Manufacturing agricultural utility vehicles in sub-Saharan Africa

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Abstract: Reliable and affordable transportation is vital to economic growth. Transportation connects products to markets, people to education, and supplies to businesses and farms. However, Sub-Saharan Africa (SSA) generally has poor road infrastructure. Cameroon, a country of 23 million people in Central Africa, is no exception with paved roads comprising only 8% of all roads. Many of the unpaved roads are not maintained and are in poor condition. In addition, access to motorized transportation is severely limited in Cameroon where there are only 19 motorized vehicles per 1000 people and all of these vehicles are imported. Little work has been done on developing a vehicle that is affordable, locally manufactured, and suitable to the roads in SSA.

A university/NGO partnership has been working on affordable transportation and agricultural mechanization through the development of the Practical Utility Platform (PUP). The PUP is a three-wheel multipurpose vehicle with a carrying capacity of 900 kg. While primarily a transportation vehicle, the PUP can be used for many other operations requiring power. Water pumps, generators, grinders, and similar devices are easily powered off of the engine, making the PUP a portable power source. Also, testing has been performed where the vehicle successfully pulled ground-engaging agricultural implements. These added capabilities make the PUP more valuable to end-users.

The PUP can be built using parts and materials that can be obtained in Cameroon. The vehicle frame uses a single, common size of angle iron that is locally available. To power the vehicle, any 5-9 kW engine can be used. A belt and pulley set and a chain and sprocket set provide the necessary reduction for a maximum vehicle speed of about 35 km/hr. The driveline uses the transmission, driveshaft, and rear axle from a small car or truck, as there are many salvaged car parts locally available. The front strut, wheels, and brake system also recycled. Various prototypes have been designed, built, and tested extensively, both at the university and in Cameroon. The vision of this partnership is to set up a micro-factory for manufacturing these vehicles independently. Local manufacturing provides employment opportunities and boosts the local economy. Similar manufacturing models can be implemented in many other places in SSA, extending the impact. The PUP is designed for simplicity in manufacturing. The only necessary power tools are a drill, a grinder, and a welder. The frame is designed to utilize simple cuts and welds. The total cost of parts and materials for one PUP is typically under $2000 USD. With the low cost of labor, and an estimated build time of three weeks per vehicle, a PUP can be built and sold with a profit for a very reasonable price. In summary, an affordable vehicle has been designed that meets multiple transportation and utility requirements, and can be built in Cameroon using locally available resources.

Keywords: utility vehicles, sub-Saharan Africa, local manufacturing, agricultural vehicles, Cameroon

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1 Introduction

Quality and affordable transportation is critical to a stable food chain. When smallholder farmers have access to affordable transportation, their cost and time in transporting agricultural products is reduced and they have better access to agricultural inputs and markets. "Transportation needs to be seen as a key element in the value chain. Transportation costs can be a large proportion of total marketing costs" (Conway, 2012). The Sub-Saharan Africa Transport Policy Program (SSATP) states in its report on rural transport services in

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Africa that, “improved rural transport is a prerequisite for poverty alleviation” (Starkey, 2007).

According to the CIA World Factbook, 92% of roadways in Cameroon are unpaved (The CIA World Factbook n.d.). Unpaved roads in rural areas are often in very poor condition, making travel even more difficult (Figure 1). In Cameroon, there are only 19 motor vehicles per 1,000 people (World Bank n.d.). A World Bank report states that, “For smallholders, the movement of grain from field to farm store is often still by head load or bicycle and, in some places, by animal-drawn carts” (The World Bank 2011). Currently, most transport is on foot, which takes significantly more time and energy when compared to motorized transportation, especially when transporting a load. Many motorbikes can be found in the cities and rural areas of Cameroon. Although fairly inexpensive, these are appropriate for transporting a few people or a small load. Imported trikes can carry a larger load, but are best suited to the city and won’t handle the poor road conditions found in many rural areas. Old, imported cars travel rural roads, but they are much more expensive and were designed to carry people, not cargo. Small trucks can carry larger payloads, but are even more expensive and complex, making maintenance difficult.

Figure 1 One of many roads in poor condition in rural Cameroon

The SSATP report states that, “In all the areas surveyed, rural women and men complained that inadequate transport prevented them from increasing their productivity and improving their livelihoods. They said it was pointless to grow or make things for sale if there was no access to a suitable market. Because of poor transport, many rural people remain primarily subsistence farmers, with little impact on the regional economy” (Starkey, 2007). Poor or limited transportation can also cause post-harvest losses, because of delays from slow transportation. A study in Nigeria showed post-harvest losses ranging from 20 to 40 percent (F.F. Olayemi, 2012). In Tanzania, up to 13% of those losses are directly caused by transportation (World Bank, 2009). The results of a 2008 study done in East Africa showed that transportation costs are around 76% of the total maize marketing costs (The World Bank, 2011).

Sub-Saharan Africa is generally lagging behind agricultural production, even in comparison to other developing regions (FAO and UNIDO, 2008). Providing power in agriculture is critical for moving smallholder farmers out of subsistence farming and growing the local and national economies. Low production is, in part, due to a general lack of agricultural mechanization across the continent. With a density of 1.1 tractors per 1000ha, the mechanical energy utilized in agriculture is weak and shrinking (FAO, 2010).

