BIOMECHANICAL REHABILITATION ENGINEERING ADVANCEMENT FOR KANSAS (B.R.E.A.K): ACCESSIBLE MILK BARN CAPSTONE DESIGN PROJECT

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ABSTRACT
A system or process was required to assist a paraplegic work on a dairy farm. Subsystems include ingress into the milking barn, negotiating the stairs into the milking aisle, and completing the milking process.

Assumptions:
- The user will never be alone
- The barn will always be humid and quite dirty
- The user needs to reach all necessary controls and items required to complete the work within reason
- The user should be able to do as much of the work as possible

The project was required to be completed by the end of the 2016. Designs were finalized and completed on time by the end of the Fall 2016 semester.

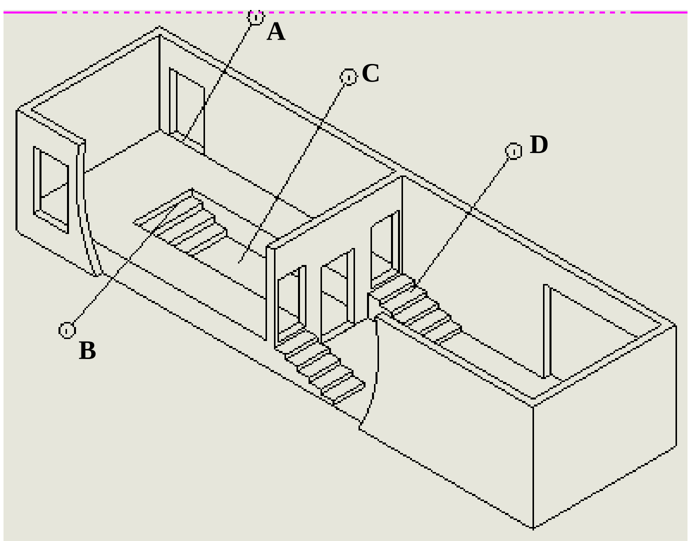

Figure 1. Isotropic cut view of the subsystems. A: Barn entry subsystem location. B: Stairway access location. C: Milking process subsystem location. D. Ramp for cows to ascend into milking stations.

1 - INTRODUCTION
The project context for is very specific. The person who will use the final product, referred to from here on as the user, has a specific disability, and the end goal of this project was to allow the user to be able to contribute effectively to his family's dairy business through the process of helping to milk cows. The user's disability is paralysis from the middle of the waist down making him a paraplegic. This disability is not degenerative; however, due to the incident that caused the disability being so recent, the user is still in stages of completing therapy and recovering to his full upper body strength.

All of the project goals will be completed within or near the dairy barn in which all of the cows are milked; therefore, the completion of the goals can be carried out through designs made specifically for application in the barn. The dairy barn was built in the 1940s and uses milking and cattle handling practices from that era, which are still effective practices for the family's dairy business due to the small scale of the business. However, the age of the barn makes it very inaccessible for anyone confined to a wheelchair. Therefore, the main goal of the project will be carried out by making the inaccessible dairy barn accessible for the user so he can carry out the daily tasks of milking cows. The essential elements of the barn are described below in the Methodology of Concepts section as well as shown in technical detail in the Appendix.

For reference, a dimensioned CAD model of the barn can be seen in Figure 5 to better represent the real-life dimensions of the area the user will be working in, and a timing chart for the project can be seen in **Error! Reference source not found.** that shows how the project progressed over the year, both of which are in the appendix.

2 - METHODOLOGY OF CONCEPTS
2.1 - Research and Assumptions
The first steps in creating concepts was to visit the milking barn to experience the conditions and gather information from the family. A list of base assumptions was made for the current operating conditions with the new solution in place. They include:

- The user always will always be accompanied by another worker for assistance
- The user will need to sit higher than a regular wheelchair in order to reach necessary items and be safe from head injury from kicking cows.
- The user needs to be able to work for the full four-hour milking time
- The user needs to be able to maneuver around and connect a small calf milk jug at a specific station if necessary
- All systems within or around the barn would get wet and dirty because of the working conditions of the dairy.

After determining the main assumptions, the overall project was divided into three main subsystems.

