Smart Mobile Vaccination Pickup for Sustainable Improvement of Medical Care and Smart Pandemic Control in Southern Africa

F. Stortz, J. Went, J. Koschikowski, Md. Nasimul Islam Maruf,
Fraunhofer Institute for Solar Energy Systems ISE
Freiburg im Breisgau, Germany
e-mail: Felix.Stortz@ise.fraunhofer.de

B. Lotz, M. Beckett
Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Stuttgart, Germany

L. Schäfer, F. Neumann
Fraunhofer Institute for Surface Engineering and Thin Films IST
38108 Braunschweig, Germany

M. Hamann
Stellenbosch University, Fraunhofer Innovation Platform for the Water-Energy-Food Nexus,
Matieland, South Africa

***Abstract*— In cases of crisis and disaster like the current Covid-19 pandemic, mobile, decentralized systems for providing medical services to the population can be a crucial addition to existing healthcare infrastructure. One of the challenges is to bring the technical solutions for containing the pandemic to bear under the economic and social constraints of developing and emerging countries through low-cost analysis and frugal innovation. In this paper an innovative self-sufficient mobile healthcare platform for different pickup vehicle models, which includes (i) a standalone and hybrid solar PV battery-based power system, (ii) a communication center for remote examination by telemedical services, (iii) a new cost-effective and reliable rapid tests for Coronavirus, but also other diseases, (iv) highly energy efficient refrigerators for medicine, vaccines, Coronavirus test equipment, etc., and (v) water treatment and purification technologies for the production of clean water is proposed.**

Keywords- PV off-grid sytem; Covid-19; Water treament; Mobile medical care; Mobile healthcare platform

I. Introduction

Mobile health clinic (MHC) is a visionary model that could help reduce health disparities in the most underserved populations [1]. Previous studies concluded that MHCs can effectively offer primary healthcare, provide preventative health checkups, and initiate chronic disease management [2]. They can deliver customized, high-impact, and reasonable healthcare that responds dynamically to the evolving needs of communities [3].

The risk of the further rapid spread of the Covid-19 pandemic is exceptionally high in many developing and emerging countries due to inadequate hygienic conditions. Demand for intensive care beds with artificial respiration, access to sterile medical equipment, disinfected surfaces, and the associated critical infrastructure during epidemic or pandemic situations rapidly outpace the capacity limits of hospitals in parallel with normal healthcare services. The situation is particularly precarious in peri-urban areas, informal settlements, and overcrowded refugee camps with limited medical services [4]. One of the challenges is to match the technical solutions for containing the pandemic with the economic and social capabilities often found in developing and emerging countries through low-cost analysis and frugal innovation. As the Covid-19 pandemic pushed the healthcare systems to the brink, innovative MHC models are needed to provide a range of services such as testing, vaccination, telemedicine, and clean water. This study presents such an innovative and integrated mobile healthcare platform (MHP) as an MHC solution with a focus on delivering vaccination services to very remote areas. The system components are modular, closely interconnected, and complement each other.

II. Status Quo of Mobile Health Clinics in Southern Africa

The concept of deploying MHCs is well established in Southern Africa [5, 6]. These clinics are invaluable to the operations of the various governments' health systems to improve the rural communities' access to primary healthcare services. MHCs have also been deployed for many years in Southern Africa as part of programmes to combat epidemics, such as HIV/AIDS, malaria, and tuberculosis [5]. These mobile clinics are typically deployed at sites on central communal areas such as schools, churches, sports fields, etc. or on workplace premises such as farms, mines, offices, etc. They are either deployed for short-term (one or more days) or long-term (weeks) periods. Short-term deployment requires the clinics to be mobile and mostly motorized, and are therefore usually vehicles such as pickups, trucks, vans, busses, trains, and even motorcycles that have been converted and customized to contain spaces for healthcare services [7]. A desktop study [8] in combination with interviews was done to identify manufacturers and operators in Southern Africa as potential future partners for the conversion of vehicles into MHCs for short-term deployments, as well as the manufacturing of accessories and components of such transformations. Many informal settlements and rural communities in Africa do not have access to healthcare services [9], especially when they are very remote and not easy to access by conventional mobile clinics. Mobile all-terrain and self-sufficient modular vaccination healthcare platforms (MHPs) mounted on pickups are able to provide healthcare to these communities with insufficient or no healthcare services.

