Uganda Mobile Irrigation

A Design Project for D – Lab II:
Designing for the Market at UC Davis

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Uganda Mobile Irrigation: Project Summary

Project & Client Background

This project was initiated by Agriworks Uganda Ltd., a company established by Abraham Salomon and Dennis Yiga. Mr. Salomon is a UC Davis graduate who has been working in Uganda since 2010 as a program representative on a collaborative research project on innovation systems in the rural economy. Mr. Yiga has over 25 years experience as a senior extension officer, farm manager, agricultural trainer, and innovation policy coordinator. The mission of Agriworks is to offer client services to small- and medium-scale rural farmers so that they can better implement extension recommendations and good agricultural practices. One of the first projects initiated by Agriworks was the development of a mobile irrigation service technology called AMIS (Agricultural Mobile Irrigation System).

The benefit of the AMIS model is that farmers who do not have the capital to invest in irrigation infrastructure could still have access to irrigation through a fee-for-service model. Irrigating current dry-farmed crops has the potential to double annual farm yields, and with prices up to four times higher in dry seasons, there are huge opportunities to increase revenues. In addition to the opportunity for an extended growing season, the AMIS system will increase yields during established growing seasons by providing supplemental irrigation during critical growth stages, which can increase yields with a small marginal cost. The AMIS target small- to medium-holder farmer has a ½-hectare or so plot where they grow a crop like bananas at some distance, up to 100 meters, from a source of water. The Agriworks mobile irrigation system operator will ride the motorcycle loaded with irrigation equipment to the reservoir or stream and unload the reservoir pump. A rigid hose is run from the pump to the source of water. Layflat hose is then run from the reservoir pump to the field, where it is connected to a booster pump that has been mounted to the motorcycle magneto. A sprinkler tripod is setup and connected to the booster pump, and the two pumps are run simultaneously to irrigate the crops.

The AMIS prototype is in the initial testing and implementation stages in Uganda (Figure 1). There are several design concerns that need to be addressed to move the project forward. Some of these design challenges are related to the hydraulic performance of the system, including the type of layflat hose, the interface between the booster pump and the motorcycle, and the sprinkler action. However, for the scope of this project D-Lab has been asked to construct a frame for the AMIS components that will reduce the amount of time currently spent on setup and breakdown time.

Figure 1. AMIS prototype in Uganda.

Design Brief

The current AMIS prototype utilizes an un-modified motorcycle; all the irrigation equipment is stacked on the back of the motorcycle and lashed down with rope (Figure 2). This system takes between 1 and 3 hours to setup and breakdown. The design challenge for this project is to critically examine system pathways to look for opportunities for saving time with a goal of reducing setup and breakdown time by 50%. The final product will be a custom frame that Agriworks can manufacture for the Bajaj Boxer 100 cc motorcycle that will make all of the irrigation system components accessible and easy to setup and breakdown.

Figure 2. Stacking equipment on the AMIS motorcycle.

Design Process & Methodology

The first step in the design process was to isolate the critical pathways in the setup and breakdown process and analyze opportunities for optimization. Our project partner Mr. Salomon timed each step in the setup and breakdown time and organized events by dependency (Appendix A: Timed Process Steps (Agriworks)). We took this data and ranked each step by percentage of time. The largest portion of time was devoted to unrolling and re-rolling the layflat hose between the reservoir pump and the booster pump. This took 24% of the total time. The second-longest process step, at 15%, was loading the equipment onto the motorcycle. The layflat hose represented not only a significant portion of time, it also weighs 43 kg, which is approximately 35% of the total irrigation system component and (estimated) frame weight (Appendix D: System Weights (D-Lab)). The layflat hose was therefore chosen as the primary design consideration.

Design Metrics

The full table of design criteria and metrics are found in Appendix E: Design Criteria and Metrics (D-Lab). The primary criteria that affected the design process are summarized below:

- The system is configurable
- The system is easy to assemble and disassemble
- The system works with the chosen Bajaj Boxer 100 cc motorcycle
- The design can be built locally
- The design is scalable
- The design optimizes trade-offs between width, height, center of gravity, and weight.