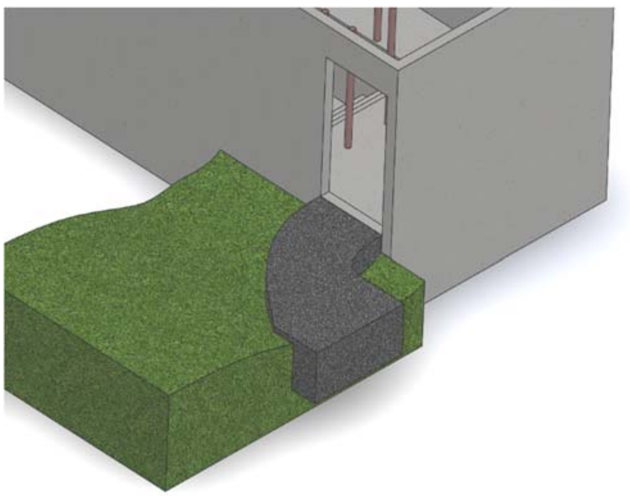

Figure 2. Concrete ramp concept for barn entry system.

2.2 Subsystem 1: Barn Entry

The barn entry subsystem location can be seen at location A in Figure 1. Because the primary human entry door is too narrow for a wheelchair, it was decided that a concrete pad could be placed outside the cow entrance to allow the user to access it. A CAD model of this concept can be seen in Figure 2. This is the most simple and straightforward solution and requires no deconstruction of the barn, and therefore was decided to be the solution for that subsystem if the subsystem is required.

2.3 Subsystem 2: Milking Well Access

The milking well access subsystem location can be seen at location B in Figure 1. This subsystem would allow the user to enter the milking well either by travelling down the stairs, or by travelling around the barn to the back entrance where the ground is level with the milking well. There were several concepts created for this subsystem of which a concept-selection matrix can be seen in Table 1.

2.4 Subsystem 3: Milking "Chair"

The goal of this subsystem is to allow the user to complete as many steps in the milking process as possible, while keeping the user safe. The milking process consists of interacting with the rear end of cows while they stand on a raised platform facing away from the milking well. The orientation of the cows provides safety and sanitation hazards to people within the well. Therefore, a solution is required to minimize these hazards. A detailed, step-by-step flowchart of the milking process can be seen in Figure 6.

3- FINAL SUBSYSTEM CONCEPTS SELECTED

For the barn entry and milking well access subsystems, the pros and cons of both the conversion of the cow's stairs to a ramp and the sidewalk to the back barn concepts were considered as the main contenders. It was decided that the cow ramp has problems concerning emergency situations if cows are in the way, as such situations would cause a great risk to the user. It is also inconvenient for normal use. The user would have to wait for the cows to finish milking and then exit the barn in order to leave, whereas the sidewalk to the back barn allows him to easily leave by himself whenever he wants. Thus, the sidewalk to the back barn was chosen, to cover both subsystems.

For the milking "chair" subsystem, the elderly track system and the ramps were discarded due to their low ratings in the selection matrix. Although those ideas seemed reasonable for the obstacles that the project is facing, their ranking was reduced in some of the most important criteria including safety, interference, and compatibility. The altered mechanical wheelchair was ultimately chosen as the Milking "Chair" subsystem solution.

The obstacle with the altered mechanical wheelchair was how it would be designed so that the user could complete the milking process. Some of the main issues with it was the height requirement, stability of his torso, and the dirty corrosive conditions.

Due to the user's trunk control limitations and the heavy milking devices themselves, a support structure or system was required. The seat height also needed to be raised so that the user would be able to reach various items and controls required to complete the work. A propulsion system was required so the user can be able move the chair in a full range of motion while hopefully maximizing cleanliness.

4- ALTERED WHEELCHAIR PROPULSION CONCEPTS

Several concepts were created for the propulsion system of the altered mechanical wheelchair. Each is described below.

