CZECH TECHNICAL UNIVERSITY IN PRAGUE

FACULTY OF BIOMEDICAL ENGINEERING

Department of Biomedical Technology

ELECTRONIC IMMUNIZATION REGISTRIES IN LOW- AND MIDDLE-INCOME COUNTRIES: ECONOMIC EVALUATION

Master thesis

Study programme: Systematic Integration of Processes in Healthcare

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MASTER'S THESIS ASSIGNMENT

I. PERSONAL AND STUDY DETAILS

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II. MASTER'S THESIS DETAILS

Master's thesis title in English:

Electronic Immunization Registries in Low and Middle Income Countries: Economic Evaluation

Master's thesis title in Czech:

Electronic Immunization Registries in Low and Middle Income Countries: Economic Evaluation

Guidelines:

The objective of the thesis is to analyze the benefits of Electronic Immunization Registries in comparison to currently used paper-based Routine Health Information Systems in Low and Middle Income Countries. Analyze previous studies related to the benefits of implementing Electronic Immunization Registries, the costs incurred when EIRS are implemented, and cost savings realized as a result of utilization of EIRs. Based on available data estimate the operation costs of implementing an EIR in a low and middle income country. Select a suitable vaccine and disease that could be used an example for EIR economic evaluation. Lastly, the thesis would end with a conclusion on whether EIRs are cost effective and beneficial in low and middle income countries.

Bibliography / sources:

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DECLARATION

I hereby declare that I have completed this thesis with the topic "Electronic Immunization Registries in Low- And Middle-Income Countries: Economic Evaluation" independently, and that I have attached an exhaustive list of citations of the employed sources.

I do not have a compelling reason against the use of the thesis within the meaning of Section 60 of the Act No. 121/2000 Sb., on copyright, rights related to copyright and amending some laws (Copyright Act).

In Kladno 08/08/2022 MUDr. Sandra Ifeoma Nnabuife

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Master’s Thesis title:

Electronic Immunization Registries in Low- And Middle-Income Countries: Economic Evaluation

Abstract:

Objectives: This Master thesis analyses the challenges and benefits, the differences in vaccination costs and vaccine program effectiveness, and the impact on disease events, health benefits and cost-effectiveness when Electronic Immunisation Registries are used in place of paper-based records in Low -and Middle-Income Countries (LMICs).

Methods: A cross-sectional analysis was carried out using primary data obtained from 61 facilities in 10 regions in Tanzania that comprised Electronic Immunisation Registry (EIR) users and non-users. The data was analysed to yield the difference in unit healthcare costs for vaccine activities per child registered in these facilities in a year and costs of 14 vaccination activities. Afterwards, a cost-effectiveness analysis was carried out using the UNIVAC model created by the Pan-American Health Organization (PAHO) and the London School of Hygiene and Tropical Medicine to assess the cost-effectiveness, and disease events averted when EIRs are used instead of paper-based records for rotavirus vaccination in Tanzania.

Results: Of the 61 facilities evaluated, 36 had implemented EIRs at some point, but only 17 facilities were currently still using them. The unit healthcare costs for vaccine activities per child per year were 1.78 USD and 1.59 USD for EIR non-users and users, respectively. Facilities using EIRs had statistically significant lower costs in 6 out of the 13 staff costs and 2 out of the 5 non-staff cost components of the 14 activities. In the cost-effectiveness analysis, the cost per DALY averted was $92 and $39 from the government and societal perspectives, respectively, when EIR use was compared to paper-based record utilization. In addition, 302,496 rotavirus cases, 151,261 hospital visits, 15,101 hospitalizations and 739 deaths were averted when EIRs were used instead of paper-based records.

Conclusion: There are challenges to EIR utilization in LMICs, but EIRs result in cost savings and are cost-effective in comparison to paper-based records in LMICs.