Design Step 1: Spool type selection

Initially, we prototyped a spool that could be rolled along the ground. However, when we tested this prototype, we found that the difference in diameter between the inside spool and the side wheels was too great for the hose to be rolled tightly. We discussed the possibility of gearing this interface, but after discussion with our project partner, we decided to try a different prototype that would drag the hose along the ground while it was cranked onto a spool mounted to the motorcycle. We have some concerns about the potential for damaging the hose as it is dragged, but Agriworks feels that dragging is the most preferable process, and they will discover during early field testing whether or not it creates a problem with hose damage. During the D-Lab testing damage was observed to the layflat hose when it was dragged over gravel with the couplers attached, but when a second test was done over a plowed agricultural field (the operational environment Agriworks is anticipating), preliminary tests did not show damage.

Design Step 2: Model the spool diameter

The spool diameter was modeled using Microsoft Excel so that different starting diameters could be entered and the resulting final diameter of the different lengths of hose calculated. After developing the model, we realized that the input width of each roll of hose might not match realworld conditions, so tests were done with rolling and unrolling hose (Figure 3). It was discovered that while the model accurately predicted the diameter of a new roll of hose, for re-rolled hose, the final diameter was consistently 30% larger than the model had predicted. This number might change again somewhat once the hose has been used to irrigate, but for the current design process the model results were adjusted upwards 30%.

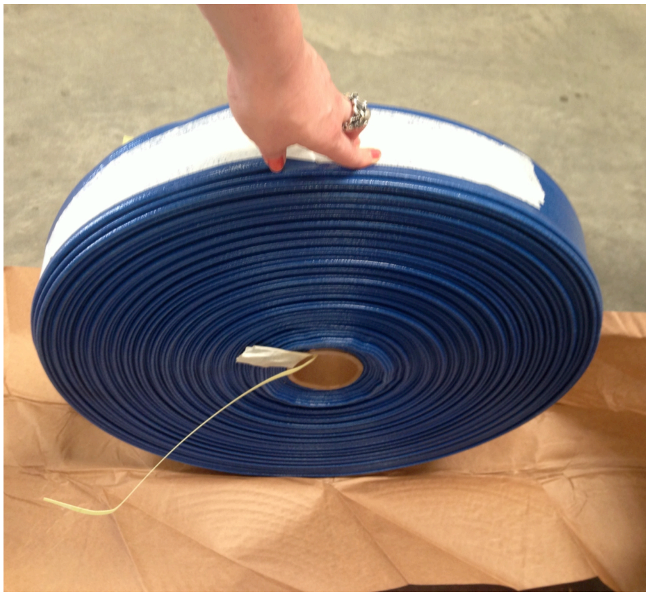

Figure 3. New hose (left) and re-rolled hose (right).

Design Step 3: First prototype

After we talked with our clients and brainstormed various different designs, it was apparent that a common component was a single spool large enough to hold all 100m of hose (two 30m and two 20m). It was also important that this prototype be strong to hold all 45kg of hose and survive multiple rounds of testing in different designs. A basic PVC pipe was used to provide a simple framework to begin building the rest of it. Hinges were screwed into the pipe at 90˚ intervals, so that the weight of the hose can be supported from above and below. And cement glue was used on the open end of the screw to help keep it from being pulled out, although now it appears better if we had used a long enough screw with a washer and nut. Then the two support beams for each side were welded together to distribute the weight across all four hinges. Finally, this was followed by bending the support beams and attaching a round metal rim, so that it guides the hose into the spool and provides an easy way to rotate it.

Figure 4. First Prototype.

Design Step 4: Second prototype

Once we established the spool performance on a spool capable of rolling all four hose lengths at once, we decided to experiment with larger diameters. A larger diameter spool will decrease the number of rotations required significantly, while minimally increasing the final diameter. We also experimented with different configurations that could allow for two side-mounted spools rather than one long spool. This prototype was constructed using reinforced cardboard tubing and plastic lids, in order to be able to experiment with different inside diameters. The prototype is wide enough to roll two lengths of hose, as would be used if two side-mounted spools were used.

Figure 5. Second Prototype.

Design Step 5: SolidWorks model

At this point, we were still talking and debating about how these different designs affect the ride-ability of the motorcycle, but there was no obvious answer from qualitative analysis. So it was suggested that we compare the different designs through Solidworks simulations of the center of mass. And we modeled the motorcycle by determining an estimate of the center of mass, and placing an object of equivalent mass there (123kg). The model riders are roughly average height and proportion, and are set with a homogenous density that adds up to an average weight of 68kg. Baseline comparison is set as the location of the center of mass of the just the motorcycle and riders alone.

