawrence Technological University is located in Southfield, Michigan. The MAC Marlette facility is located about 75 miles north of campus (about a one and a half hour drive). It simply was not possible to go to the MAC facilities each day. It was possible to do spreadsheet development work remotely on the Lawrence Tech campus. But a few times a week travel to the Marlette facility to meet with MAC staff to clarify and address questions was required.

The initial development of the spreadsheet was intentionally kept very basic so that results could be checked easily. Pull-down screens and lookup tables were used to provide easy processing by users. Over the spreadsheet's development, more restrictions, options and process routing permutations were included for analysis. Spreadsheets were frequently assessed by MAC personnel and revised based on their input. Understanding which data were critical and what output information from the spreadsheet was needed was crucial. In addition, showing the MAC staff the evolving tool and having them participate in its creation provided them an understanding of what was done, how to edit it, and if any outputs were not correct.

Another challenge faced was that two key members of the Marlette staff (who were also members of the project team) had major health issues either with themselves or members of their families. Because of this they were often not available to assist when needed during the summer. But with phone calls, and with emails back and forth, all parties involved were eventually able to provide the inputs and reviews required.

## 8) The Working Spreadsheet

Three worksheets within the spreadsheet were developed: "Receiving", "Transporting & Drying", and "Aeration Costs". Look-up and calculation table data set for each spreadsheet was also developed. The spreadsheets and their related look-up and calculation tables provide the ability to compute energy usage, process transfer times time, and energy usage costs for each process selected.

**Receiving:**
The grain receiving process is perhaps the simplest operation within the Marlette facilities. Because of this the "Receiving" worksheet is the simplest as there is just one possible path with dumping the grain into the receiving pit. Data entry is facilitated by pulldown menus for various cells to assure consistent and repeatable data storage. Computed results depend on the kind of grain, quantity, destination and utility kWh cost, see Figure 4. The accompanying "Receiving" look-up and calculation table is found in Figure 5.

It was necessary to define which motors are used to take the grain from the receiving pit to the destination bin. By doing so within the spreadsheet the receiving calculations in the spreadsheet become quite simple. The needed data are listed in a secondary look-up and calculation table spreadsheet (see Figure 5) that contains the input voltage, the filling rate time for each commodity, as well as the respective power consumptions. In Figure 4 the white cells the type of commodity, quantity of bushels received, and destination values are inserted. The gray cells contain the related formulas and display the needed calculated items. Using IF and INDEX functions, and basic math calculations, it is possible to predict the energy consumption, how long it will take to finish the process and its cost. Also, there are per bushels parameters so the MAC managers are conscious of their expenditures.

$$\text{Filling time [hr]} = \left(\text{bushels received } \left[\frac{\text{bu}}{hr}\right]\right) \times \left(\text{bushels rate } \left[\frac{\text{bu}}{\text{hr}}\right]\right)$$

$$\text{Energy consumption [kWh]} = (\text{power [kW]}) \times (\text{filling time [hr]})$$

$$\text{Total cost [\$]} = (\text{electricity cost [\$/kWh]}) \times (\text{energy consumption [kWh]})$$