Key words:

Electronic Immunisation Registry, Tanzania, Cost-effectiveness Analysis, Low -and Middle-Income Countries, Rotavirus

Table of Contents

List of Abbreviations

Abbreviation	Meaning
BID	Better Immunization Data
CI	Confidence Interval
DALY	Disability Adjusted Life Year
HER	Electronic Health Record
EIR	Electronic Immunization Registry
EPI	Extended Program on Immunization
GAVI	Global Alliance for Vaccines and Immunization
GDP	Gross Domestic Product
ICER	Incremental Cost Effectiveness Ratio
IIS	Immunization Information System
LMIC	Low -and Middle-Income Country
PAHO	Pan-American Health Organization
PROVAC	Promoting Evidence-Based Decisions about Vaccine Introduction
QALY	Quality of Life Years
RHIS	Routine Health Information System
RV1	Rotarix
RV5	RotaTeq
RVGE	Rotavirus Gastroenteritis
TSh	Tanzanian Shillings
UNIVAC	Universal Framework for Evaluating Vaccine Policy Decisions
USD	United States Dollars
VPD	Vaccine-Preventable Disease
WHO	World Health Organization
YLD	Years Lived with Disability
YLL	Years of Life Lost

1 INTRODUCTION

Technology has developed rapidly over the past few years, which has led to the emergence of novel ways of information management (Lafky et al., 2006). In healthcare, the requirement for immediate communication and portable health records has resulted in increased use of Electronic Health Records (EHR), particularly those that use advancements like internet technology to ensure data is handled comprehensively (Sood et al., 2008). Widespread use of EHRs increased globally after the challenges of paper-based health records were brought to light by various incidences. A significant incidence was the loss of medical records due to hurricane Katrina, which led to Electronic Medical Records being made mandatory in the United States. The increased research into Electronic Health Records and their benefits has also increased the implementation of EHRs worldwide and across multiple medical fields (Sood et al., 2008).

A field of medicine that has particularly benefitted from comprehensive electronic data management is immunisation, and the EHR used in this field is called an Electronic Immunization Registry (EIR) (Dolan et al., 2019). The WHO and the Pan-American Health Organization define an EIR as a classified, computerised information system containing data about the population's vaccine doses (PAHO, 2017). It contains information that facilitates the monitoring and follow-up of patients. This data includes immunisation coverage based on the quantity, provider, target population, age range, and geographic location (PAHO, 2017). EIRs with additional features like vaccine logistics management or the ability to communicate with other electronic systems are called Immunization Information Systems (IIS) (Dolan et al., 2019). As IISs incorporate EIRs, the two terms are considered synonymous for this paper's purpose.

Electronic Immunisation Records facilitate the standardised collection of vaccination information. They also enable vaccination information to be quickly assessed due to the searchable format and processed in real-time (Dolan et al., 2019). Overall, these information systems manage data in a manner that meets the three critical criteria outlined by Papania et al. for information to be most beneficial to vaccination program staff, namely individuality, precision, and promptness (Papania & Rodewald, 2006). Individuality refers to how granular the data is, precision refers to the accuracy of the data, and promptness refers to data access speed. Combining these three factors makes the information more valuable, leading to increased vaccination coverage and more efficient immunisation programs (Dolan et al., 2019)

In most developed countries, limitless research exists regarding EIR implementation and how it positively impacts immunization and healthcare in the long run. This research has aided the roll-out and use of EIRs in these countries. Conversely, grossly limited studies exist concerning how EIRs and IISs can be adapted and utilized in Low- and Middle-Income Countries (LMICs). This results in continued substandard data quality and poor data utilization as paper-based records remain prevalent (Dolan et al., 2019; Mvundura et al., 2020). The result of this is that the efficiency of immunization programs in these countries remains stagnated (Shen et al., 2014) and manifests as an astronomical under-five mortality rate which can be primarily attributed to vaccine-preventable diseases (VPDs) (World Bank, 2021).