Although mechanizing agriculture by importing tractors may work in the short-term and on large farm operations, this method is neither sustainable nor viable for small-holder farmers. With no in-country parts distributers, it takes just one broken part to put the whole machine out of service. Even if the owner or operator can order a part, the time delay makes the machine useless for field and processing operations that season. Additionally, there is likely to be little or no local expertise on maintaining and repairing foreign-made agricultural equipment. This is true for transportation vehicles, as well. A motor vehicle is expensive to import and the supply of parts is limited, although this is improving with some manufacturers, particularly Chinese motorbike companies. If importing machines, equipment, or vehicles is to be successful, it must be coupled with technical and supply-chain infrastructure to support it.

Importing is not the only option. Local manufacturing has many advantages. First, the cost to the customer for the equipment or vehicle decreases greatly, as shipping costs and import duties are removed. Another advantage is the development of the products is within close proximity to the customers of the products. This helps in making tools and machines that are suitable for the work required of them. Designs can be made that accommodate the local agricultural practices, climate, and specific demands. The close proximity allows for better feedback for better products. "Local manufacture has the advantage of being able to respond directly and rapidly to the demands of the agricultural sector" (Sims et al., 2012). Another advantage of locally manufacturing equipment is that it boosts the economy. Not only do farmers benefit, but they will pass the benefits on to the consumers of their products and the manufacturing industry will also help build the local economy.

2 Design

The Practical Utility Platform (PUP) (Figure 2) is a vehicle designed to be an affordable and locally sustainable intermediate means of transport (IMT) for goods and materials in rural Sub-Saharan Africa (SSA) and also a platform for powering other machines. The three-wheel vehicle can be built completely out of parts and materials available in Cameroon. Most of the main driveline and suspension parts are recycled from old cars. The PUP is designed with flexibility as to the type of cars and light trucks from which the parts are taken. In Cameroon, parts from 1980's RWD Toyota Corollas are used since these cars have been common and the recycled components required for the PUP (coil springs, rear axle, and transmission) still function well when the vehicles are scrapped. In addition to field tests of the PUP, several agricultural attachments and implements for the PUP have also been designed and tested (Wilson and Lumkes, 2014).

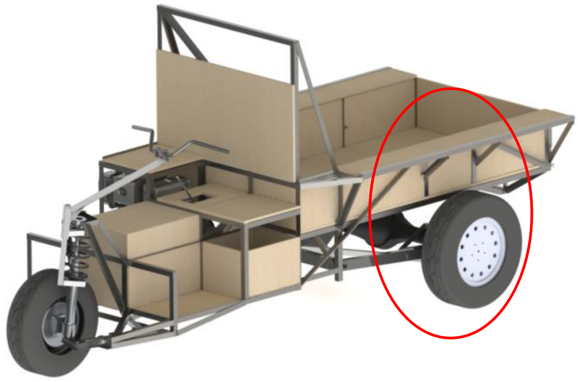


Figure 2 CAD model of the practical utility platform (PUP)

The overall length of the vehicle is 3.6 m and the height is 1.7 m (

Figure 3). The bed is 1 m wide and almost 2 m long, giving a total cargo area of 1.9 m^2. The wheelbase is about 2.5 m. Because of the flexibility of the design (e.g. the use of parts from a variety of cars), some of these dimensions can vary from vehicle to vehicle. The track width depends on the rims and rear axle that are used. The frame of the PUP uses about 100 m of 30x30x3 mm angle iron, a very common size of angle iron. Because of the efficiency of the truss design, minimal material is required to make the frame, allowing it to be lightweight, yet very strong. The bed, seats, and floor board, can be made of a variety of wood boards.

The PUP is designed to use a small diesel or gasoline engine (Figure 4A), around 5-8kW. The vehicles built in Cameroon have so far used single cylinder, 6.8 kW (9.1 hp) diesel engines, however, the make and model do not matter, allowing each manufacturer to utilize locally available options. From the engine under the passenger seat, a pulley and belt reduction (Figure 4B) of 1.5:1 (low) or 2.25:1 (high) transmits power to a jackshaft (Figure 4C). The clutch is an idler pulley tensioning and de-tensioning the belt. There is a 3:1 sprocket and chain reduction (Figure 4D) from the jackshaft to the transmission gearbox. This is very close to the 15 to 42 tooth reduction common on motorbikes, which can be found throughout SSA. The transmission gear box (Figure 4E) is a manual transmission from a RWD car or small truck. Depending on the model of the vehicle from which the transmission is taken, it provides four to five forward speeds and one reverse speed. A drive shaft (Figure 4F) transmits the power from the output of the transmission to the input of the differential rear axle (Figure 4G), which provides the final reduction of the driveline.