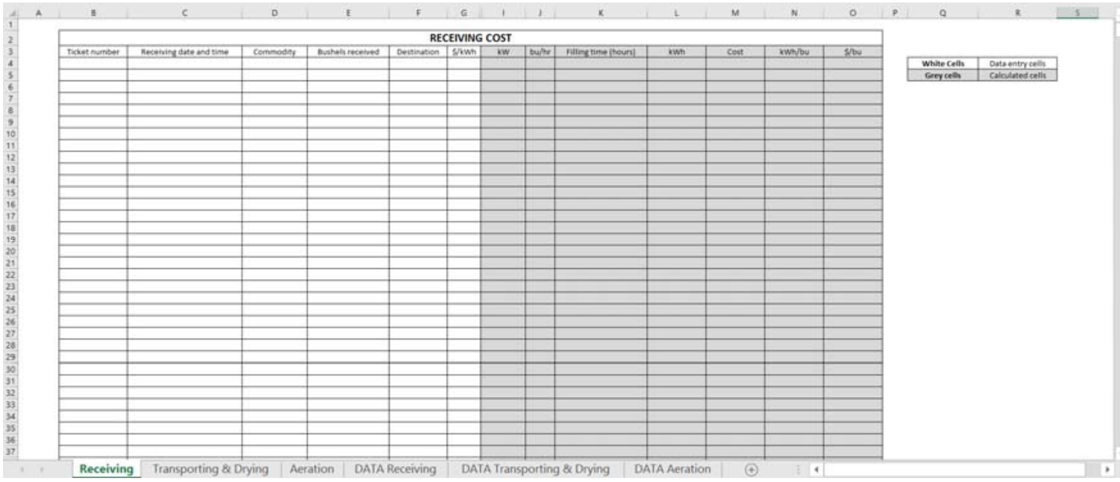


**Figure 4:** A screen capture illustration of the "Receiving" worksheet data entry page. The white areas are for manually entered data. The shaded areas are spreadsheet calculated.

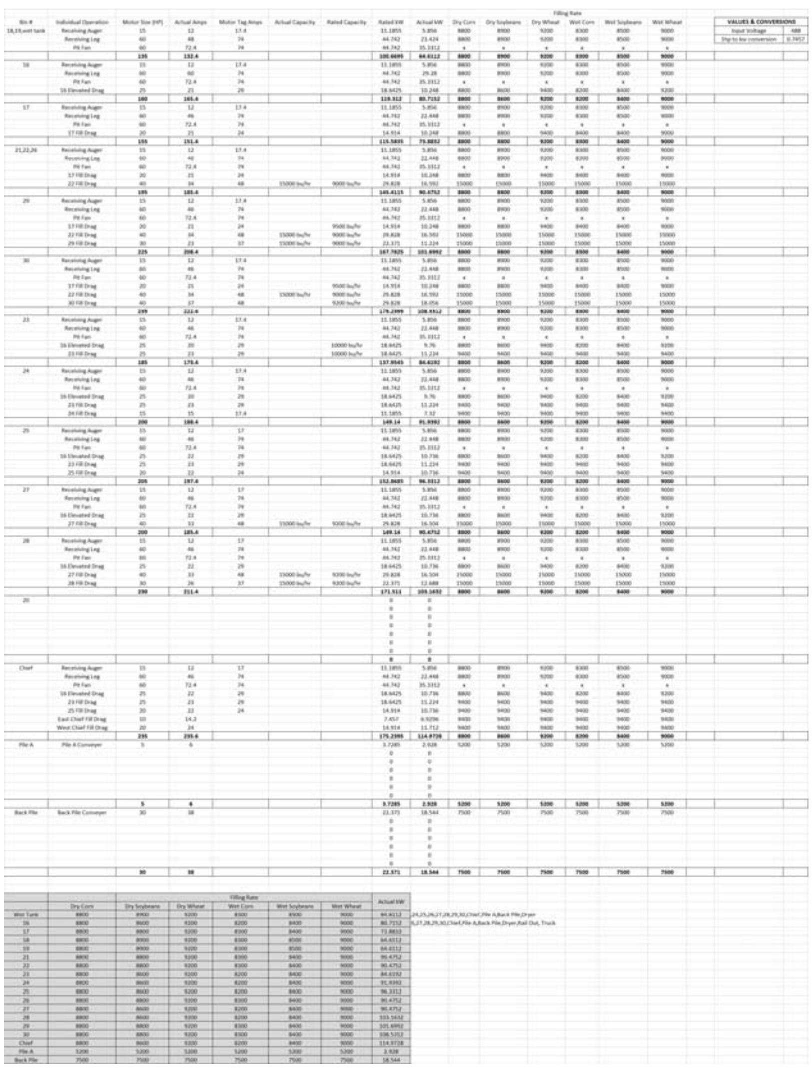

**Figure 5:** A screen capture of the "Receiving" worksheet look-up and calculation table. These data can easily be changed and updated by MAC personnel.