Hence, this thesis aims to contribute to available research regarding the utilization, advantages, disadvantages, hindrances, and cost-effectiveness of EIRs in Low- and Middle-Income Countries and how decision makers in these regions can utilize EIRs to improve vaccination program efficiency.

Structure

Chapter one includes an overview of the problem and why it was chosen. The next part of the first chapter will analyse the existing literature on how EIRs can improve vaccination information management, the challenges experienced with implementing and using EIRs, and the associated cost consequences and savings for health facilities. The specific country chosen as the population of study, the vaccine-preventable disease and the details of the model used for our cost-effectiveness analysis are also discussed. Afterwards, the aim of this thesis is discussed in detail. Chapter two details the research methodology, which explains the qualitative and quantitative approach, questionnaires, and modelling parameters. Chapter three contains the results and findings of the analysis, and chapter four details the inferences from our results. The last chapter presents the conclusions obtained from our study, any limitations, and the ways we attempted to overcome some of these limitations, if any.

2 OVERVIEW OF THE CURRENT STATE

This paper aims to contribute to the available information; hence this literature review will analyse recent research regarding immunisation information management in LMICs, particularly in Sub-Saharan Africa. First, this state of the art will discuss the methods of keeping immunisation records currently used in these countries and outline the significant disadvantages of these methods and the benefits of switching over to EIRs. Afterwards, we will explore the challenges in the utilisation of EIRS. Then, this chapter will include an analysis of the costs of implementing an Immunization Information System and the savings realised from the implementation. Finally, the country and vaccine-preventable disease used as the case study are also discussed, as well as the topics yet to be addressed that could contribute immensely to this field.

2.1 Vaccination Information Management in LMICs, especially Sub-Saharan Africa and its Weaknesses.

In LMICs, the information on vaccination reach is obtained from a Routine Health Information System and cyclic population surveys (Dolan et al., 2019). A Routine Health Information System (RHIS) is an information system that provides data at periodic intervals, typically under a year, to meet standard information requirements (Hotchkiss et al., 2012). The data in the RHIS is obtained by aggregating the information in paper-based registries with accumulated monthly summaries and home-based records; hence, this paper uses paper-based records and RHIS interchangeably.

Dolan et al. described three fundamental areas where the detrimental effect of this method of immunisation data management can be observed (Dolan et al., 2019). The three key areas include calculating vaccine coverage, determining dose validity and timeliness, and estimating the number of fully immunised children (Dolan et al., 2019).

A) Vaccination Coverage:

Vaccination coverage is calculated by dividing the number of vaccines administered over a specified period by the estimated target population in the same period (Dolan et al., 2019). In LMICs, this is routinely calculated at the health facility, district, regional and national levels (Burton et al., 2009).

Afterwards, the final national estimate is determined during an annual evaluation process that incorporates context and compares the information obtained from administrative data to survey data (Burton et al., 2009).

The data obtained in this manner are often incorrect, incomplete and untimely due to the delays and errors associated with the paper-based recording. Hence, these records' cumulative data are largely inaccurate, and immunisation programs rely on substandard information (Bosch-Capblanch et al., 2009; Lim et al., 2008). Also, the estimated target population for vaccination, which serves as the denominator in the equation for calculating vaccination coverage, is obtained from population projections that are rarely revised and become more inaccurate as time elapses between updates (WHO, 2015). Although survey data is considered more accurate than paper-based recordings, it is collected every 3-5 years, so the lack of timeliness is not eliminated (Cutts et al., 2013).

On the other hand, using an EIR would drastically increase the accuracy of vaccination coverage. First, as the data obtained would be more individual, the recorded number of vaccines administered would be more accurate (Dolan et al., 2019). Also, the denominator (estimated target population) can be calculated directly from the EIR; hence, the challenges with inaccuracy due to delayed updates would be resolved (Dolan et al., 2019). Finally, immunisation facilities would have the ability to carry out more precise calculations like the target age within a target population (Burton et al., 2009). This increased detail level, which is instantly accessible, ultimately results in immunisation programs making more precise, well-informed decisions.