Of all of the concepts of propulsion devices, the consistent foundation for all of these ideas is creating a method of conveniently moving around the milking aisle in a way that is highly maneuverable and in a way that keeps the user's hands clean. The standard wheelchair design of push rims is less acceptable as it limits maneuverability because of interference when in use in parallel with the milking aisle wall. Push rims also are less acceptable because it requires the user's hands to be near the tread of the wheelchair's tires which would cause the user's hands to get dirty very quickly.

5- FINAL DESIGN

5.1 Barn Entry

As mentioned above, the chosen concept for the stairway access subsystem was a sidewalk from the front entrance of the barn to the large opening in the barn behind the milking barn. The user would go down the sidewalk, enter the back barn through the large back door, and then go into the milking well from the back barn through an existing door that is already wide enough for his current wheelchair. Because the back barn is already concrete, and part of the path to the back barn door is already concrete, only the approximately 32ft by 6ft dirt area would need to be replaced with concrete. Upon presenting this idea to the user and his family, it was discovered that the dirt area was actually part manure and part dirt, and would therefore need to be dug out several feet to get to suitable hard ground. It would then need to be filled in with a filler material, likely rock or dirt, and then covered with concrete.

Two companies were contacted who were thought to be able to complete the job. The first meeting at the dairy was with Mike Miller from Miller Excavating Inc. Upon meeting with him, he had several ideas for how the project could be completed more effectively. First, he realized that there were two small steps, about an inch or two each, down into the back barn from the concrete pad outside. Having the user go down the step would require a small solution, such as pouring a very shallow concrete ramp. Rather than implementing this, Mr. Miller had the idea of creating a door in the wall just past the bottom of the cow ramp into the milking area. The doorway would have a large regular door for entry and exit with a hinged metal gate on the inside of the barn to prevent the cows from pushing out or damaging the actual door. Mr. Miller and Mr. Courtney both knew people who could make the door fit the needs of the area, and Mr. Courtney mentioned already having a metal gate that could be used. Next, Mr. Miller discussed digging out the dirt and manure, and said he would be able to do it quite easily. He also said that putting in the concrete sidewalk would be fairly easy, but he might have to subcontract someone to help. Finally, upon discussing fencing the sidewalk Mr. Courtney said he had posts that could be used for the vertical posts of the fence, as well as metal "panels," or fences, which could be used for the actual fencing. Using his materials, rather than buying new fencing pieces will help reduce the overall cost of the project.

The other company the team was supposed to visit that day had a break down with transportation, and was unable to meet. They were no longer considered after Mr. Miller returned a very reasonable quote for the work.

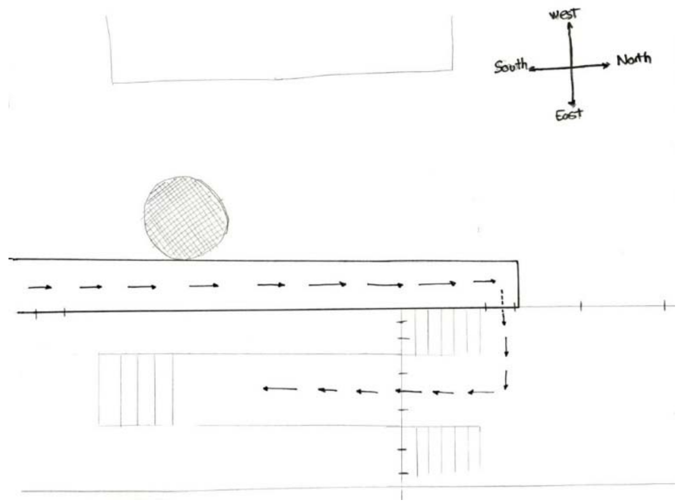

Figure 3. Back barn sidewalk with new door into back barn concept sketch.

Overall, this approach allowed for getting the user into the back barn with an almost completely fenced off path. The only point the user would come into contact with cows is when going from the new side door to the back door of the milking well. This is only a few feet, and could be easily kept clean. The overall modifications to the barn are minimal, as only a new door with a gate would be added. For the outside of the barn, the dirt area will be dug out, filled in with rock and/or new dirt, and then covered with a fenced off concrete sidewalk for the user from the pen entrance to the new door with the new concrete extending from the front edge of the silo to the new door. A sketch of the new path and door can be seen in Figure 3.