The first design is the stacked design, where the reservoir pump sits on the back seat and the spool sits on top of the pump. This design is simple to support because all the weight sits directly on top of the seat. The reservoir pump is placed under the spool, as that is an easier location to lift a heavy weight from; however, this design would require a frame built above the pump to house the spool. The hanging design involves placing the heaviest component, the spool, in the optimal location and placing the rest of the components around it. Although this design keeps the weight low and the bike narrow, there is a large overhanging load on the rear tire which could have a negative effect on ride-ability. If the pump was supported with attachments that connect above or just in front of the back wheel it would neutralize the fulcrum that causes the front wheel to go up. One downfall is that it may introduce torque to the frame, but with proper attachments it should be strong enough to support just the reservoir pump. The last design is the two-spool design. This design has optimal center of mass and does not pull weight off the front wheel that would effect steering. In addition, it keeps the center of mass low, which helps keep the motorcycle from wobbling left and right. However, this design does add significant width to the bike – potentially as much as 60 cm.

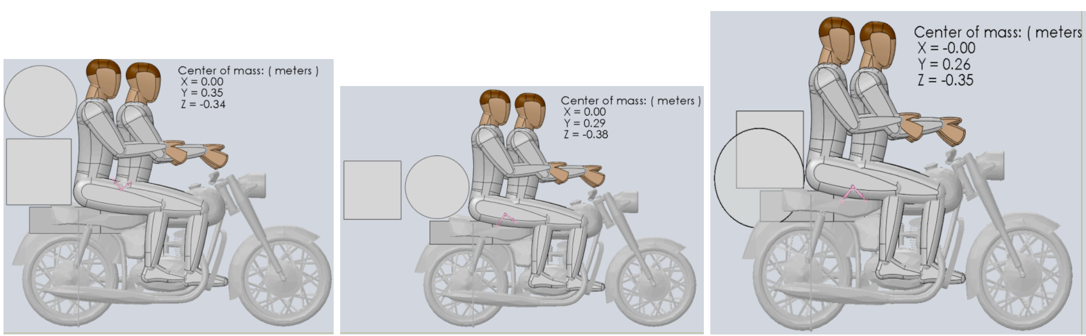

Figure 6. SolidWorks models.

Main Results

The main result of this design process was successfully rolling and un-rolling 50 m of hose in 5-7 minutes, an 85% reduction in time for this step. The larger diameter spool decreased the total number of rotations by about 40% with only a 6 cm, or 10%, increase in total final diameter (Table 1).

Table 1. Results of Hose Spool Experiments.

Method	Starting Diameter (cm)	Final Diameter (cm)	Number of Rotations	Time to Unroll 50m Hose (min)	Time to Re-Roll 50m Hose (min)	Change in Time (%)
Baseline	N/A	N/A	N/A	5 – 10	25 - 30	--
Wide Spool	12	46	54	1.5	5	-81%
Half-Spool	31	53	34	1.5	4	-84%

From the SolidWorks portion of the design, all three designs were compared relative to their different centers of gravity (Table 1).

Table 2. SolidWorks Model Center of Gravity.

Design	1 Rider Height offset	1 Rider Length offset	2 Rider Height offset	2 Rider Length offset
Just riders	0	0	0	0
Design 1 – Stacked design	0.18	0.21	0.12	0.15
Design 2 – Hanging design	0.09	0.25	0.06	0.19
Design 3 – Two spool design	0.06	0.22	0.03	0.16

Discussion and Conclusions

There are pluses and minuses to all three spool designs. The second design, which was only examined in SolidWorks, was viewed as the weakest option, because of the rear-hanging weight. However, there might be room to move the weight forward on the bike depending on the position of the riders. This design was considered because we wanted an alternative to a wide design (Spool design #3, 60 cm of extra width) or a tall design (Spool design #1, 40 – 50 cm taller). The side-mounted spool design (#3) has the potential benefit of lowering the center of gravity and making the bike more maneuverable. However, this is offset by the increase in the width of the motorcycle. In addition, this design requires that the layflat hose spool be split in half. These two halves could require additional frame or crank considerations, and would require that the hose length be disconnected at the midpoint for setup and breakdown. The top-mounted spool design (#1) has the benefit of being able to roll all four lengths of hose in one connected piece. In addition, it does not add much width to the bike. The height of the load is increased; however, this does match the weight distribution of the current setup.