**Transporting and Drying:**

Whenever an amount of grain needs to be moved or dried within the facility, the “Transporting & Drying” worksheet is used. See Figure 6. In this spreadsheet, the commodity and the quantity have to be selected, and then there is a checklist of the used motors to be marked. This spreadsheet is similar to the receiving spreadsheet. The gray cells contain the formulas, and values need to be inserted in the white cells. There is a secondary look-up and calculation table spreadsheet (see Figure 7) with the input voltage, filling time for each commodity, power, and current. IF, MIN, SUM, and OR functions, and basic math calculations were used to obtain the results. As different paths can be taken to carry the grain around, checkboxes need to be selected according to the motors used, and the respective values are taken from the data spreadsheet to obtain the necessary power to complete the process. After that, the same calculations made in the receiving spreadsheet are applied.

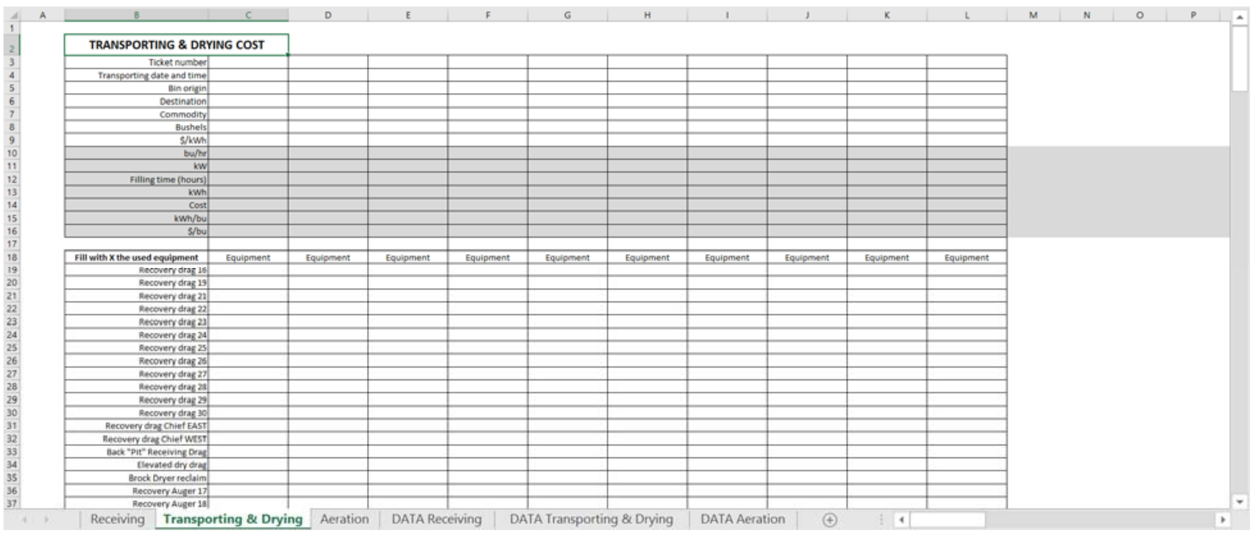


**Figure 6:** A screen capture illustration of the “Transporting & Drying Cost” worksheet data entry page. The white areas are for manually entered data. The shaded areas are spreadsheet calculated.