5.2 Chair Modifications

As the design process continued it became apparent that none of the propulsion systems for the modified mechanical wheelchair would be appropriate. The decision was made to constrain the project further by removing the requirement of implementing a propulsion system on the modified mechanical wheelchair. Through the process of design assessments, which are explained in detail in the following section, the critical dimension for raising the user was found, which is 11.5 inches. This is the minimum height at which the user is reasonably safe from potential injuries induced by cows kicking and also able to reach all controls and equipment to complete the work with a reasonable amount of ease. At this height, the user would be able to reach the wheels and maneuver himself in a traditional manner sufficiently to complete the work. Also, due to the space constraints of the milking barn the user will be able to use his surrounding to help himself maneuver.

Therefore, the final design of the subsystem of milking "chair" can be summarized by applying a custom designed "lift kit" to a purchased wheelchair.

Figure 4. Stock Karman Flexx wheelchair [5].

The wheelchair selected to purchase was a Karman Flexx Lightweight Fully Adjustable Wheelchair. It was the best option on the market that had a 16 inch wide seat, adjusted to a height of 20 inches, and was made out of a durable yet lightweight aluminum which is optimized for the tight spaces and corrosive conditions of the milking barn. The Flexx also had conveniently adjustable armrests which will help give the user more leverage when he completes his work. The Flexx needed to still be raised to an overall height of 31 inches, measured from the base of the seat for consistency. A "lift kit" system was design that used durable steel to extend the designed framework of the wheelchair. The system utilized current holes in the frame of the Flexx, which conserved the structural integrity of the chair. The drawings of the designs can be seen in **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.**. Minor adjustments were necessary to keep the Flexx operational after the height modifications were made. The braking system was adjusted to accommodate the new location of the wheels by drilling minimal holes in the frame of the Flexx to relocate the stock braking module. In order to accommodate the user sitting in the Flexx for long periods of time the durable medical goods provider, NuMotion, which regularly maintains the user's current personal wheelchair, was contacted and through them a seat cushion was ordered to be used with the Flexx. The cushion ordered was similar in every element except for size to the user's current personal wheelchair cushion in order to have consistency and insure safety and comfortability when he is using the Flexx.

Finite element analysis was completed on the final design of the lift system to ensure the safety of the user. The main purpose of the analysis was to determine the required thickness of plates on the back end of the frame that hold the axel of the larger wheels. A picture of the CAD model of the life kit for the back wheels can be seen in **Error! Reference source not found.**, pictures of stresses with loads applied can be seen in **Error! Reference source not found.** through **Error! Reference source not found.** of 1/8", 3/32", and 1/16" plates respectively, and summarized results can be seen in **Error! Reference source not found.** The analysis was run with forces that were based on the center of mass of a human in the actual chair, but with a weight double the maximum load listed for the chair. The maximum load was listed as 286lbs from Reference [5], so the analysis was done with a load of 600lbs, which also included the 28.5lb weight of the chair itself. This allowed for a large factor of safety within the design. The yield stress used as the criteria for failure was 36000psi, which is the approximate yield stress of the steel being used. It was determined that the 1/8-inch steel plates would need to be used.

6- DESIGN ANALYSIS

6.1 Design Assessment #1:

The mother of the user brought forward concerns pertaining to safety of a seated chair versus use of a standing wheelchair. To explore this a design assessment was completed. Factors such as reach to farthest cow udder and overall height were examined, as well as distance from the back legs of a cow for safety.

To allow total control over the environment and assessment, a full-scale milking well was required with correct dimensions. Following the dimensions taken from the dairy, a model was created out of wood and PVC pipe to allow simulations to be run on the end of the well closest to the stairs where turning and maneuvering would be the most difficult. To simulate a cow for the assessment, a simple model was also constructed out of wood with bends in the legs and a blown up surgical glove in place of the udder to simulate the correct height and location of the udder. After contacting multiple companies in search of a rentable, standing wheelchair with no avail, it was decided that the well would be used to simulate raising the seat height of a regular wheelchair. The platform where the cow would stand was designed with the ability to be raised or lowered by increments of 4 inches, effectively simulating the user being raised or lowered, while only adjusting the model.

