FABRICATION OF BICYCLE CULTIVATOR

1.SAFWAN MOHAMMED KUNHI,2. SAHAL MUHAMMED,3. MUHAMMAD BANNA,4. ATUL S
PRIST University, Puducherry campus.

ABSTRACT

As it currently stands, most farmers in Zambia utilize hand tools in order to complete agricultural work, which is a physically taxing and time-consuming process. Typically, small- scale farmers in Zambia cultivate a piece of land about 5 acres, which has been reported to take the majority, if not the entire day to finish without more advanced technology ("Correspondence with a client," 2015). To save on time and effort, potential technological advances could be taken advantage of to supplement or replace the use of hand tools. The creation of a bicycle-source cultivator was implemented in order to remedy the current situation. Taking advantage of the plethora of bicycle frames and parts scattered across Zambia, this bicycle-source cultivator, shortened to bike cultivator or cultivator, was researched as an option to supplement/replace the use of hand tools for agricultural work.

1. INTRODUCTION

The idea is to take an old bicycle and strip all the parts, sans the back wheel. Then one can flip the frame upside down, weld the handlebars back into place, and place a cultivating tool on the bottom where the seat previously was. When implemented in the fields, pushing this mobile tool through the soil will cultivate with less physical stress in less time. The initial design referred to as Green Machine Mk. I is depicted in Figure 1 below

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Figure 1: Initial Bikultivator

Previous work on the bike cultivator consisted of fabricating the initial design currently utilized in Zambia in a local shop in the United States. This was done in order to analyze the inherent properties of the bike cultivator, perform tests and examine the inner workings of the tool. It was found that fabricating this initial design was feasible, and when compared to hand tools it saved an immense amount of time and effort in the field. This acted as the starting point of the designs depicted in this report, proving the bike cultivator is a successful agricultural tool.

The client was Jordan Blekking, a Returned Peace Corps Volunteer who served in Zambia from 2012 until May of 2015. The motivation for these designs was to save the people of Zambia from spending so much time and effort in the field. Jordan received a personal experience with the farmers in Zambia and was able to get a primary view on the issue. His depiction of the problem, as well as the motivation behind it, allowed for the team to design two separate prototypes to help solve the issue, which designs are presented in the appendix. It was reported that the bolts holding the sweep to the bike were shearing, and the seat post that connects the sweep to the frame was fracturing from stress. While the latter has recently been fixed by adding rebar as a support, the goal of this project was to design a sweep attachment that helps to solve both the issue with the bolts and the seat post-fracturing. In addition, Jordan also desired technical drawings of these new designs, in order to better disseminate and communicate to the welders in Zambia.

II DESIGN PROCESSAND METHODOLOGY

It was decided that the team would design two separate prototypes; One using bolts and removing the seat post (Design # 1, referred to as Green Machine Mk. II), and one utilizing the seat post but removing the bolts (Design # 2, referred to as Blue Bomber). This was done to see if both were feasible in Zambia and to analyze two different design paths. Following this, if both designs were technically reproducible in-country, comparison between the two designs could shed light on which would be preferred given available parts/costs of bolts and scrap metal.

Table 1: Criteria Matrix

Criteria	Qualitative or Quantitative	Metric	Target
Ease of fabrication	Qualitative	Likert scale of fabrication difficulty 1. Very easy 2. Somewhat easy 3. Average 4. Somewhat difficult 5. Difficult	No more than 3
Strength of sweep attachment	Qualitative	Stronger than previous design	Withstands more force over time than previous design
Amount of frame modification	Quantitative	Percentage by mass	Less than 25 percent
Repeatability	Qualitative	Repeatable in country	Yes

In Table 1 above, it can be seen that four main criteria were decided upon for analysis: ease of fabrication, strength of sweep attachment, amount of frame modification, and repeatability. Skill level for fabrication and welding was examined using the Likert scale. The Likert scale is an ordered scale from which respondents choose one option that best aligns with their view, often used to measure attitudes or opinions (Losby & Wetmore, 2012). The values are listed below:

1) Very easy
2) Somewhat easy
3) Average
4) Somewhat difficult
5) Difficult

A value of no more than 3 was the target goal, and it was found that with the team's basic skills, both designs were feasible. Strength of sweep attachment was analyzed next, with the goal being that these two designs could withstand more force at the sweep attachment than the previous design. Extensive testing was not completed for these designs, but Design #1 ran numerous times through local soil to test for functionality. Future tests should be completed in order to analyze this metric and are outlined in the recommendations section, but from a theoretical standpoint, both designs should be stronger than the previous design. The third criteria are the amount of frame modification, which is based on a percentage of mass added to the frame. Less than 25 percent was the goal for both designs and was found that both achieved this with little problem. Design #1 added less than 15% by mass, while design #2 added just above 10% by mass. The final criteria used to examine both designs was their reproducibility. It is desirable that either design could be repeated in-country by local workers with the available resources and within close tolerances. It was found that materials and resources are widely available and detailed drawings would allow for higher precision when creating future tools.

III RESULTS

According to measurements taken, represented by in Appendix B.2, the percentage of force experienced by the new bolt placement in Design #1 was determined using calculations performed with Equation 1, represented below. Shear force is equivalent to the amount of force experienced by the bolt perpendicular to its axis. As can be seen in Appendix B.1, the original orientation of the bolts put them at a 45-degree angle with respect to the ground. Substituting 45 degrees in for theta in the equation results in the bolts experiencing over 70% of the total force caused by the sweep (0.70711). Design #1 moved the bolts away from the sweep and closer to the attachment point, resulting in a shear angle with respect to the ground of 70 degrees. Substituting 70 degrees in Equation 1 produces a shear force of 34% of the total force, or 0.34202. This new orientation more than halves the forces experienced by the bolts, strengthening the design by removing a previous weak spot. These calculations do not take into consideration the strength added by modifying the attachment and distributing the forces over more of the bike frame.

$\sum F! = \sum F!$ =Blade force *cos(θ) (1)

Where $\sum F!$ is the sum of forces in the x-direction

$\sum F!$ is the sum of forces in the perpendicular direction

Θ is the shear angle of the bolts with respect to the horizontal

Initial tests indicate there were no efficiency losses due to the reinforced design and users reported that the sturdier frame "felt stronger". The team tracked the time it took to cultivate a 200-foot plot of land and compared it against the previous design's result. Design #1, modified from last quarter, was the prototype used for these tests in order to stay consistent with previous parameters. Due to constraints with the fabrication of Design #2, it is assumed that it would fare similarly. Table 2 below shows the average time between the two sets of tests was nearly identical, differing by only one second. This is likely due to the limited number of trials; It is assumed that the differences would be much smaller given larger sample size. To put this in perspective, the average time to cultivate this section of land by hand was reported from previous results to be approximately 15 minutes. If this estimation is correct, the bikultivator is nearly 15 times more efficient than conventional means.

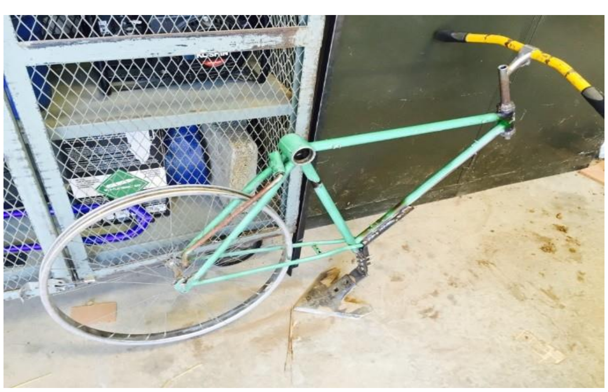
Table 2: Comparison between Green Machines Mk. I and Mk. II

Trial Number	Time (seconds)	Prototype
1	58	Mark 1
2	67	Mark 1
3	47	Mark 1
Average	**57.333**	
1	60	Mark 2
2	65	Mark 2
3	50	Mark 2
Average	**58.333**	

Another concern was loss of cultivation efficiency, measured by the ability of the user to remain in the furrow. The type of cultivation only requires a tool depth in soil of 2.5 centimeters. Workers using hand tools are able to control their direction more precisely because of their close proximity to the ground while the bikultivator designs from last semester shifted the perspective. However the prototypes were more manageable due to their increased strength and users reported more control in the direction of cultivation. Thus, high cultivation accuracy is maintained by allowing the tool to stay within the predetermined plot lines.