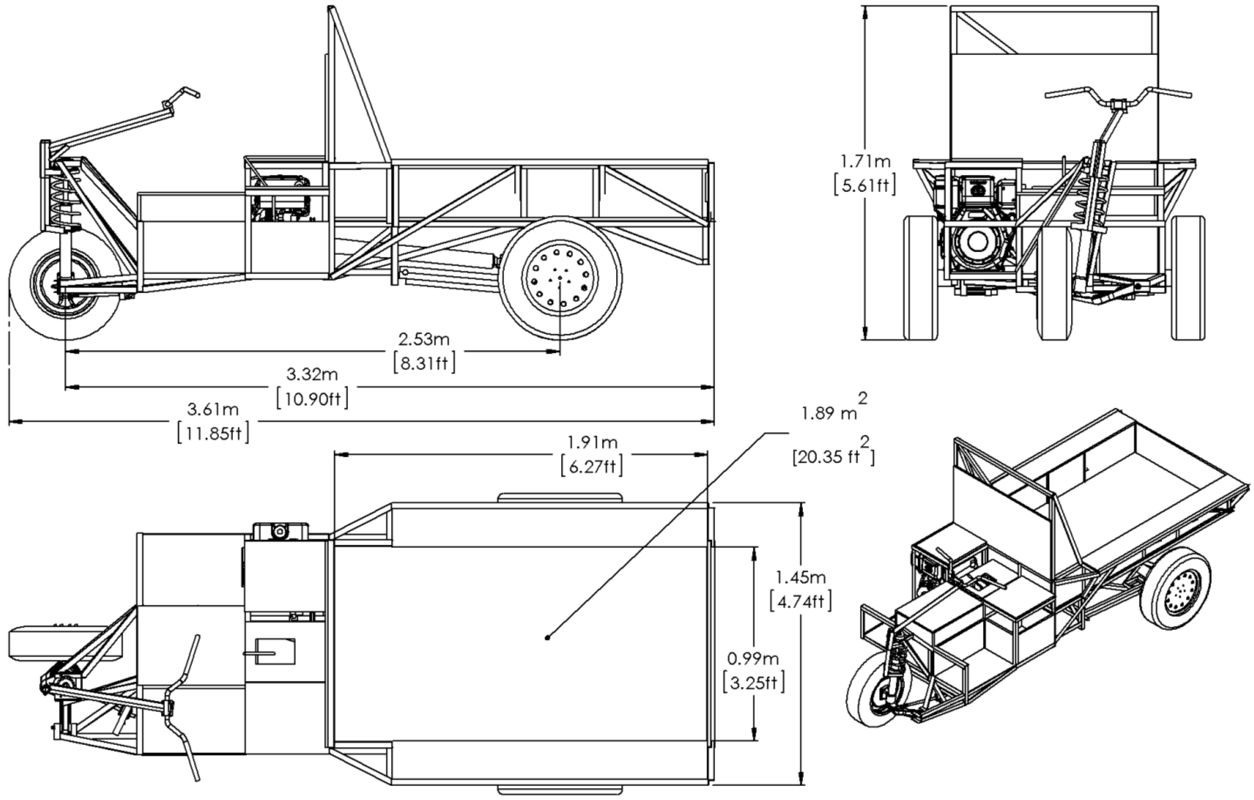


Figure 3 Dimensions of the PUP

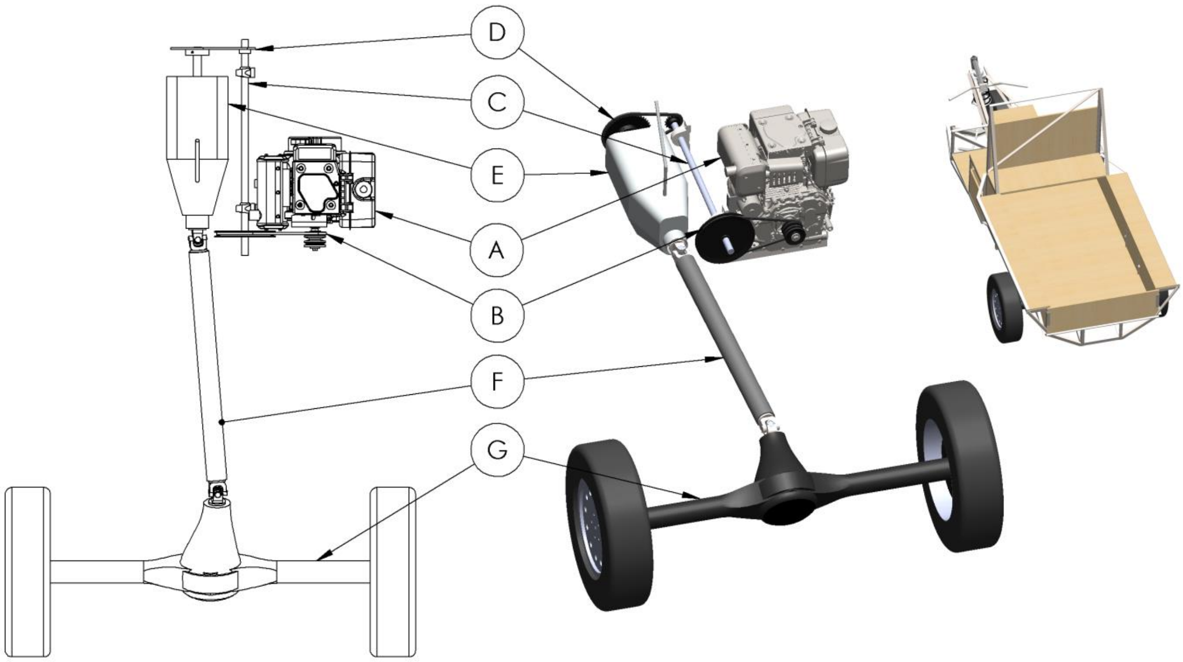


Figure 4 The PUP driveline: engine (A), belt-pulley reduction/clutch (B), jack shaft (C), chain-sprocket reduction (D), RWD transmission gearbox (E), drive shaft (F), and rear differential (G)

The rear suspension consists of two shocks and, depending on the stiffness required, two or four coil springs between the trailing arm and the bed. The rear axle is rigidly attached to a trailing arm frame that is hinged on the frame below the front of the bed. The trailing arm integrates a torsion bar to provide excellent roll-stiffness relative to typical three-wheel vehicles. The torsion bar is made by welding four pieces of angle iron into the shape of a square. The front wheel uses a full strut, left or right, from the front of a car. As in a car, it is attached to the frame so as to allow freedom of motion to steer. A simple handle bar and extension is attached for steering. The braking system uses a master cylinder from a car, the original brakes on each of the three wheels, and regular brake lines. The clutch and brake are activated with pedals as in a car and the engine throttle cable can also be attached to an accelerator pedal or a squeeze lever on the handle bar. Other small components of the PUP can be made or found locally.

3 Manufacturing

The PUP is designed to be manufactured using only local skills and tools. The primary processes in manufacturing the PUP are cutting angle iron, welding, grinding, and drilling. The ACREST workshop has the equipment required for each of these tasks. For four years, teams of students from Purdue have spent three to four weeks in Cameroon, and each year they have built a PUP while working alongside ACREST employees. This has provided invaluable feedback for designing the PUP for manufacturability. Usually a PUP can be driven within three weeks of the start of the build process. These three weeks consist of 7 to 8 hour days, five days a week, and the help of 6 to 8 students, one professor, one welder, and one mechanic or technician. However, there are often power outages and missing parts, which delay progress during the three weeks. Also, during that time, some people may be gone for a day getting parts or be working on repairing another vehicle. If there is power, the main frame assembly can take just a few days. The slowest parts of manufacturing are positioning and attaching the front strut and the driveline.