| | Grain rating (bushels/hour) | | | | | | | | Horsepower rating (HP) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dry Corn | Dry Soybeans | Dry Wheat | Wet Corn | Wet Soybeans | Wet Wheat | Actual kW | Rated kW | | Amps | |
| Recovery drag 16 | 3000 | 4500 | 4500 | 2800 | 4500 | 4500 | 4.7824 | 5.59275 | 7.5 | 9.8 | |
| Recovery drag 19 | 3000 | 4500 | 4500 | 2800 | 4500 | 4500 | 4.64576 | 5.59275 | 7.5 | 9.52 | |
| Recovery drag 21 | 14000 | 14000 | 14000 | 12000 | 10000 | 14000 | 23.424 | 29.828 | 40 | 48 | |
| Recovery drag 22 | 9000 | 8900 | 9400 | x | x | x | 8.4912 | 11.1855 | 15 | 17.4 | |
| Recovery drag 23 | 9500 | 9000 | 9500 | x | x | x | 8.4912 | 11.1855 | 15 | 17.4 | |
| Recovery drag 24 | 9500 | 9000 | 9500 | x | x | x | 11.712 | 14.914 | 20 | 24 | |
| Recovery drag 25 | 9500 | 9200 | 9500 | x | x | x | 17.568 | 22.371 | 30 | 36 | |
| Recovery drag 26 | 9000 | 9000 | 9500 | x | x | x | 11.712 | 14.914 | 20 | 24 | |
| Recovery drag 27 | 7000 | 7000 | 7500 | x | x | x | 23.424 | 29.828 | 40 | 48 | |
| Recovery drag 28 | 7001 | 7001 | 7501 | x | x | x | 18.056 | 22.371 | 30 | 37 | |
| Recovery drag 29 | 9500 | 9000 | 9500 | x | x | x | 11.712 | 14.914 | 20 | 24 | |
| Recovery drag 30 | 9000 | 9000 | 9000 | x | x | x | 18.056 | 22.371 | 30 | 37 | |
| Recovery drag Chief EAST | 9500 | 9000 | 9500 | x | x | x | 14.7864 | 18.6425 | 25 | 30.3 | |
| Recovery drag Chief WEST | 9500 | 9000 | 9500 | x | x | x | 14.7864 | 18.6425 | 25 | 30.3 | |
| Back "Pit" Receiving Drag | 9000 | 9000 | 9400 | x | x | x | 14.64 | 18.6425 | 25 | 30 | |
| Elevated dry drag | 10000 | 10000 | 10000 | 10000 | 10000 | 10000 | 11.712 | 14.914 | 20 | 24 | |
| Brock Dryer reclaim | 3000 | 4000 | 4000 | 2800 | 4000 | 4000 | 6.1976 | 7.457 | 10 | 12.7 | |
| Recovery Auger 17 | 5000 | 5000 | 5000 | 4500 | 4700 | 5000 | 3.416 | 3.7285 | 5 | 7 | |
| Recovery Auger 18 | 5000 | 5000 | 5000 | 4500 | 4700 | 5000 | 3.416 | 3.7285 | 5 | 7 | |
| Wet Tank auger | x | x | x | 4000 | 4000 | 4800 | 9.0768 | 11.1855 | 15 | 18.6 | |
| Receiving Auger | 8800 | 8900 | 9200 | 8300 | 8500 | 9000 | 5.856 | 11.1855 | 15 | 12 | |
| Receiving Leg | 8800 | 8900 | 9200 | 8300 | 8500 | 9000 | 34.648 | 44.742 | 60 | 71 | |
| Big Leg | 9500 | 9300 | 10000 | 9000 | 9000 | 10000 | 40.992 | 55.9275 | 75 | 84 | |
| High Leg | 4000 | 4000 | 4400 | 3500 | 3700 | 4400 | 28.304 | 37.285 | 50 | 58 | |
| Receiving dry leg | 8000 | 8000 | 8000 | 8000 | 8000 | 8000 | 28.304 | 37.285 | 50 | 58 | DELETE |