III. Product Design

The modular self-sufficient MHP includes different components, which turns it into a unique concept. The components can be divided into (i) the hydraulic concept with the raw water treatment composed of an ultra-filtration unit, the on-board disinfectant production with a disinfection unit and the greywater treatment components, e.g., UV lamp, (ii) the electrical components, which includes the photovoltaic panels, the power electronic converters, the monitoring unit and the battery, and (iii) the medical concept mainly with the telemedicine components and the refrigerator. The different concepts are described in the following subsections.

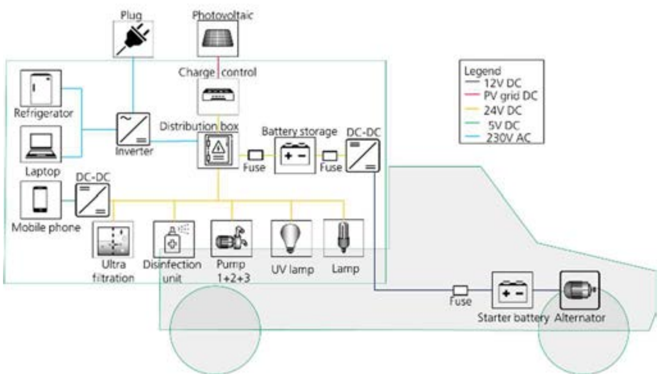


Figure 1: Schematic of the modular self-sufficient MHP with the electrical loads.

A. *Hydraulic concept*

The hydraulic concept is mainly responsible for the water treatment and purification technologies for clean water production and sanitation systems for hand washing and disinfection. Therefore, different technologies for the on-board production and distribution of disinfection substances are developed and designed for the modular self-sufficient MHP. The whole concept is presented in Figure 2 and described in more detail in the following subsections.

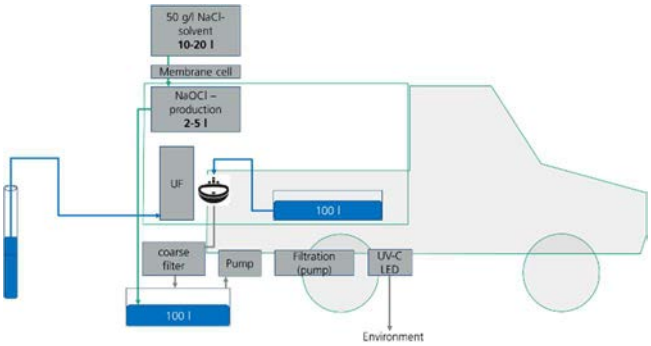


Figure 2: System plan of the hydraulic concept of the modular self-sufficient MHP

1) *Raw water treatment*

One major objective of the MHP is to produce fresh water on-site from local sources. These sources typically contain a huge variety of pollutants, which need to be removed by the water treatment system. Ultrafiltration was selected as a highly efficient and cost-effective membrane process. The small pore size of the membranes acts as safe barrier for e.g. biomolecules, bacteria, viruses, polymers, as well as colloidal particles, which are the most common pollutants of rural wells and surface waters. The selected UF system from SolarSpring GmbH is designed for low maintenance operation and is equipped with a pre-filtration unit and an automated backwash system based on intelligent control algorithms.

The fresh water is stored in a 100 litre buffer tank, where frequent disinfection guarantees a residual protection against germination. The disinfectant is produced on-board.

2) *Disinfectant production*

Disinfectants and antimicrobial agents play a substantial role in fighting diseases and the spread of viruses and bacteria. Although the antibacterial properties of sodium hypochlorite and sodium dichloroisocyanurate as hospital disinfectants have been known for many decades, sodium hypochlorite does not play a significant role in hand and surface disinfection today [10]. However, with the so-called Electrochemical Advanced Oxidation Processes (EAOP®) [11, 12], which has been developed and investigated over the last three decades, disinfectants such as sodium hypochlorite can easily be produced on-site by electrochemical oxidation [13]. Since biocide and hand sanitizers have to be brought along to remote areas currently, on-board disinfection production is a considerable advantage.