The assessment focused around having the user attempt to milk a cow at a specific height from three different orientations in his chair. The reach to the farthest udder, body turning angle and overall comfort were the main variables taken note of for each platform height. Alterations and ideas were tested during the assessment as well to try and maximize the user's reach. The first round of assessments were all conducted in the user's current wheelchair.

After locating a two electric motor powered wheelchairs with the ability to raise and lower automatically, the assessment was run a second time to get a better visual and feel of the user being raised with the platform and cow at the actual dairy barn height.

6.2 Design Assessment #2:
Once all the modifications were finalized and added to the chair, a second design assessment was required to allow the user to try the chair and find any potential extra modifications needed before the end of the project. The finalized chair with added lift kit and anti tippers was taken to the farm.

The user could transfer directly from his car to the chair and then given plenty of time to acclimate to the chair before going down the completed sidewalk ramp into the barn and cow well. The assessment was conducted within the cow well without any of the cows present, but with all of the required equipment there for the user to grab onto and test reachability from the new chair. The user felt that he had ample reach from his new height in the chair and that the only problem that arose was the gap between floor mat and wall where the front wheel was getting stuck. This problem was already addressed by the floor mats that were to be added.

It was discovered that the floor mats purchased were slightly too large and could easily be modified by cutting a strip off.

7- FINAL PRODUCT

7.1 Sidewalk Installation
The completed barn entry path is very similar to the back barn sidewalk concept mentioned above and in Figure 3. It involved digging out part of the dirt pit with excavation equipment and replacing it will gravel, putting rebar throughout the path, drilling holes for rebar into existing concrete to mesh the two structures together, placing vertical fence posts along the path, pouring concrete for the sidewalk, putting fencing on the fence posts, cutting a hole in the wall of the barn, and placing a steel frame and door in the hole.

The only changes from the concept and the finished product are that a curb was placed between the sidewalk and the rest of the lot. This was done to correct a minor height difference, but also to keep manure and dirt from getting on the path. This provides safer conditions for entering and exiting, and will reduce wear on the wheelchair. Pictures of the completed sidewalk can be seen in **Error! Reference source not found.** and **Error! Reference source not found.**.

7.2 Barn Modifications
The barn modification items include elbow pads, a calf milk jug dolly, and additional floor mats.

The elbow pads were purchased from REI Outdoor Store. They are intended for mountain biking, and are therefore flexible yet strong and lightweight. They will allow the user to be able to rest his elbows on the armrests and lean for extended periods of time without causing injury to his elbows.

A 16-inch plant dolly was purchased to hold the calf milk jug when necessary. The dolly is designed to hold heavy pots up to 500 lbs, and has wheels that allow it to roll around. The dolly will give the user the ability to easily push the calf milk jug out of the way if necessary, allowing him to continue to have full motion within the well even when the jug is present.

The floor mats were purchased through McMaster-Carr. They are made to withstand heavy loads and rough use. They are used to fill gaps on the side of the floor mat that was already in the milking well. Filling the gaps prevents the front wheels of the wheelchair from falling in and becoming hard to get out. They allow the user to focus on the job, rather than worrying about his wheels getting stuck on the mats.

7.3 Chair Modifications
A complete itemized list of all items purchased, their source, and their price can be found in the following section. The wheelchair mentioned in the final design above was purchased through 1-800-Wheelchair.com and required many modifications to meet the specifications of the design listed above in the Final Design section. The following are the specifications of the manufacturing process for the modifications.

The multiple modifications that were made to the wheelchair had parts almost completely manufactured from materials bought from McMaster-Carr. Once the raw materials were purchased, the University of Kansas Mechanical Engineering Machine Shop machined the parts represented by the drawings of **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.**, and **Error! Reference source not found.** to the drawings specifications. The modifications to the steel riser plates found in **Error! Reference source not found.** and the front steel riser tubes found in **Error! Reference source not found.** were finished by being powder coated black by HMC Performance Coatings located in Tonganoxie, KS. HMC Performance Coatings was generous enough to do the job for no cost. The Machine Shop was also employed to make modifications to the existing braking system of the wheelchair. The Machine Shop cut excess material off the brakes and drilled holes in the wheelchair frame. The Machine Shop was also employed to drill holes in the Anti-Tippers that were purchases so that they could be used in conjunction to the tipper block they also manufactured, seen in **Error! Reference source not found.**. A list of raw materials and hardware used for the lift kit can be seen in **Error! Reference source not found.**.

