the Pontifical Academy of Sciences

Award Ceremony of the Pius XI Medal

Experience of building a low-cost tractor in a developing country Context: A case of Uganda

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Introduction

Most developing countries have an economy strongly dominated by the agriculture sector (Intarakumnerd, Chairatana, & Tangchitpiboon, 2002). Agriculture generates up to 50% of gross domestic product, contributing more than 80% of trade in value and more than 50% of raw materials to industries (Joshi, Gulati, Birthal, & Tewari, 2004). In Uganda, Agriculture and forestry contributes 14.6% of GDP (Fan, Mogues, & Benin, 2009; Kiddugavu *et al.*, 2003; UBOS, 2014) and employing about 80% of the population. Despite the domination, agriculture is grossly underdeveloped in most African countries (Mrema, Baker, & Kahan, 2008). Furthermore, 30-40% of agricultural produce is lost owing to poor post-harvest handling, storage and processing methods (Salami, Kamara, & Brixiova, 2010). Studies have shown that 99.4% of smallholder farmers use traditional, rudimentary and obsolete technologies and methodologies for post-harvest operations with devastating effects of high post-harvest losses and low market value. Therefore, there is high potential for expansion of the agriculture sector at all levels (Aksoy & Beghin, 2004). The low level of engineering technology inputs in agriculture has been cited as one of the main constraints hindering the modernization of agriculture and food production systems in Africa.

In Sub-Saharan Africa (SSA), land productivity is among the lowest in the world (Böttinger, Doluschitz, Klaus, Jenane, & Samarakoon, 2013), and Agricultural Mechanization has stagnated in recent years. In SSA countries, over 88.6% of farm power is still provided by people's muscles, mostly from women, the elderly and children, 10.2% of farm power is provided by drudge animals and less than 1.2% of mechanization services are provided by engine power (Kienzle, Ashburner, & Sims, 2013). These methods place severe limitations on the amount of land that can be cultivated per family. They reduce the timeliness of farm operations and limit the efficacy of essential operations such as cultivation and weeding, thereby reducing crop yields. 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 (Tiffen, 2003). As such 90% of the transportation of agricultural produce from field to home and/ or local markets is done on the heads of women and children (Boserup & Kanji, 2007).

Africa has enormous potential, not only to feed itself and eliminate hunger and food insecurity (Clover, 2003), but also to be a major player in global food markets, agriculture as a sector can therefore contribute towards major continental priorities, such as eradicating poverty and hunger. Despite a slight increase in production in Sub-Saharan Africa, Agricultural growth in SSA is generally achieved by cultivating more land and by mobilizing a larger agricultural labor force (Diao, Hazell, Resnick, & Thurlow, 2007), but there has been very little improvement in yields and barely any change in production techniques. Farm power in African agriculture, especially SSA, relies to an overwhelming extent on human muscle power, based on operations that depend on the hoe and other hand tools. Such tools have implicit limitations in terms of energy and operational output in a tropical environment

Current statistics indicate that there are about 470,000 tractors in Africa (Houssou, Diao, & Kolavalli, 2014). The total number of working tractors would have to be about 3.5 million (7 times more) to put Africa on a par with other regions. There are 0.175 tractors per 1,000 people in Uganda. The highest being Slovenia with 54.2 tractors per 1,000 people. In SSA the general average number of tractors is about 28 tractors per 1000 ha whereas it is about 241 tractors in other regions. Many areas of the developing world lack affordable transportation. Habitants spend a significant percentage of their time transporting agricultural products and water manually, over rough terrain and long distances, and it can be difficult to get fresh produce to markets where it can be sold before spoilage occurs. In Sub-Saharan rural Africa, Lumkes (2012) found that transportation problems cannot be solved simply by improving the roads.