Fig 3: Bike Cultivator Design #1 fig 4: Bike Cultivator Design #2

Discussion



Once construction of the two separate bike cultivator design were complete, pros and cons of each design were apparent. Table 3 below depicts these pros and cons. The comparison between the two came down to the use/removal of bolts and seat post, how much scrap metal was used in the design, ease of attachment removal, and how engineered the design was. A prototype that has a higher dependence on small tolerances and additional functionality is considered to be more engineered. This is not always a positive, given the facilities available in- country may not be able to provide the necessary tolerances. It was found that Design #1 used less steel in its design and was easier to remove the attachment, but was more engineered when compared to Design #2. The opposite can be said about Design #2; more steel is used in the design and it is more difficult to remove the attachment, but it is less engineered. The use of bolts lends itself to ease of attachment, but can be seen as an expensive addition with the potential of shearing. Utilizing the seat post takes advantage of the bike frame, but also runs the risk of fracture. These major design differences lead into other points of interest.

Table 3: Comparison of designs

Prototype	Pros	Cons
#1 (Green Machine Mk. II)	• Use of bolts (ease of connection between attachment and frame) • Removal of seat post (No chance of fracturing) • Adjustable • Easy to remove attachment • Greatly reduces bolt shearing potential	• Use of bolts (expensive) • Rely on bike specifics for correct angle • More engineered • Requires relatively skilled welder • Holes for bolt connection difficult to produce evenly
#2 (Blue Bomber)	• Removal of bolts (No bolts, no shearing) • Addition of support bar hinders seat post fracturing • Less engineered • Utilized more of the bike frame • Less steel used in fabrication	• Lack of adjustability • Difficult to remove attachment • Requires relatively skilled welder • More steel used in fabrication

First, bolt holes in-country are produced by welding as opposed to the drills available in the United States. This produces an issue for Design #1, due to the reliance on bolt holes being at the same location. However, a skilled welder should have no problem producing relatively even holes that make for a flush connection between the sweep and the bike ("Correspondence with the client," 2015). It was discovered that the use of a jig could reduce the tolerance issue of bolt holes. This jig could be a hardened piece of steel with previously measured holes that the skilled welder could use repeatedly in order to assure that the holes are produced at the same location.

The angle of the sweep must also be augmented for each bike. This is due to the fact that bike frames vary in dimensions, so each frame would have an inherently different angle (referred to in the drawings as θ in Appendix B.2) at which the apparatus would have to be attached. This can be tested before welding by simple trial and error in order to avoid incorrect angles. To facilitate the necessary welding, bike frames would have to be made of steel. This is the most abundant type of bike frame in general, and this is especially the case of the older bikes found in Zambia ("Correspondence with the client," 2015). As for the various sizes, one of the pros of these designs is the fact that the attachments for each bike must be produced individually, and therefore a smaller bike frame would have its own unique attachment size over a larger bike but be able to follow the specifications provided by the technical drawings.

It was previously stated that usable bike is in abundance in Zambia, but seat posts for Design #2 are a different story. While it can be inferred that because bikes are abundant, then seat posts are also as readily available, but the real issue is finding a seat post diameter that is within proper tolerances. Design #2 depends upon seat posts and this could be an issue moving forward. Adjustability is limited in Design #2, due to the increased rigidity of welding the C- brackets onto the frame. Design #1 also experiences a lack of adjustability, but to a lesser degree. The number of holes at the connection point outnumbers the number of bolts used, resulting in one inch of vertical adjustability. This change could add to the physical comfort of the user and cause less exertion.

While outside the scope of this project, there is also a cultural impact these bike cultivators may have to the farming community of Zambia. Because agricultural work is a long process, it is often a time of socialization. Removing this from the workers could be detrimental to the social infrastructure of the community. Along the same lines, the use of a bike cultivator could possibly remove jobs for farmers due to reduced time and effort necessary to cultivate the land. Further information needs to be gathered to understand the long-term impact of such a project.