Since there are about 200 separate pieces of angle iron used in the PUP, cutting angle iron is one of the most repeated tasks in building a PUP. Cutting can be done by hand with a hacksaw, with a cutting wheel on a grinder, with a band saw, or with an angle iron shear. A hacksaw is inexpensive, but time and energy consuming. Although the hacksaw blades do not last long, they are inexpensive and easy to replace. When using a hacksaw, it can be difficult to make exact or straight cuts, although that is unnecessary for most parts. Using a grinder with a cutting wheel is much quicker than a hacksaw, but can also be difficult to control for precise and straight cuts. While more expensive than hacksaws, grinders are not very expensive, although they require electricity to run. Grinder blades also wear down and area slightly more expensive compared with hacksaw blades. Bandsaws are easy to use, make straight and exact cuts, but are expensive, slow, and require electricity. Although bandsaw blades last a long time, they are even more expensive and difficult to replace relative to grinder and hacksaw blades. An angle iron shear is very fast and can be precise. The cuts are very straight, but the angle iron can twist slightly at the ends. A shear is somewhat expensive as are the replacement blades, although they do not need to be replaced often. A shear does not require electricity to operate, but, unlike the other options, it can only make 90° cuts. Hacksaws and grinders are available in Cameroon and were used to fabricate the PUPs until the trip in 2014 when an angle iron shear was brought to ACREST to make the task easier. A band saw would be difficult to obtain and maintain.

The ACREST machine shop has a shielded metal arc welder, also known as a stick welder, which is widely used in Cameroon as it is a fairly simple welder. When the voltage and current are correctly set, stick welding is sufficient for the whole vehicle. However, care must be taken to make good penetration for solid welds, as some weld points in the frame and trailing arm will see high stresses. If a PUP has good welds, it should not fail under normal loading conditions, but it is subjected to over-loading and does fail, it can be easily fixed with welding, and sometimes the addition of reinforcing members.

The assembly manual contains instructions for the frame assembly, suspension assembly, transmission and jackshaft assembly, clutching and engine assembly, and woodworking. The assembly manual also includes a parts list, a tool list, and fabrication tips and tricks. To reach a broader audience, many photographs, models, and drawings are used, minimizing the dependency on written words for comprehension. Example pages from the assembly manual are in the Appendix,

Figure 5 through

Figure 8.

4 Cost

There is no stock price for a PUP, as each vehicle built so far has been a prototype, but the following is a description of the expenses occurred or approximated for the PUP built in Cameroon in May of 2014. A summary of the cost for the PUP is in Table 1. A more complete listing is provided in the Appendix in Table 2 (page 149).