The remaining modifications to the wheelchair required no manufacturing, only assembly. The completed chair can be seen in Figure 7 and Figure 8.

8 - COST ESTIMATION

The main sources of cost for the project include the concrete sidewalk materials and contractor payment, the chair rentals for the design assessment and the materials for the full-scale model, the new wheelchair, the wheelchair modifications materials, the wheelchair cushion and elbow pads, the barn modifications, and the manufacturing cost for the wheelchair lift.

The total cost for the project was approximately $6766.21. **Error! Reference source not found.** in the appendix lists an amount for each expense mentioned in this report.

9 - ACKNOWLEDGMENTS

The team would like to thank the Occupational Therapist, Kelly Grabendike of Children's Mercy for being a constant source of advice and knowledge, Mike Miller for constructing the barn sidewalk and new side door, the University of Kansas Engineering Machine Shop supervisors for manufacturing the chair modifications, HMC Performance Coatings for providing powder coating for all chair add-on modifications, and Dr. Ken Fischer and Professor Thomas DeAgostino for providing constant advice and counsel. The team would also like to thank Pedro Wettel for joining and assisting us in the first semester and the Courtney Family for their patience while we worked all year towards a solution for them.

10 – REFERENCES

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11 - APPENDIX

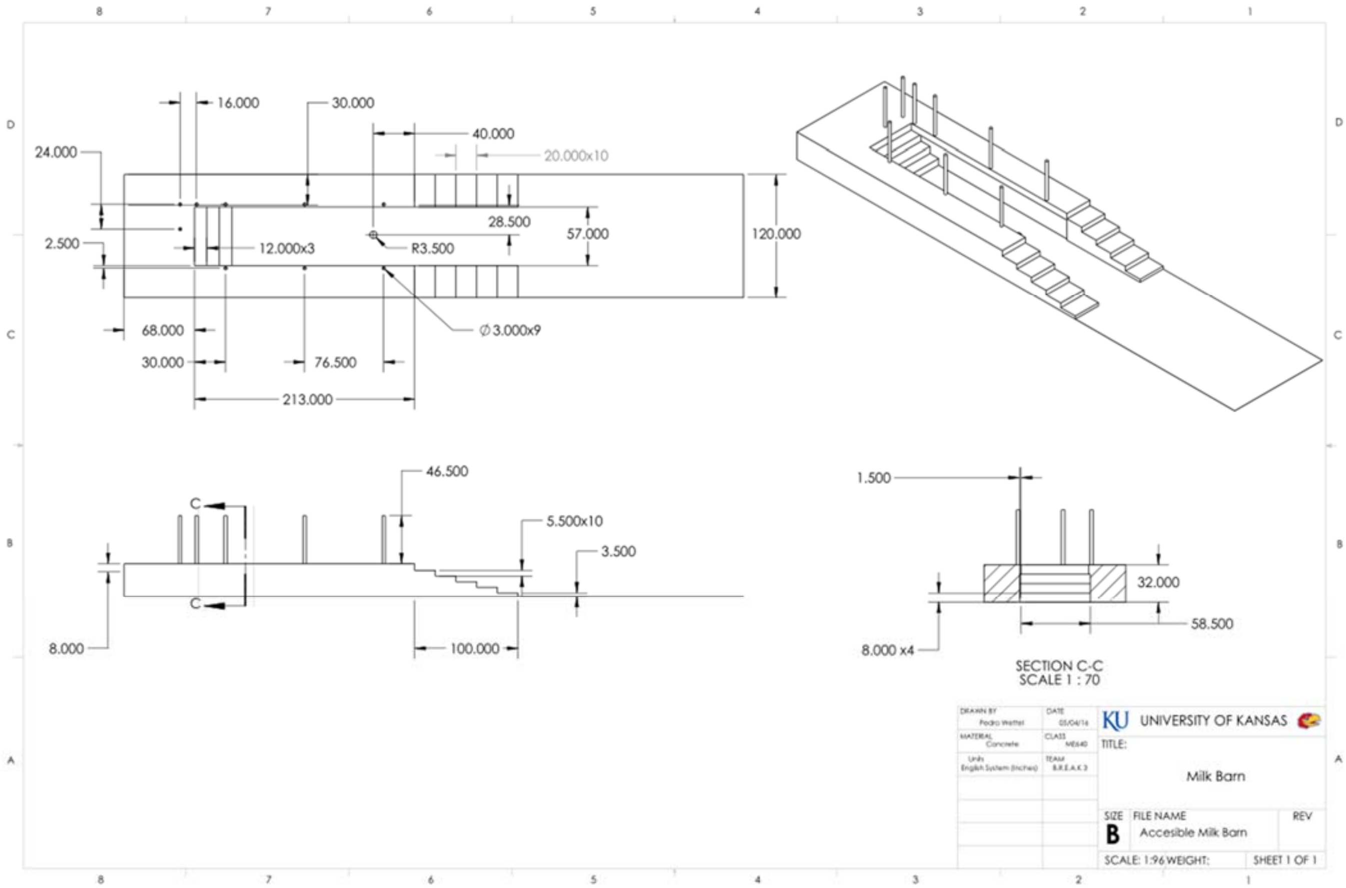

Figure 5. Dimensioned CAD model of the barn with more detail.