1V CONCLUSION / RECOMMENDATIONS

It is important to note that the results of the prototypes are not final and should be viewed as steps in the process. While the designs might have been successful in terms of cultivator efficiency and increased strength, there is still work to be done before these models are considered complete. It is, therefore, more appropriate to view the results through a lens of what was learned and what can be applied to future iterations. A major concern is the issue of tolerances. The current design used in-country reported both bolt failure and frame failure due to the forces experienced. Much of this can be attributed to imprecise hole tolerances. If the diameter of the hole is much larger than the diameter of the bolt, the bolt has room to move perpendicular to its axis, causing shear and bending. Furthermore, this perpendicular movement can stress the frame in unexpected ways, resulting in the failure along with the seat post-seat tube interface. Current in-country practices do not use a drill press or hand drill, but rather create the holes by dripping hot weld that melts through the steel. While this can be considered a means to an end, the holes produced can be completed with the desired tolerance with a skilled enough welder. Therefore, while creating precise holes through the two plates that attach the sweep to the frame was difficult to even with modern machines, it is feasible in-country. Design #2 depends on the tolerances of the steel support bar to be tight and consistent in order to lock in the sweep attachment. Measurements and welds have to be precise to keep the bar in the narrow range between too tight and too loose.

Despite these issues, the project is still considered to be a success according to its scope. The two prototypes are still much faster than conventional hand cultivating, approximately 15 times faster, while not sacrificing efficiency or accuracy. Strength of the sweep attachment has been improved in both designs by over 50% without radical changes. More importantly, the cost per tool did not change by a significant amount. Steel is widely available and is the only metal used in the improvements. Both designs have little increase in material, with Design #1 needing the most (Ten extra inches of angle iron). But even this amount does not cause a sizeable price increase since steel is usually scavenged from scrap materials. Other than tolerance limitations,

current welding practices in Zambia are more than sufficient to make the necessary changes to the design. Welders are not required to make welds that are more sensitive or weld for a significantly longer period of time. By increasing the strength of the cultivator design without sacrificing cost or efficiency, the team considers this project a success and offers suggestions as to where to invest future resources.

Potential future work consists of further testing on current designs to establish benchmarks. This testing should include force calculations, force applications, and surveyed field use. As of now, there is not a known average applied force on the sweep or the frame, making it difficult to determine improvements in each design iteration. Understanding the physical limitations of the design or the materials allows for target values to be met and exceeded. Field testing by agricultural workers in Zambia could prove how effective and efficient design is based on how long the fields take to cultivate and the longevity of the design. For example, if the cultivator can complete a field in half the time but it breaks three times as often as hand tools, it should not be considered a successful or sustainable design. Feedback from the workers would prove invaluable as they are the ones who will ultimately be utilizing this tool.

Specifically, future designs need to understand the in-country feasibility and the desires of the agricultural workers. Bike availability is not an issue, but it is important to use quality steel frames that are structurally sound. Design #2 requires multiple similarly sized bike posts to fit tight tolerances and it is unclear if that is possible in Zambia. Manufacturing is the biggest area of concern, with the tools and methods currently available making it difficult to reproduce accurate designs. Creating a jig system would aid in replication and incorporating more modern tools could increase accuracy further.

Designs 1 and 2 both suffer from a lack of height adjustability which was outside the scope of this project. However, this has been mentioned as desirable by the client and potentially by the workers themselves. Adjusting sweep depth would allow for a greater range of applications and be more ergonomically appealing for the user. Finally, the team has recommendations specifically in regards to the current designs. Design #1 still has bolts in shear, although this has been reduced by 50% from previous prototypes. Moving the angle of the bolts to be completely parallel to the force of the blade, and in this case, the ground would theoretically eliminate bolt failure. Design #2 is dependent upon the fit of the steel bar between the two C-brackets. If this bar were to come loose, the tool would lose much of its strength and be unable to function in its intended use. The team recommends an option where the bar is fixed at one end so it cannot be lost or easily come loose. A pin joint between the bar and the bike frame is one possible solution, although there are many others. Investigating the above recommendations would allow for a more robust design that meets the exact needs of the workers.

V. REFERENCES

1. Correspondence with the client (2015).

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