Table 1 Cost list summary for 2014 PUP built in Cameroon

Parts	Cost	Percentage of total
Driveline subtotal	$ 1,101.89	58%
Frame subtotal	$377.51	20%
Front assembly subtotal	$87.23	5%
Supplies subtotal	$134.26	7%
Wheels and suspension subtotal	$196.38	10%
Parts and supplies total	$ 1,897.27	100%

The driveline is clearly the most expensive subassembly of the PUP, claiming 58% of the total estimated costs. The most expensive part in the driveline, and in the whole PUP, is the engine. For this prototype, a new Chinese, single cylinder, diesel engine was purchased in Cameroon for 596 USD, 31% of the total PUP cost. Smaller engines (4.8 kW; 6.5 hp) can be found for about 350 USD (diesel) or 170 USD (gasoline). The other major cost in the driveline is the car parts: clutch plate, transmission, drive shaft, and differential. These cost 280 USD (15% of the total) for the 2014 prototype in Cameroon (included new brake shoes and lug nuts). The only other single large cost of the PUP is the 100 m of angle iron for the frame, which cost 319 USD (17% of the total). Together, these three account for 63% of the vehicle cost.

It is expected that if multiple vehicles were to be manufactured, then parts could be purchased in a larger quantity and unit prices would decrease. For example, if ACREST plans to build 20 PUPs, they could order a crate of engines through a supplier or directly from the engine manufacturer. This would decrease or eliminate middleman, stock, and display costs from the price. The same is true for most of the other parts, even if locally supplied. Also, many of the parts were purchased in Cameroon by the Purdue team. Since few items have listed prices there, retailers sometimes mark up the prices for the foreigners, while a local would get a lower price. In addition, there was usually a shortage of time for acquiring parts, so it wasn’t always possible to find the lowest prices. If these factors could be eliminated, then the parts and supplies total for one vehicle could be reduced to less than 1500 USD.

5 Conclusion and future work

Similar versions of the PUP described here have been built in Cameroon in 2012, 2013, and 2014. During the 2014 visit to Cameroon the 2012 and 2013 vehicles were still useable, although both required maintenance, primarily with the engine and driveline components, and one had been set aside for a lack of good tires. Additionally, a change in the 2013 trailing arm design led to crack propagation along the welds, and ultimately failure. This was rebuilt and updated to the 2014 design. In total, both the 2012 and 2013 vehicles have experienced significant hours of use and valuable feedback has been collected. The design continues to evolve in pursuit of lower operating costs, manufacturing costs, and features. Each year, alternative clutching mechanisms, engine and drivelines configurations, and manufacturing methods are considered by students on capstone design teams. The basic platform has performed very well, with the angle iron truss frame providing a light-weight and durable platform, and recycled automotive components providing a durable and economical driveline. Local belts, used for the clutch, have suffered premature failures. These belts are locally available and low cost, but it is inconvenient in terms of maintenance. Alternative clutching mechanisms are being considered.

The PUPs are heavily relied on by ACREST to haul water, people, construction equipment, and transporting goods to and from the markets. Significant progress has been made on the development of a reliable, low-cost, and locally manufactured and sustainable multipurpose utility vehicle.

6 Acknowledgements

The authors are thankful to ACREST for a productive partnership and to the many undergraduate students who have been a critical factor in the development of PUP. This project would not have been possible without the support of the John Deere Foundation, Global Center for Food Systems Innovation (GCFSI)/USAID, the ASABE Giving Back Fund, and Purdue University through the Global Engineering Program, Vice Provost Office for Engagement, and the Department of Agricultural and Biological Engineering.

References

Conway, Gordon. 2012. *One Billion Hungry: Can We Feed the World?* Cornell University Press.

Olayemi, F. F., Adegbola, J. A., Bamishaiy,e E. I., and Awagu, E. F. 2012. Assessment of post harvest losses of some selected crops in eight local government areas of rivers state, Nigeria. *Asian Journal of Rural Development*.

FAO and UNIDO. 2008. *Agricultural mechanization in Africa: Time for action.* Vienna, Austria: FAO.

FAO. *Summary of world food and agricultural statistics.* 2010. Rome: Food and Agriculture Organization of the United Nations.

Sims, Brian G., Bhatti, Akhtar M., Mkomwa, Saidi, and Kienzle, Josef. 2012. Development of mechanization options for smallholder farmers: examples of local manufacturing opportunities for sub-Saharan Africa. *Paper presented at The International Conference of Agricultural Engineering.* Valencia, Spain: CIGR-AgEng2012.

Starkey, Paul. 2007. *Rural transport services in Africa.* Working Paper, Sub-Saharan Africa Transport Policy Program (SSATP),.

The CIA World Factbook. 2014. n.d. https://www.cia.gov/library/publications/the-world-factbook/ (accessed June 27, 2014).

The World Bank. 2011. *MISSING FOOD: The Case of Postharvest Grain Losses in Sub-Saharan Africa.* Technical Report, Washington D.C.: The World Bank; NRI; FAO.