| New Dry Leg | 3000 | 4000 | 4000 | 2800 | 4000 | 4000 | 28.304 | 37.285 | 50 | 58 | |
| New Wet Leg | 3000 | 4000 | 4000 | 2800 | 4000 | 4000 | 34.648 | 44.742 | 60 | 71 | |
| Elevated Dry Drag ? | x | x | x | x | x | x | 18.544 | 22.371 | 30 | 38 | |
| Pile A Conveyer | 5200 | 5200 | 5200 | 5200 | 5200 | 5200 | 2.928 | 3.7285 | 5 | 6 | |
| Back Pile conveyer | 7500 | 7500 | 7500 | 7500 | 7500 | 7500 | 18.544 | 22.371 | 30 | 38 | |
| 16 Elevated Drag | 8800 | 8600 | 9400 | 8200 | 8400 | 9200 | 10.248 | 18.6425 | 25 | 21 | |
| 17 Fill Drag | 8800 | 8800 | 9400 | 8400 | 8400 | 9000 | 10.248 | 14.914 | 20 | 21 | |
| 22 Fill Drag | 15000 | 15000 | 15000 | 15000 | 15000 | 15000 | 16.592 | 29.828 | 40 | 34 | |
| 23 Fill Drag | 9400 | 9400 | 9400 | 9400 | 9400 | 9400 | 11.224 | 18.6425 | 25 | 23 | |
| 24 Fill Drag | 9400 | 9400 | 9400 | 9400 | 9400 | 9400 | 7.32 | 11.1855 | 15 | 15 | |
| 25 Fill Drag | 9400 | 9400 | 9400 | 9400 | 9400 | 9400 | 10.736 | 14.914 | 20 | 22 | |
| 27 Fill Drag | 15000 | 15000 | 15000 | 15000 | 15000 | 15000 | 16.104 | 29.828 | 40 | 33 | |
| 28 Fill Drag | 15000 | 15000 | 15000 | 15000 | 15000 | 15000 | 12.688 | 22.371 | 30 | 26 | |
| 29 Fill Drag | 15000 | 15000 | 15000 | 15000 | 15000 | 15000 | 11.224 | 22.371 | 30 | 23 | |
| 30 Fill Drag | 15000 | 15000 | 15000 | 15000 | 15000 | 15000 | 18.056 | 29.828 | 40 | 37 | |
| East Chief Fill Drag | 9400 | 9400 | 9400 | 9400 | 9400 | 9400 | 6.9296 | 7.457 | 10 | 14.2 | |
| West Chief Fill Drag | 9400 | 9400 | 9400 | 9400 | 9400 | 9400 | 11.712 | 14.914 | 20 | 24 | |
| Rail out motor | 22000 | 22000 | 24000 | x | x | x | 11.712 | 14.914 | 20 | 24 | |
| Chief Gooseneck | 9500 | 9000 | 9500 | x | x | x | 8.4912 | 11.1855 | 15 | 17.4 | |
| Pit Fan | x | x | x | x | x | x | 35.3312 | 44.742 | 60 | 72.4 | |
| Ferris Wheel Discharge Drag | 3000 | 4000 | 4000 | 2800 | 4000 | 4000 | 3.7285 | 3.7285 | 5 | 7.64 | |
| Brock Dryer Fans | x | x | x | x | x | x | 186.416 | 186.425 | 250 | 382 | |
| 1Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |
| 2Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |
| 3Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |
| 4Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |
| 5Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |
| 6Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |
| 7Extra motors as needed | x | x | x | x | x | x | 0 | 0 | | | |