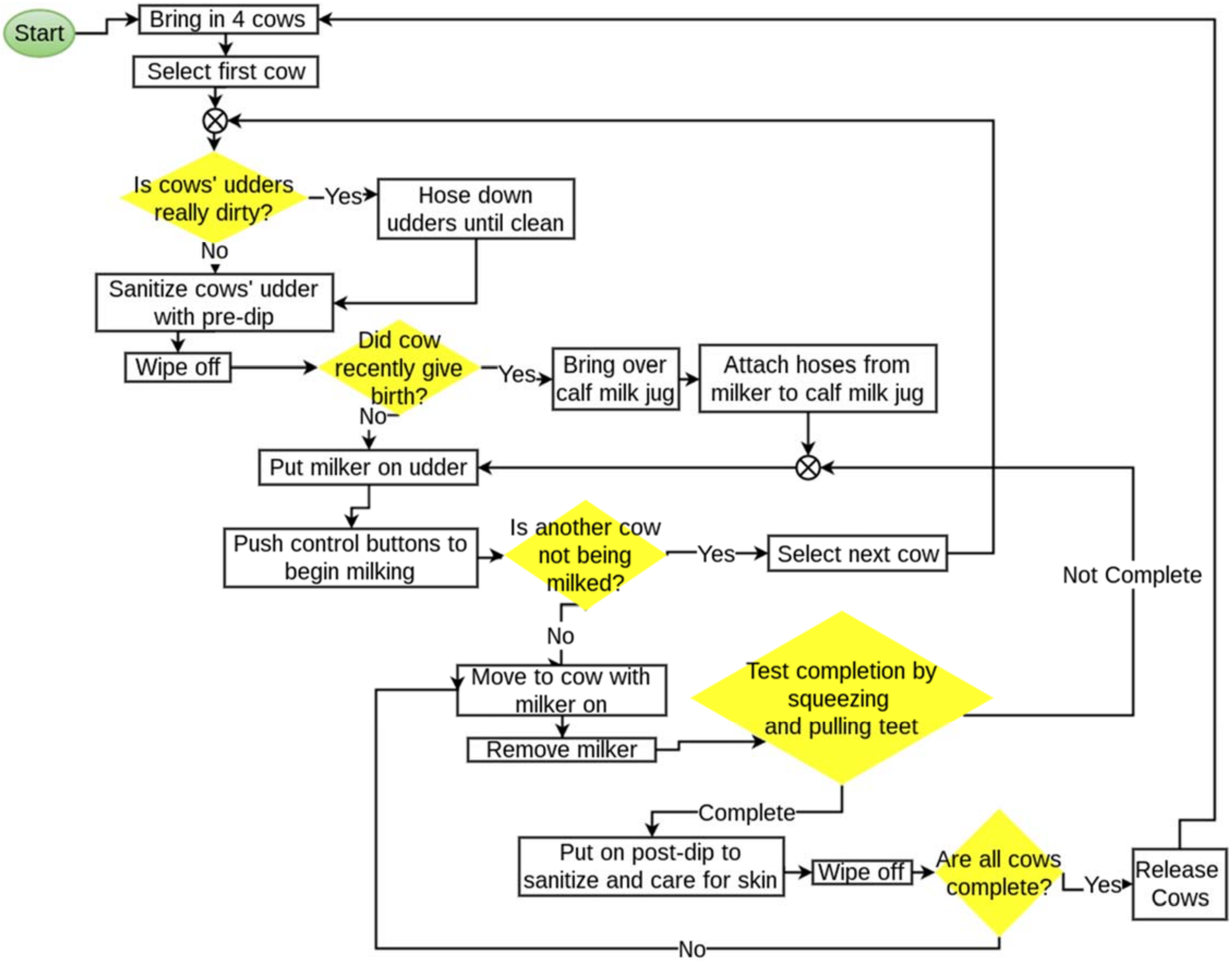

Figure 6. Process flow chart.

Table 1. Stair system selection matrix.

Selection Criteria	Rank	Weight	1) Motorized Platform Rating	1) Motorized Platform Weight	2) Cow Ramp Rating	2) Cow Ramp Weight	3) Moveable Ramp (winch) Rating	3) Moveable Ramp (winch) Weight	4) Back Barn Sidewalk Rating	4) Back Barn Sidewalk Weight
Safety	**1**	**0.2**	3	0.6	4	0.8	3	0.6	5	1
Ease of Use	**2**	**0.15**	5	0.75	4	0.6	4	0.6	4	0.6
Interference w/others	**3**	**0.15**	4	0.6	5	0.75	4	0.6	5	0.75
Simplicity of Design	**4**	**0.15**	2	0.3	5	0.75	5	0.75	5	0.75
Durability	**5**	**0.1**	3	0.3	5	0.5	5	0.5	4	0.4
Manufacturability	**6**	**0.1**	3	0.3	5	0.5	5	0.5	4	0.4
Compactibility/Storage	**7**	**0.1**	4	0.4	5	0.5	3	0.3	5	0.5
Cost Effective	**8**	**0.05**	3	0.15	5	0.25	4	0.2	4	0.2
Total Score			**3.4**		**4.65**		**4.05**		**4.6**	
Rank			**4**		**1**		**3**		**2**	

Legend	
(green)	High Score
(red)	Low Score

Higher= better

Table 2. Milking process selection matrix.