Wilson, David W. and Lumkes, John H. 2014. Agricultural applications of the practical utility platform for developing countries. Beijing: CIGR.

World Bank. 2014. n.d. http://data.worldbank.org/indicator/IS.VEH.NVEH.P3 (accessed June 27, 2014).

World Bank. 2009. *Eastern Africa - A study of the Regional Maize Market and Marketing Costs.* World Bank, 70.

Appendix

Step 5.

Parts needed

-F014 x 2 (366mm)

-F015 x 3 (971mm)

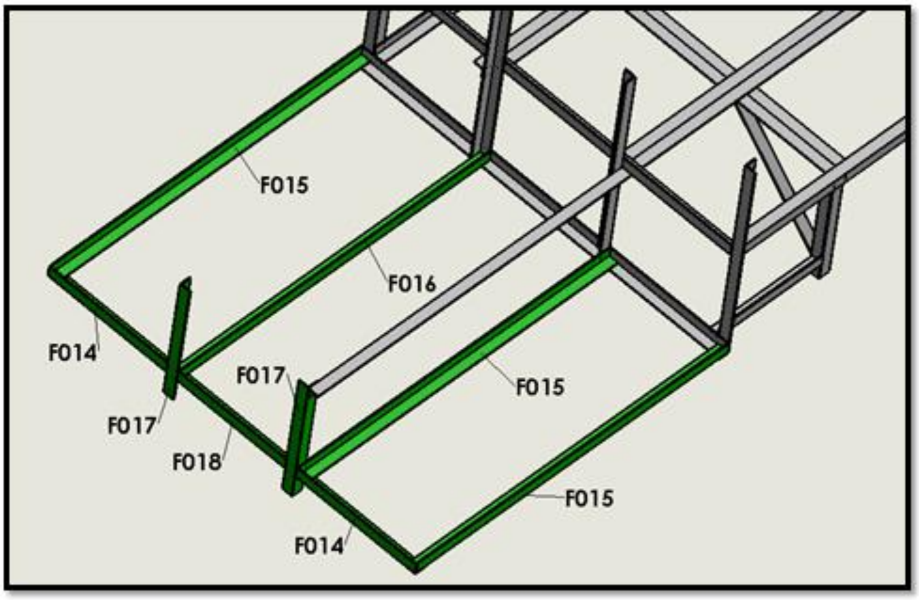
-F016 x 1 (968mm)

-F017 x 2 (360mm)

-F018 x 1 (388mm)

Note: Flip frame so that it is right side up for this step.

Layout and Dimensions



Welding Procedures:

Manufacturing Tips:

1. Spot weld 1 F014 and 2 F015 together to make driver floor.
2. Spot weld F018 to F016 to make lower transmission compartment.
3. Spot weld 1 F014 and 1 F015 together to make passenger floor.
4. Spot weld 1 F017 to F001.

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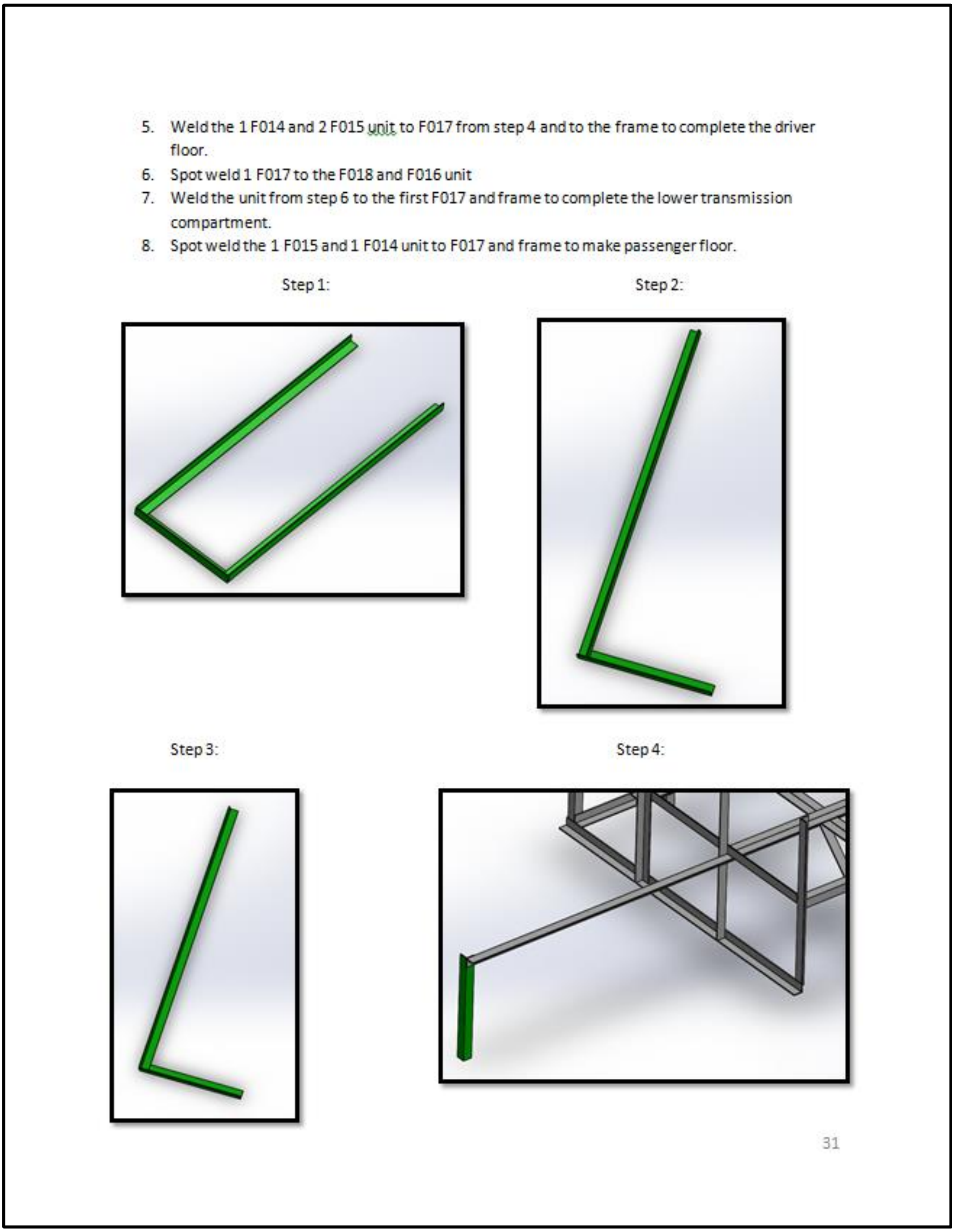
Figure 5 Assembly manual - frame step 5, page 1