After discussing these considerations with our project partner, it was decided that the final frame design should be based on the design of spool #1, the top-mounted spool. The starting inner diameter of the design will probably be increased in the final prototype. Considerations for manufacturing this design include finding a durable cylinder that could serve as the inner diameter of the spool. Ideally, this cylinder would be approximately 30 cm in diameter, but it may not be feasible to find local materials with that dimension. A cylinder could also be fabricated, depending on the trade-offs between strength, fabrication time, and operational time.

Assessment of the Design Process

Fundamental to this design process was the experience of working directly with layflat hose and field conditions. The first design we wanted to work with – the spool that would roll on the ground – seemed potentially feasible if adjustments were made during operation. However, after constructing a prototype of such a spool, we found that it was impossible to roll the hose onto the spool in a tightly-wound fashion. Working directly with the hose also allowed us to adjust our spool diameter model, and allowed us to feel the working weight of the system and qualitatively judge what type of handles and leverage would be needed for the design to be ergonomically sound.

More would have been accomplished in this project if the design process for the spool and the frame had been undertaken concurrently. Because solving the placement of the spool was viewed as being fundamentally upstream of the design of the frame, the layflat hose experiments dominated the shop time. One of the biggest things learned was how to build functional prototypes. Early prototypes we built were constructed out of steel, and this meant a lot of shop time was spent sawing or welding pieces that were only going to be briefly used for a conceptual consideration. One of the lessons of D-Lab's minimalist tool philosophy (using hacksaws and files, for example) is the ability to use time and materials efficiently in the design process. By the end of the quarter, we had learned a lot about fabricating prototypes, being creative with materials, and how to replicate pieces of a process to study them, rather than attempting to replicate the entire process.

Recommendations for future work

The recommended steps for future work on this project are:

1. Finalize the location of the spool with the client
2. Examine other options for hose coupling
    a. Currently the client feels strongly that the four lengths of layflat hose are critical to the configurability of the AMIS design. However, depending on the final business model, it may be more cost effective and increase ease of operation if something other than quick-release camlock couplers are used to connect the lengths of hose.

3. Determine the dimensions, specifically relative to the shocks, of the Bajaj Boxer under various load conditions (no rider, one rider, two riders, previous 3 conditions with equipment weight added)
4. Draft a frame design in Autodesk Inventor
5. Fit the remaining pieces of equipment onto the frame for easy access
    a. The remaining pieces of equipment are the booster pump, the sprinkler tripod, the toolbox, and the two pieces of hose that sit at the beginning and end of the system. These pieces should be incorporated into the frame in a streamlined manner, but they are small enough and simple enough that their placement is considered a far second to the layflat hose and reservoir pump.
6. If a motorcycle is purchased in Davis, fabricate a prototype frame and fit to the bike
    a. If a motorcycle is not purchased in Davis, it may be more productive to send the design to Uganda and have the prototype fabricated there
7. Work with Agriworks on pump interface challenges
    a. Agriworks is experimenting with solutions for strengthening the booster pump : magneto interface; a keyed shaft may ultimately be required
    b. Agriworks should purchase at least 2 pressure gauges in order to pinpoint the performance of their system upstream and downstream of key points
8. Work with Agriworks on a layflat hose supplier
    a. The current hose leaks excessively although it is one of, if not the, highest quality layflat hoses locally available. If a better hose cannot be found, it may be worthwhile to import the layflat hose.

Appendices

Appendix A: Timed Process Steps (Agriworks)

Appendix B: Process Steps Ranked by Timeshare (D-Lab)

Appendix C: Spool Diameter Model (D-Lab)

Appendix D: System Weights (D-Lab)

Appendix E: Design Criteria and Metrics (D-Lab)

Appendix F: SolidWorks Design (D-Lab)

Appendix G: Emails and Communications (D-Lab & Agriworks)

Appendix H: Equipment Specification Sheets (Agriworks)

Appendix I: Pre-Completion Deliverables (D-Lab)