To address the problems of SSA by providing affordable transportation of agricultural produce while offering portable power options for agricultural mechanization, water pumping, food processing, and electrical power generation, a team from Makerere University embarked on a project to develop a basic utility vehicle (BUV) that is low-cost, durable, adaptable and easily manufactured, which was modification of the existing BUV from Purdue University (Lumkes, 2015). A multi-purpose tractor dubbed the MV Mulimi was designed and fabricated at the Makerere University Agricultural Research Institute Kabanyolo under the sponsorship of the Presidential Initiative on Science and Technology. The tractor was intended for the vast majority of Uganda's farmers who cultivate on 10 acres or less, who may not be in a position to buy large-scale agricultural equipment given their incomes and farm sizes. With a body made out of a combination of wood and steel, the three-wheel vehicle 13-horsepower five-speed engine does not only plough fields, it also transports produce, threshes maize, pumps water for irrigation and can charge phones. It has a pump that pumps water from depths of up to seven meters to a height of 33 meters. The tractor comes with a three-disc plough. This will save farmers from the laborious task of using a hand hoe. This attempts to solve farmers' problems at the source. This paper seeks to show the experience of constructing a BUV in a developing country.

Design Considerations

A multi-purpose tractor dubbed the MV Mulimi was to be manufactured at the Makerere University Agricultural Research Institute Kabanyolo under the sponsorship of the Presidential Initiative on Science and Technology. The tractor is intended for the vast majority of Uganda's farmers who cultivate on 10 acres or less. These may not be in position to buy large scale agricultural equipment given their incomes and farm sizes, yet they still need labor to run their operations. A body is made out of a combination of wood and steel (made from locally available materials), a three-wheel vehicle 13-horsepower five-speed engine which does not only plough fields, but also transports produce, threshes maize, pumps water for irrigation and can charge phones would be fabricated. The tractor was to have a provision for mounting a three-disc plough.

Tractor & Engine Configuration

The selected configuration is a full-time rear-wheel drive with a Chinese 186F engine situated longitudinally besides the control foot pedals in line with the front wheel linked with the clutch through the sprockets-chain combination reduction system. From the clutch rotary power is transmitted in to the five-speed gearbox to the propeller shaft, differential and drive axles and finally to the hubs where the agricultural tires are mounted. The technical specifications are as in Figure 1.

Construction Procedures

The first week was spent laying out a fabrication plan, purchasing all the required tools, and clearing the work area inside the shop. A working table was made by screwing a steel plate onto a wood table and leveling it using spirit levels, after which purchase of the steel was done. There are many different steel suppliers in Kampala (Figure 1) and the steel comes from a variety of sources. Much of the steel was manufactured in Uganda or in other East African countries with some being imported from China, India, and South Africa. The market is flooded with very poor quality steel and supplies seem to be rather inconsistent with a short time on the shelf. Because of this, it was crucial to buy steel in bulk for small-scale vehicle production to ensure quality and consistency. Once the steel was purchased, the shop was equipped, the frame fabrication went on smoothly (Figure 2), although there were challenges of power outages in the shop. It is important to note is that manufacturing of the BUV was done using only local skills and tools.

Procurement Process

Procurement of vehicle parts was a slow process for the tractor because a middleman was used to locate the parts needed, which led to a limitation in terms of price negotiations to reduce costs for the vehicle. There was, however, an abundance of rear axles (Figure 3) and front strut assemblies as most of the cars in the country were four- wheel drives but rear-wheel drive transmissions were hard to find. A supplier was later found to supply transmissions, clutch assemblies, flywheels, and crankshafts.

For the sake of battery charging with the vehicle, the BUV required an alternator but one-cylinder diesel and petrol engines with in-built alternators and key-start were not easily available in Kampala. Agricultural tires were needed for the rear wheels, but small agriculture tires were not easily available in Kampala. These were purchased from Nairobi along with sprockets and chain, as they were more readily available than in Kampala.

The wood for the vehicle was locally purchased, machined to the precise size and cut into the required dimensioned pieces (Figure 4). The crankshaft hub was also cut and machined at a machine shop in town before being pressed on the shaft, balanced, then welded in place.

The electrical components were mostly taken from used cars with the taillights coming from motorcycles and the purchase of new headlights. The electrical system was installed (Figure 5) and tested, a plough provision was incorporated using a 2-disc plow from a walk-behind-tractor. Used lower links and an upper link from small tractors were purchased and then modified and a winch was added for raising and lowering the plow to save on materials.

Once the plough was complete (Figure 6), a threshing machine was purchased from one of the local government organizations that specialize in fabricating custom agricultural equipment and post-harvest processing machinery. The thresher was relatively large but could process up to 700 kg/hour and was easily mounted to the side of the vehicle allowing the operator to feed from the bed.