| VALUES & CONVERSIONS | |
|---|---|
| Input Voltage | 488 |
| 1hp to kw conversion | 0.7457 |

**Figure 7:** A screen capture of the "Transporting & Drying Cost" look-up and calculation table. These data can easily be changed and updated by MAC personnel.

**Aeration:**

The third worksheet is "Aeration". See Figure 8. The commodity, quantity in bushels, and bin number have to be manually entered in the top section of the worksheet. Next, different quantities of fans can be selected depending on the established needs. Figure 9 shows the look-up and calculation table for the "Aeration" spreadsheet.

The aeration spreadsheet involves some Fluid Mechanics concepts, and it is computationally more complex than the others. As in the previous spreadsheets, the values are inserted in the white cells, and the green cells contain the formulas. Depending on the bin selected, the options of available fans change in a drop-down menu using a combination of INDIRECT and VLOOKUP functions that get data from a spreadsheet which contains the data collected about the silos, equipment, and some conversions. The main results wanted are the minimum power needed, time to cool the grain, energy consumption, and costs. Air Volume (cfm/bu) and Fan Static Efficiency are estimated fixed parameters.

$$\text{Volumetric flow rate } [\mathrm{m}^3/s] = \left( volumectric\ flow\ rate \left[ \frac{\mathrm{m}^3}{s.bu} \right] \right) \times (\text{quantity of grain } [bu])$$

$$\text{Fan power [W]} = \frac{(\text{volumetric flow rate } [\mathrm{m}^3/s]) \times (\text{Pressure [Pa]})}{fan\ static\ efficiency}$$

$$\text{Pressure [H2O”]} = \frac{(1.907 \times 10^{-5}) \times (\text{quantity of grain } [bu])}{0.5}$$

$$\text{Time to cool the grain [hr]} = \left( \frac{(\text{weight to be cooled [kg]}) \times \left(1.67 \left[\frac{\text{kJ}}{kg\ C}\right]\right)}{\text{Volum. flow rate} \left[\frac{\text{m}^3}{min}\right] \times \left(1.15 \left[\frac{\text{kg}}{\text{m}^3}\right]\right) \times \left(1 \left[\frac{\text{kJ}}{kg\ C}\right] \times 60 \left[\frac{\text{min}}{hr}\right]\right)} \right)$$

$$\text{Energy consumption [kWh]} = \left(\text{Available fan power [HP]} \times 1.341 \frac{kW}{HP}\right) \times \text{Time to cool the grain [hr]}$$

| AERATION COST | C | D | E | F | G | H | I | J | K | L | M | N |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ticket number | | | | | | | | | | | | |
| Date and time | | | | | | | | | | | | |
| Commodity | | | | | | | | | | | | |
| Bushels | | | | | | | | | | | | |
| Bin | | | | | | | | | | | | |
| $/kWh | | | | | | | | | | | | |
| Air Volume (cfm/bu) | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Fan static efficiency | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Minimum HP needed | | | | | | | | | | | | |
| Aeration Fans HP | | | | | | | | | | | | |
| Ventilation Fans HP | | | | | | | | | | | | |
| Time to cool the grain (hours) | | | | | | | | | | | | |
| Time to cool the grain (days) | | | | | | | | | | | | |
| kWh | | | | | | | | | | | | |
| Cost | | | | | | | | | | | | |
| $/bu | | | | | | | | | | | | |

| Calculations and conversions | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Minimum kW needed | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Calculated time to cool the grain (hours) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Weight per bu (kg) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total weight to be cooled (kg) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Air Volume (m^3/s) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Air volume (m3/min) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pressure (inches os water) | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Pressure (Pa) | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 | 124.587 |

Receiving | Transporting & Drying | Aeration | DATA Receiving | DATA Transporting & Drying | DATA Aeration

**Figure 8:** A screen capture illustration of the "Aeration Costs" worksheet data entry page. The white areas are for manually entered data. The shaded areas are spreadsheet calculated.