B) Determination of Dose Validity and Timeliness:

Appropriate vaccinations administered at the wrong time can be ineffective; hence, proper timing is essential for children to be adequately protected from Vaccine-Preventable Diseases (VPDs). Vaccination validity depends on each dose in a vaccination series and is crucial for estimating if the child would develop the required immunity following vaccination based on their age. Timeliness refers to whether the vaccine is given to a child within a definite timeline, and a dose can either be received early, on time or late (Dolan et al., 2019).

Vaccination schedules are termed up to date if vaccines are delivered within the stipulated timeline or before a specific age(MacDonald et al., 2019). Historically, the validity of doses administered has not been an evaluated parameter in LMICs as the data available in RHIS is insufficient for this calculation. Doses are counted in RHIS, whether valid or not (Dolan et al., 2019).

Conversely, since EIRs provide a platform for efficient collection and easy accessibility to individual data, including the date of birth and vaccination administration details, information for calculating dose validity and timelines are available. Dose validity and timelines obtained using statistics from an EIR can be based on several criteria. They can also be calculated using empirical evidence and specifically defined criteria to enhance relevance to a particular population (Dolan et al., 2019).

The data's granularity enables the measurement of vaccine validity as doses can be valid or invalid. A dose's validity is determined based on a culmination of clinical guidelines and the dose's administration time. For example, doses administered too early are deemed invalid as they do not confer the desired immunity on the patient. In contrast, doses administered in line with the schedule or after are considered valid. For a vaccination series, the validity depends on each dose's timely administration and the maintenance of the stipulated interval between all doses. These additional parameters provide a valuable layer that complements vaccination coverage as we know the number of people vaccinated and the number of people vaccinated either right on schedule, at delayed intervals or those who drop out altogether (Dolan et al., 2019).

Consequently, these additional measures increase the efficiency of immunisation programs. It allows the programs to follow up with patients who switch categories and address the causes of decreased compliance. The facilities can also monitor the percentage of invalid doses due to early administration. The information obtained is then utilised to track healthcare workers' performance and adherence to standard practice (Dolan et al., 2019).

C) Partial Vaccination and Lost to Follow-up

Partial vaccination is when the patient delays obtaining subsequently scheduled vaccine doses. While in lost to follow-up, the patient fails to return to the immunisation facility to complete a vaccination series (Dolan et al., 2019).

Vaccination programs utilise dropout data to assess the proportion of patients who drop entirely out of the vaccination series. It gives them an idea of the population's vaccine demand and the healthcare system's calibre. Currently using RHIS, the dropout rate in most facilities is calculated by subtracting the number of follow-up doses dispensed in a month from the number of first doses given out in the same month. Then, the proportion of patients dropping out is estimated by dividing the above by the number of first doses administered in the same month. However, this calculation is a crude estimate as it does not utilise individual data, and the comparison is between different groups of patients. Hence, it is atypical for vaccination programs to include it in the reports, although facilities might monitor it (Dolan et al., 2019).

In contrast to RHIS, EIRs enable a more accurate calculation of dropout rates as patients who fail to return for subsequent doses are monitored individually. In some cases, the EIR also contains a column that captures why a specific patient could not return for subsequent doses (Dolan et al., 2019). As a result, immunisation program managers have more insight into the obstacles hindering patients from returning to the facility. Hence, these programs monitor patients more effectively and design specific strategies to increase immunisation reach and reduce dropouts.

Also, individual-level data enables staff members to measure the duration between subsequent visits, so recurring patterns of patients who return at the appropriate time and those who fail to follow up can be analysed. Based on this analysis, what it means for a patient to be lost to follow-up can be defined for each population to make it more specific and applicable to the population in question. Beyond the use of individual information, modern technology increases the accuracy of patients' temporal and geographic monitoring as EIRs can be centralised. Hence, there is clarity when a patient goes to a different facility, ensuring they are not erroneously classed in the category of patients lost to follow-up.