For the MHP, an on-site disinfection module was built consisting of an 18 L feed tank (Wyndale Plastics Ltd.), two DIACHEM® boron-doped diamond (BDD) electrodes with a total active surface of 6 cm^2 (Condias GmbH), and a 4 L free available chlorine (FAC) tank (Wyndale Plastics Ltd.), see tank (on top).Figure 3. With the feed tank enriched with 50 g NaCl per litre, the system is designed to produce 2.5 L disinfectant per day for a period of 7 days. Maximum FAC concentration is set to 100 mg/L NaOCl allowing emergency chlorination of the on-board produced fresh water with 0.5 mg/L as well as the use of 2.0 L with 100 mg/L FAC solution for greywater chlorination or surface disinfection on demand. With a single pass of NaCl solution through the electrodes at a specific charge of 6 A.min/L, the formation of persistent chlorinated byproducts, such as chlorate or perchlorate, was maintained far below the limit value in drinking water of 0.7 mg/L published by the World Health Organization (WHO). Antimicrobial tests showed a sufficient reduction of *E.coli* K12 on steel substrate of 3.5 to 5 log depending on residence time (Figure 4).

Figure 3: Basic disinfection setup with feed tank (below) and FAC tank (on top).

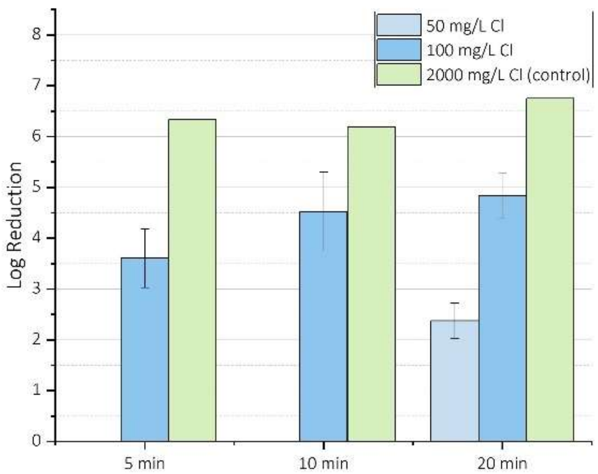


Figure 4: Log reduction at different NaOCl concentrations and exposure times. Tested with *E.coli* K12 on a stainless steel surface. Control at 2000 mg/L Cl (NaOCL).

3) Greywater treatment

The MHP aims to reduce the spread of the Coronavirus and other potentially harmful substances and pathogens. Thus, the water used on board, such as from the sink of the handwashing basin, requires effective treatment. A modular and flexible system is chosen to cater for the limited space on the vehicle itself but also in order to provide adequate treatment. A compressible and foldable collection tank (100 L storage volume) is connected to the sink outlet via a tube. A coarse filter in the sink or at the outlet of the sink removes larger particles. The process is designed in a way that the tank is emptied via a pressurized water pump (up to 14 L/min), mounted onto the vehicle by manually activating the respective switch. This way, it is ensured that energy is efficiently used and only used for the duration of the treatment process. The short period of time in which the treatment scheme is activated also extends the duration for which the greywater remains in the collection tank, enabling adequate settling of solids and particles. Activation of the pump simultaneously activates the subsequent UV-C LED disinfection unit. A screw filter mesh is placed before the pump, and a 5 µm PP filter is placed before the UV unit to ensure the protection of the pump and adequate sanitation. The disinfected water can then be discharged into the environment. Once the greywater is released from the collection tank, the pump and UV unit are switched off. Staff can complete the greywater treatment cycle (100 L) in under 10 minutes. The system is capable to treat several cycles of backwash water during one day. A combination with the on-board produced sodium hypochlorite is also possible and envisaged for the cleaning protocols of the components.