| | | Aeration fans Horsepower ratings (HP) | | | | | | | | | | | | | | Ventilation fans horsepower ratings (HP) | | | | | | Size of the bin | | | Type of roof |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fan 1 | Fan 2 | Fan 3 | Fan 4 | Fan 5 | Fan 6 | Fan 7 | Fan 8 | Fan 9 | Fan 10 | Fan 11 | Fan 12 | Fan 13 | Fan 14 | Fan 1 | Fan 2 | Fan 3 | Fan 4 | Fan 5 | Fan 6 | Diameter (ft) | Height (ft) | Max. Capacity (bu) | |
| MAIN PLANT | **16** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | x | x | x | x | x | 34 | 104 | 52800 | FLAT |
| | **17** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | x | x | x | x | x | 34 | 104 | 52800 | FLAT |
| | **18** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | x | x | x | x | x | 34 | 104 | 52800 | FLAT |
| | **19** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | x | x | x | x | x | 34 | 104 | 55,000 | FLAT |
| | **20** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | x | x | x | x | x | 34 | 104 | 55,000 | FLAT |
| | **21** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | x | x | x | x | x | 34 | 104 | 55,000 | FLAT |
| | **22** | 30 | 30 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | 2 | x | x | x | x | 45 | 103 | 125,000 | FLAT |
| | **23** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | 2 | x | x | x | x | 60 | 70 | 165,000 | |
| | **24** | 20 | 20 | x | x | x | x | x | x | x | x | x | x | x | x | 2.5 | 2.5 | x | x | x | x | 60 | 70 | 165,000 | |
| | **25** | 15 | 15 | 15 | 15 | x | x | x | x | x | x | x | x | x | x | 2.5 | 2.5 | x | x | x | x | 90 | 58 | 355,000 | |
| | **26** | 30 | 30 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | 2 | x | x | x | x | 60 | 68 | 185,000 | |
| | **27** | 50 | 50 | 50 | 50 | x | x | x | x | x | x | x | x | x | x | 2 | 2 | 2 | 2 | 2 | x | 90 | 80 | 472,000 | |
| | **28** | 50 | 50 | 50 | 50 | x | x | x | x | x | x | x | x | x | x | 2 | 2 | 2 | 2 | 2 | x | 90 | 80 | 472,000 | |
| | **29** | 30 | 30 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | 2 | 2 | x | x | x | 60 | 85 | 225,000 | |
| | **30** | 40 | 40 | x | x | x | x | x | x | x | x | x | x | x | x | 2 | 2 | 2 | 2 | x | x | 72 | 85 | 310,000 | |
| | **Chief** | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 15 | 5 | 5 | 5 | 5 | 2 | x | 242 | 13.5 | 950,000 | |
| | **Wet tank** | 50 | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 20 | 104 | 24,000 | FLAT |
| | **Pile A (CN & SB)** | 10 | 10 | 5 | 3 | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 186 | 60 | 400,000 | |
| | **Pile A (WHEAT)** | 10 | 10 | 10 | 10 | 10 | 10 | 3 | x | x | x | x | x | x | x | x | x | x | x | x | x | 186 | 60 | 400,000 | |
| | **Back Pile** | 10 | 10 | 5 | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 120x260 | | 390000 | |
| | **Parking Lot Pile** | 10 | 5 | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | 150x240 | | 220000 | |
| | **Little Parking Lot Pile** | 5 | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | | | 75,000 | |

| Values | |
|---|---|
| Pressure equation | 0 |
| | 0.5 |
| 1"H2O in Pa | 249 |
| 1 ft in m | 0.3 |
| 1 min in sec | 60 |
| 1 KW in HP | 1.34 |
| Grain constant (kJ/kg C) | 1.67 |
| Air density (kg/m3) | 1.15 |
| | |
| Air constant (kJ/kg C) | 1 |
| 1 bu of corn in lb | 56 |
| 1 bu of wheat or soybeans in lb | 60 |
| 1 lb in kg | 0.45 |
| 1 hour in minutes | 60 |
| 1 day in hours | 24 |

**Figure 9:** A screen capture of the "Aeration Costs" loo-up table. As with the other look-up and calculation tables these data can easily be changed and updated by MAC personnel.

After the various worksheets of the overall spreadsheet working tool was completed it was once again submitted for review, assessment and trial usage by MAC Marlette operations personnel. They tried several of the grain routing permutations possible of processes at their Marlette facilities in the worksheets. They were also shown how to update the various lookup tables containing the computational components of the various worksheets. This was critical should they change out equipment with different sized motors, or if they modified processes. The MAC Marlette staff were also shown how to add new equipment for future process expansion.