5. Weld the 1 F014 and 2 F015 unit to F017 from step 4 and to the frame to complete the driver floor.
6. Spot weld 1 F017 to the F018 and F016 unit
7. Weld the unit from step 6 to the first F017 and frame to complete the lower transmission compartment.
8. Spot weld the 1 F015 and 1 F014 unit to F017 and frame to make passenger floor.

Step 1:

Step 2:

Step 3:

Step 4:

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Figure 6 Assembly manual - frame step 5, page 2

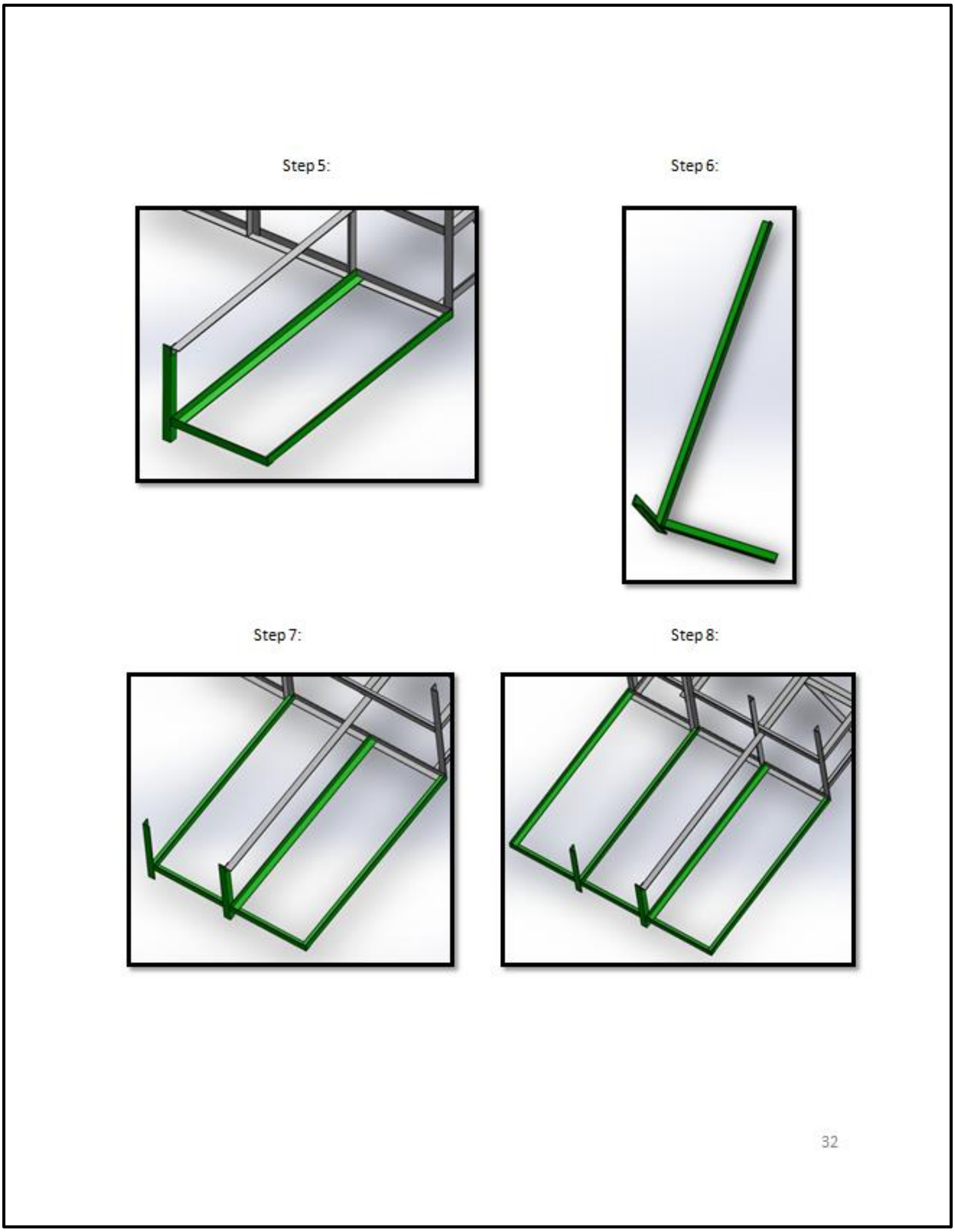
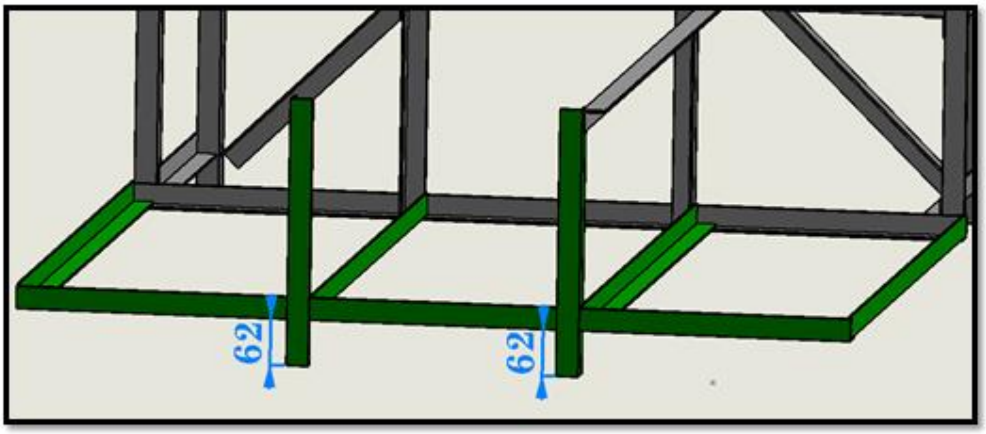