Selection Criteria	Rank	Weight	1) Elderly Track System Rating	1) Elderly Track System Weight	2) Aerial Track System Rating	2) Aerial Track System Weight	3) Altered Mechanical Wheelchair Rating	3) Altered Mechanical Wheelchair Weight
Safety/Failure	**1**	**0.175**	4	0.7	2	0.35	4	0.7
Ease of Use	**2**	**0.175**	4	0.7	5	0.875	4	0.7
Interference	**3**	**0.15**	3	0.45	2	0.3	4	0.6
Simplicity of Design	**4**	**0.15**	2	0.3	1	0.15	5	0.75
Durability	**5**	**0.1**	3	0.3	3	0.3	5	0.5
Requires Stair Subsystem	**6**	**0.075**	5	0.375	5	0.375	1	0.075
Manufacturability	**7**	**0.075**	3	0.225	1	0.075	4	0.3
Ease of Storage/Compactibility	**8**	**0.05**	1	0.05	4	0.2	5	0.25
Cost Effective	**9**	**0.05**	2	0.1	3	0.15	5	0.25
Total Score			**3.2**		**2.775**		**4.125**	
Rank			**2**		**3**		**1**	

Legend	
(green)	High
(yellow)	Middle
(red)	Low

Highest - best

Figure 7. Completed Karmen Flexx chair with lift system.

Figure 8. Completed Karman Flexx chair with lift system opposite view.