**8) Assessment of Work and Final Reporting:**

Upon completion of the final version of the spreadsheet it was submitted to MAC Marlette operations staff to use and apply to their operations. Since the operations personnel in Marlette had previously seen earlier iterations of the spreadsheet tool before, there was no need for a great deal of training or orientation. But to bring all parties "up to speed" a final review of the spreadsheet tool was done over two days in the latter part of July, 2015 at the MAC Marlette facilities. Several test assessments were done with the worksheet to verify and validate the cost outputs of the tool. In each test case the spreadsheet outputs gave energy cost estimates that were able to be verifiable with known time of operation data, and where possible, cross-checked with Load Watch data. In all repeated review cases by MAC personnel the comparison of predictions made by spreadsheet to actual know process routings and those routings actual energy use were considered acceptable to MAC personnel (typically within $\pm$ 2%).

MAC Marlette staff were given the final version of the spreadsheet in early August 2016. This was very helpful as the harvest season for wheat in this area of Michigan spans late July through late August, the season for soybeans from mid-August through early October, and the harvest season for corn runs from mid-September through early December. Marlette staff were able to use the spreadsheet tool through the entire 2015 harvest and grain collection season for the most economical energy routing of their grain receivables, processing, storage and shipments. They are now using the spreadsheet for planning the provided better energy cost planning for future equipment and process expansion.

All the MAC personnel who worked with the spreadsheet tool found it easy to use, they understood the methods of how to use the spreadsheet, and felt it easy to interpret the results. Their feedback was extremely positive. They stated the spreadsheet was "very useful", "surprising" to what it revealed versus what they had assumed were their actual energy costs, and "insightful" as to how the spreadsheet could be used. A key operations staff member said "Finally, we have a tool that lets us really know what is going on with energy costs!"

**9) Benefits of Project to MAC and Student Intern:**

At the start of this effort it was well understood that having an accurate process routing and storage assessment computational tool would be of great help to the MAC Marlette operations staff. They needed such a tool to help them make good energy cost decisions for receiving, routing, processing, storage and out-loading of the grain commodities they handled at their facility. The developed spreadsheet tool provided by the student intern was able to deliver that tool.

The spreadsheet tool allows MAC Marlette staff to see the related energy costs of their process decisions. They can now understand their operations, using the spreadsheet tool to make predictive estimates for energy usage. They now can undertake better process planning with improved cost projections. They also now have improved decision making capabilities for future equipment installations and their energy use. Ultimately, they can now see real and tangible energy costs savings based on knowledge they previously only could guess or assume.

The benefits to the student intern were many. They are best expressed in her own words here. "This real world experience was a rich learning opportunity to me. Academic experience was brought to a formal project with actual financial consequences, due dates, customers and requirements. It also forced me to deal with ambiguities and how to yet deliver a meaningful and useful spreadsheet tool. Furthermore, the practical contact provided learning of new processes and how to creatively develop an approach to provide answers to how to address the energy knowledge needs for those processes. This internship significantly improved my oral and written communication to various levels within the MAC and to State of Michigan agency staff. The project success was very satisfactory."

**9) Conclusions and Summary of Efforts:**

This work summarizes the efforts undertaken in the spring and summer of 2015 to pursue, successfully secure, and to carry out and complete a Michigan Energy Office Student Internship Program grant. The subsequent project required hiring an undergraduate engineering student to work with the Michigan Agricultural Commodities, Inc. (MAC) staff in Marlette, Michigan to develop a spreadsheet tool to assist them in understanding their energy costs associated with receiving, processing, storage and out-loading of the various grain commodities in their business operations.

A spreadsheet tool was developed, assessed and validated by MAC staff in late July and early August of 2015. This spreadsheet tool allows MAC Marlette staff to see the energy costs of their process decisions, give them the ability to make predictive estimates for energy usage so they can make better process planning with improved cost projections. Using the spreadsheet they now can make better decisions on future equipment installations and their energy use.

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