Table 1 below summarises the expected advancements in immunisation programs due to the use of EIRs over paper-based systems (Dolan et al., 2019).

Table 1. Advancements in Vaccination due to EIR Utilization

	Paper-based Routine Health Information System (RHIS)	**Electronic Immunisation records**
Vaccination Coverage	• Vaccination coverage: $\frac{\text{number of vaccines administered}}{\text{target population}}$ • Inaccurate numerator due to errors and untimeliness of paper-based recording.	• Individual data so the number of vaccines administered is more accurate. • The estimated target population is calculated

	• Delayed updates of the denominator results in inaccuracy between updates.	from the EIR; hence delay is eliminated.
Dose Validity and Timeliness	Not monitored as it is difficult to estimate without individual data.	• Granular data so dose validity can be monitored. • The available data can be used to set custom dose validity calculation criteria resulting in increased specificity and applicability for various populations.
Partial Vaccination and Lost to Follow-up	Current lost to follow-up data is a crude estimate as it compares different patient cohorts (both the numerator and denominator are based on the same month). $\frac{\text{no of follow up doses} - \text{first doses}}{\text{no of first doses}}$	• Calculation on patients lost to follow-up is done based on individual data. • It also provides an avenue to record reasons for missed/delayed doses so immunisation programs can organise targeted sensitisation programs. • EIRs provide a centralised system, so patients who follow up in other facilities are not erroneously recorded as patients who dropped out

Source: Author's processing of data from (Dolan et al., 2019)

Mvundura et al. thoroughly describe the expected transition when a region moves from paper-based health records to IISs based on the implementation of IISs, which comprised an EIR and supply chain software in Tanzania and Zambia (Mvundura et al., 2019).

Health care providers transitioned from using paper-based records to an IIS which enabled patients to be digitally enrolled and monitored and automated the reporting process. The IIS provided individualised and centralised patient data. Each patient had a specific number and quick response code in the EIR, which enabled individual records to be accessed in participating facilities. Beyond the unique registration number and barcode, data registered to a specific patient could be obtained using their name, guardian name or address. In addition, each child had all information on vaccination like their date of birth, sex, vaccination history and schedule, and non-vaccination information related to health services provided in the healthcare facility stored in the EIR. Also, reports that informed health care staff when patients missed an appointment and the information to follow up on these patients were available (Mvundura et al., 2019).

This EIR provides individual, precise data and can be accessed promptly. Hence, it essentially revolutionises and dramatically increases the accuracy of calculated immunisation data like vaccination coverage, dose validity, timeliness, and the percentage of the population partially vaccinated or lost to follow-up. These improved management methods of data related to vaccine coverage, timeliness, partial vaccination, and patients lost to follow-up, in turn, aids vaccination facilities improve these vaccination parameters as they can make informed decisions (Dolan et al., 2019).

2.2 Challenges Associated with EIR Utilisation in Sub-Saharan Africa

Clarke et al. (Clarke et al., 2019) conducted a study to assess the quality of data recorded in an EHR adapted for immunisation records and the overall staff perception of the system. The study was a qualitative evaluation based on an Information System Success (ISS) model by DeLone and MacLean, which postulates the three main characteristics of a successful information system: superlative system quality, service quality and information quality (Delone & McLean, 2003). During the research, it was discovered that of the 103 healthcare facilities where the EIR had been implemented, only 10% had any vaccination information in the EIR national database. In addition, only 2% of the facilities were using the electronic system. This discovery prompted further investigation into why local healthcare workers were not using the EIR (Clarke et al., 2019).