B. Electrical concept

The main goal of the electrical concept is the independent and standalone energy supply of the modular self-sufficient MHP. The base of this concept is the integrated photovoltaic (PV) cells in the roof and side panels of the MHP combined with a modern lithium-ion battery pack. Besides the PV energy supply, the system is also able to draw its electrical energy from the alternator, the buffer battery, and an external plug if the environmental situation does not allow full power support through the PV. The power electronics, battery, and capacitor of the refrigerator are cooled down to extend the lifetime of the electronic system in the hot sub-Saharan zones. The different loads are connected to the charge controller via a distribution box. A detailed schematic is shown in Figure 5.

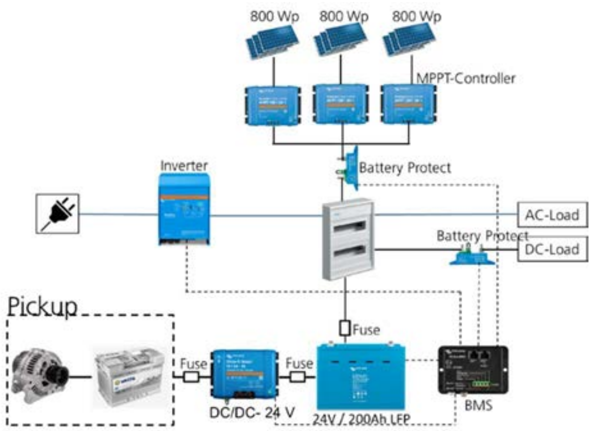


Figure 5: Schematic of the electrical self-sufficient power system with integrated PV and novel lithium-ion battery.

A calculation tool was developed to calculate the size of the components for self-sufficient mobile system. As the battery capacity design bases, the following boundary conditions were set. The battery needs to fulfill at least a self-sufficient level of one day, including the system consumption and the system losses. The degradation and the net/gross capacity was also taken into account in the design of the battery. The sizing of the PV was adapted to the area of the MHP. A newly integrated PV arrangement is shown in Figure 6. During stationary operation of the pickup, the PV panels at the side of the cabin will be unfolded to extend the PV field on the roof. This increases the PV area, and optimizes the irradiation angle, as well as increases the shaded area. During traveling, the system is packed together, to avoid damage. Additionally, a smart battery management system is installed to monitor and control the PV battery system.

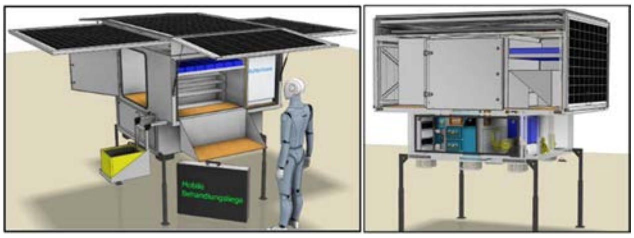


Figure 6: 3D design of the developed modular self-sufficient MHP.

C. *Medical concept*

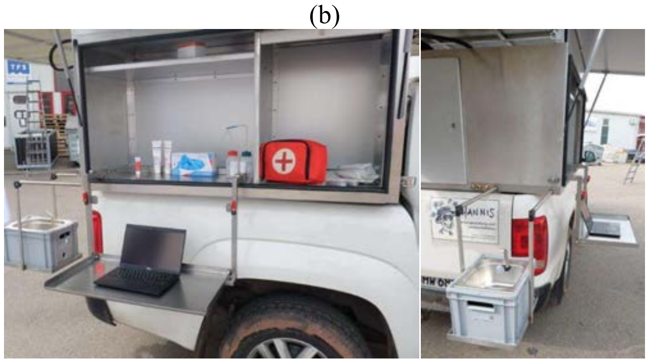
The medical concept of the pickup is divided into four main areas, which includes (i) a vaccination area, (ii) telemedicine area for remote medical advice, (iii) a testing area to test the patient on different diseases and (iv) a data monitoring area and digital patient file for reporting.