Functional Capabilities

The MV Mulimi after its completion could accomplish five major tasks: ploughing agricultural fields, transportation of agricultural produce and/ or workers up to 1 ton, pumping water up to a head of 33 m, providing electrical power for lighting and phone charging with output port built on the dash-board and, finally, availing rotary power to run stationary agro-processing equipment, for example, a maize thresher.

Performance-Related Challenges and Design Improvements

Since the machine design is new in the country, the plough and maize thresher which were used on the machine were not compatible. Some effort was made to modify the maize thresher in order to match the vehicle performance during testing, but more is still needed where one graduate student will have to come up with the best design. Ploughing was also tested and found not working effectively. Therefore, research will be done centering on the hitching system to maximize the ploughing capability of the multipurpose vehicle.

Conclusions

Despite the success of the project, this does not guarantee future success and sustainability of the project. There are still aspects of the project that are being learned and could lead to problems in the near future or even failure of the project if not considered. In particular, a project management strategy should be developed before beginning the planned small-scale production. The project is in need of a solid marketing strategy to integrate ICT in its operations. It is also necessary to mention that waste plastics are melted to liquid fuels that run this vehicle. Smallholder agriculture that represents the vast majority of farmers on the African continent is in dire need of technologies that work and are multi-purpose.

References

Aksoy, M.A., & Beghin, J.C. (2004). *Global agricultural trade and developing countries*: World Bank Publications.

Boserup, E., & Kanji, N. (2007). *Woman's role in economic development*: Earthscan.

Böttinger, S., Doluschitz, R., Klaus, J., Jenane, C., & Samarakoon, N. (2013). Agricultural Development and Mechanization in 2013 A Comparative Survey at a Global Level. *CECE-CEMA Summit*, 16 (17.10).

Clover, J. (2003). Food security in sub-Saharan Africa. *African Security Studies, 12* (1), 5-15.

Diao, X., Hazell, P. B., Resnick, D., & Thurlow, J. (2007). *The role of agriculture in development: Implications for Sub-Saharan Africa* (Vol. 153): Intl Food Policy Res Inst.

Fan, S., Mogues, T., & Benin, S. (2009). Setting priorities for public spending for agricultural and rural development in Africa: International Food Policy Research Institute (IFPRI).

Houssou, N., Diao, X., & Kolavalli, S. (2014). *Agricultural Mechanization in Africa South of the Sahara*.

Intarakumnerd, P., Chairatana, P.-a., & Tangchitpiboon, T. (2002). National innovation system in less successful developing countries: the case of Thailand. *Research policy, 31* (8), 1445-1457.

Joshi, P.K., Gulati, A., Birthal, P.S., & Tewari, L. (2004). Agriculture diversification in South Asia: patterns, determinants and policy implications. *Economic and Political Weekly*, 2457-2467.

Kiddugavu, M., Makumbi, F., Wawer, M.J., Serwadda, D., Sewankambo, N.K., Wabwire-Mangen, F., … Group, R.P.S. (2003). Hormonal contraceptive use and HIV-1 infection in a population-based cohort in Rakai, Uganda. *Aids, 17* (2), 233-240.

Kienzle, J., Ashburner, J.E., & Sims, B. (2013). *Mechanization for rural development: A review of patterns and progress from around the world*: FAO, Rome (Italy).

Lumkes, J.H. (2012). *Design of a Sustainable, Locally manufacturable, Agricultural Utility Vehicle for Developing Countries.* Paper presented at the International Conference of Agricultural Engineering. Valencia: Cigr-Ageng.

Lumkes, J.H. (2015). Manufacturing agricultural utility vehicles in sub-saharan Africa. *Agricultural Engineering International: CIGR Journal*.

Mrema, G.C., Baker, D., & Kahan, D. (2008). *Agricultural mechanization in sub-Saharan Africa: time for a new look*: FAO.

Salami, A., Kamara, A.B., & Brixiova, Z. (2010). *Smallholder agriculture in East Africa: trends, constraints and opportunities*: African Development Bank Tunis, Tunisia.

Tiffen, M. (2003). Transition in sub-Saharan Africa: agriculture, urbanization and income growth. *World Development, 31* (8), 1343-1366.

UBOS. (2014). *Uganda Demographic and Health Survey, 2004*: Uganda Bureau of Statistics.