Regarding system quality which mainly entails the ease of use of the EIR, although the system itself was easy to use, most staff members had challenges with the fact that paper-based records still had to be maintained alongside electronic records, increasing their workload. Also, most facilities' current workflow did not adequately incorporate the EIR. For example, most colleagues managed electronic health records in different facility areas from vaccinators, leading to an increase in patient wait time. Other hindrances to the ease of use of the EIR were power cuts making it impossible to access the EIR during specific periods and lack of access to the EIR during immunisation outreaches due to desktop computer immobility which both resulted in retrospective data entry (Clarke et al., 2019).

Service quality involves the ability to respond to Information System malfunctions. In the investigated facilities, the technical response time was highly variable. Healthcare centres where the EIR was still being used reported rapid response times regarding technical support. Computer literacy among healthcare workers also influenced the time required to resolve technical challenges. Healthcare facilities with more computer-literate staff members reported shorter response times and provided feedback on how the system could be improved to serve immunisation facility staff better (Clarke et al., 2019).

The final category, information quality, encompasses perceptions of accuracy, completeness, usefulness, and ease of access to data. The EIR was incomplete compared to paper records, mainly due to the inability to enter data into the system at specific points because of power outages and the limited availability of staff trained to use the software. The lack of completeness of the EIR resulted in diminished utility as features like data analysis, and report generation could not be utilised. Hence, the system's potential was far from fully maximised. In addition, most healthcare workers underestimated the system's usefulness, with only administrative and data entry staff understanding the full functionality of the EIR (Clarke et al., 2019).

After the challenges of EIR utilisation enumerated above were obtained from interviews with healthcare workers in investigated facilities, some potential solutions were proposed. Power outage is one of the biggest challenges as it adversely influences the system and information quality. These challenges can be overcome by providing the facilities with EIRs on tablets or mobile phones, as these store charges and enable access to the EIR during power cuts. These tablets and mobile phones would also provide the flexibility required for outreaches so that data can be entered immediately. The increased patient wait time can also be addressed by training more staff to use the EIR. Incorporating how the workflow can be managed using an EIR into staff training would also increase efficiency. All the challenges addressed above would, in turn, lead to improved data completeness in the EIR and hence accuracy and perception of utilisation (Clarke et al., 2019).

Another challenge outside these three domains highlighted by the staff members was the lack of sustainability of most EIR pilot projects. Most projects were introduced, run for short periods, and then discontinued, leaving the healthcare facility stranded and unable to access the EIR data. These resulted in decreased enthusiasm for future projects. An ideal solution to this challenge would be to manage staff expectations when pilot projects are being run and have systems to minimise data loss (Clarke et al., 2019).

2.3 Costs of Implementation of Immunization Information Systems in LMICs

To achieve the benefits of transitioning from aggregate RHISs to IISs in developing countries discussed above, multiple organisations have made efforts to implement EIRs in these regions. An indispensable aspect of the successful implementation of EIRs in LMICs, particularly in Sub-Saharan Africa, is the ample understanding of the project's cost implications. Estimating EIR implementation cost has remained a significant challenge as an exiguous amount of research detailing these costs exist (Mvundura et al., 2019).

The Better Immunization Data (BID) Initiative was set in motion in 2013 to enhance vaccination data compilation and utilisation in Sub-Saharan Africa. Mvundura et al. described the cost of building, introducing, and sustaining an IIS based on the BID Initiative implemented in Tanzania and Zambia. The documentation provides valuable insight into the financial forecast for similar projects in other Sub-Saharan African countries (Mvundura et al., 2019). However, for the costs to be explicitly understood, a breakdown of the various facets involved in the Initiative's execution is essential.