IV. Implementation

A prototype of the modular self-sufficient MHP was implemented to understand the system better and test the system under operational conditions. Therefore, in South Africa and Namibia partners will use the system under real-life conditions for several months respectively. This will produce important data for further development. In Figure 7, the modular self-sufficient MHP (a) with opened PV modules, with (b) the driving configuration and with (c) impressions of the inside are shown. The system can be adapted very rapidly for different pickup models to offer a wide range of use configurations.

(a)

(b)



(c)

Figure 7: Implemented modular self-sufficient MHP (a) with opened PV modules, with (b) the driving configuration and with (c) impressions of the inside.

V. BUSINESS MODEL

A. Evaluation of different business models for sustainable commercialisation of the developed solution

State healthcare in Southern African countries is characterized by poor performance delivery and insufficient funding [14]. Therefore, these countries are heavily reliant on supplemental funding from external donors, which flows through private channels in many cases. The private sector consists of for-profit providers, non-governmental organizations and not-for-profit organizations (local and international) [15]. In the last few decades, it has become more evident that a public-private engagement (PPE) to deliver on healthcare projects in Southern Africa could provide for a sustainable business model [15]. As a result, different PPE mechanisms have been developed for healthcare financing and delivery.

The only PPE mechanism relevant to the modular self-sufficient MHP is the Public-Private Partnership (PPP) model [8]. The PPP model can be further sub-divided into six sub-models: Private Finance Initiative, Public-Private Integrated Partnership, Alzira Model, Franchise, Co-location Public-Private Partnership and Global Public-Private Partnership [14]. Of these sub-models, the Private Finance Initiative and the Public-Private Integrated Partnership are the most relevant to the piloting modular self-sufficient MHP in Southern Africa. These sub-models are explained in the subsections below.

1) Private Finance Initiative

This PPP sub-model involves a long-term contract. Following the public health authority requirements, a facility's design, building and non-clinical operation are contracted to a consortium of private entities. A private entity provides financing.

2) Public-Private Integrated Partnership

Like the Private Finance Initiative, the Public-Private Integrated Partnership is also a long-term PPP between a consortium of private entities and state healthcare. The private consortium also provides the finance. However, in this partnership, contracted services also include clinical operation and the facility's design, building, and non-clinical operation, per the public health authority requirements. Also, the contract in a Public-Private Integrated Partnership will specify specific outcomes, such as a certain quality of a particular service to a specific segment of the population.

B. Development of a preliminary business model for Public-Private Integrated Partnership

The Public-Private Integrated Partnership seems like the most suited business model for introducing the modular self-sufficient MHP to Southern Africa, since the project will entail sophisticated technology that would require a great deal of care at first during the pilot phases in Southern Africa. The project's success rate will be higher if a small private entity such as a not-for-profit organization can first be trained to operate the mobile health clinic of the modular self-sufficient MHP for a particular service, such as COVID-19 testing and vaccination. Later, a Private-Finance Initiative can be considered for a broader application of health services by a public healthcare institute once all teething problems have been solved.

Business model and value proposition exercises were performed to define better the value of the proposed mobile clinic of the modular self-sufficient MHP that would justify a rollout of the pilot programme in Southern Africa. The most important finding that came out of the business model exercise, which was not previously considered, was that the rollout of the pilot phase would also need to budget for nurses' salaries, as many clinic operators do not have the resources to staff an additional deployment. The value proposition exercise showed alignment between the expected value the proposed mobile health system provides and the expectations from the customer (mobile clinic operator); however, security (hijacking of vehicles and theft of equipment) is still a concern that must still be addressed on the value proposition side.

VI. CONCLUSION

In this paper, an independent modular innovative self-sufficient MHP for underserved, very remote areas was introduced. The cabin was constructed for a wide range of pickups. The market and the need for a modular self-sufficient MHP in Southern Africa are given, and a business model was worked out. To summarize, the system includes:

- Standalone PV and hybrid energy supplies for an independent pickup cabin,
- communication center for remote examination by “telemedical services”,
- highly energy-efficient refrigerators for medicine, vaccines, Covid-19 test equipment, etc.,
- on-board production of disinfectants,
- water treatment and purification technologies for the production of clean water and treatment of greywater, and
- flexible use of the MHP, meaning that different pickup models can use the cabin.

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