Figure 7 Assembly manual - frame step 5, page 3



Note: Take extra care to insure that all connections are square before and after welding.

Photos of Step 5:

Figure 8 Assembly manual - frame step 5, page 4

Table 2 Cost list for 2014 PUP built in Cameroon

Category	Parts	Number	USD/unit	Cost
Driveline	New diesel engine	1	$595.74	$595.74
	Driveline set (clutch plate, transmission, drive shaft, differential, new brake shoes, lug nuts)	1	$279.79	$279.79
	CV joint, master cylinder, and other parts	1	$59.15	$59.15
	1 inch pillow block bearing w/ lock collar	4	$9.60	$38.40
	Oil for gearbox, L	6	$4.26	$25.53
	3.95 inch OD, 1 inch bore, 2 groove pulley	1	$18.00	$18.00
	5.95 inch OD, 1 inch bore, 1 groove pulley	1	$16.25	$16.25
	40 pitch 45 tooth sprocket	1	$15.25	$15.25
	1.3125 inch 2-Bolt Flange Bearing w/ Lock Collar	1	$14.95	$14.95
	Box of 10 feet of #40 roller chain (3 feet needed)	0.33	$42.27	$13.95
	Oil for engine, L	3	$3.19	$9.57
	Rear axle U-bolts	1	$5.32	$5.32
	40 pitch, 15 tooth sprocket	1	$5.30	$5.30
	V-belt	1	$2.55	$2.55
	Gearbox vent hose	1	$2.13	$2.13
	Driveline subtotal			**$1,101.89**
Frame	Angle iron, 100m	100	$3.19	$319.00
	Un-planed wood boards	1	$56.38	$56.38
	Wood screws	1	$2.13	$2.13
	Frame subtotal			**$377.51**
Front assembly	Front strut assembly and brake pedal	1	$76.60	$76.60
	Handle bar	1	$10.64	$10.64
	Front assembly subtotal			**$87.23**
Supplies	Welding rods	120*	$0.50*	$60.00
	Grinding/cutting wheels	10*	$3.00*	$30.00
	Paint supplies for PUP	1	$25.11	$25.11
	Grease	1	$6.38	$6.38
	Brake fluid	1	$12.77	$12.77
	Supplies subtotal			**$134.26**
Wheels and suspension	Tires	3	$27.66	$82.98
	Tire rim	3	$15.96	$47.87
	Coil Spring	4	$10.00*	$40.00
	Shock absorber	2	$12.77	$25.53
	Wheels and suspension subtotal			**$196.38**
	Parts and supplies total			**$1,897.27**

*Estimated values