First, an Electronic Immunization Registry that catered to these regions' specific requirements was developed as none existed before the BID Initiative. To ensure it met these countries' particulate needs, system prerequisites that illustrated the components of what would constitute an ideal EIR were collected from ten Sub-Saharan African Countries. An Immunization Information System, which comprised an EIR with supply chain information, was developed based on this information. Although it was not feasible to create one EIR that could be used across all the countries, software that could be easily adapted to meet each country's specific needs was developed. The EIR was adapted to Tanzania (Open Immunize-Open Iz) and Zambia (Open Smart Registry Platform-Open SRP) for the BID Initiative. In creating this software, two unsatisfactory versions were developed by the BID Initiative in Tanzania and Zambia. As a result, they both had to be shelved, constituting dissipated costs, which were still recorded as part of this project's total expenditure. The anticipated costs for IIS development of similar ventures are expected to be considerably less. First, both software platforms developed in the BID Initiative are open source and are freely accessible for future use. Secondly, the cost incurred from developing incompatible software can be avoided (Mvundura et al., 2019).

Subsequently, the next phase was the rollout of the EIR. The EIR was rolled out in three regions in Tanzania, Arusha, Kilimanjaro and Tanga, and the Southern province of Zambia. The roll-out encompassed barcode scanners and tablets with the EIR software installed being provided to the participating healthcare facilities. Furthermore, the back-entry of vaccination data of children below nine months of age was manually entered into the EIR, and the BID Initiative also had to bear these costs. Training programs were also organised in the various healthcare facilities, ranging from peer-to-peer training to expert supervision in each facility. Lessons learnt from implementing the EIR in one facility and training staff members were used to improve the rollout strategy and applied to the following facilities, so implementation became less challenging as the BID staff gained more experience from various facilities (Mvundura et al., 2019).

The costs accounted for by Mvundura et al. were purely financial costs obtained from the BID Initiative's records from 2013-2018, as those are considered essential for financial planning for future projects (Mvundura et al., 2019). Table 2 below shows the classification of costs incurred, as well as the total monetary value of the expenditure in 2018 U.S. dollars

Table 2. Financial Expenditure of the BID Initiative

Cost Category	Cost Description	Tanzania	Zambia
System Design and Development			
EIR which is being used	Development and design of EIRs adopted in each	US$867 851	US$486 965

	country, including the trial.		
Learning Costs	Development and design of shelved EIRs.	US$527 644	US$427 407
Other Costs			
Back entry costs	Costs to transfer old records from paper-based registers to EIRs	US$84 441	US$21 086
Peer Learning and guideline printing (Tanzania alone)	Printing of vaccination guidelines and peer learning exchange in Zambia	US$6242	-
Labour Costs			
BID Initiative Staff	BID Initiative and in-country staff time	US$1 648 484	US$1 851 105
Rollout costs			
Hardware	All hardware used for the BID project	US$439 109	US$254 424
Meetings	Meetings for rollout strategy and with the government	US$25 608	US$32 470
Training	Training of Staff for rollout	US$71 066	US$29 368
Deployment	Lodging and transport costs	US$412 671	US$445 655
Recurrent Costs			
Internet Connectivity	Access to the internet for data upload and transfer	US$53 038	US$20 007
Data hosting	Server for EIR data	US$28 024	US$2061

Supportive Supervision	Costs for Supervision by BID Initiative or Ministry of Health Staff	US$14 964	-
Printing	Printing of bar codes on Immunization Cards	US$14 503	US$2926
Total Country Costs		US$4 193 647	US$3 573 474

Source: Author's processing of data from (Mvundura et al., 2019)

The total cost for development, introduction and sustenance of the BID EIR over the 5-year duration was approximately US$4.2 million and US$3.5 million for Tanzania and Zambia, respectively, and although this seems like a large percentage of countries' immunisation expenditure, funding for immunisation information system development in LMICs come from international donors (GAVI, 2015, 2019; Mvundura et al., 2019). The total cost per facility in Tanzania was between $709-$1320, and in Zambia was $2591 per facility. The price per child was US$3.30-US$3.81 for Tanzania and $8.46 per child in Zambia. These figures were obtained by annualising all the costs except the recurrent cost over three years and dividing them by the national or regional birth cohort depending on the expenditure reach. Other valuable discoveries include that the most significant expenditure was personnel costs, constituting 39% of total cost in Tanzania and 52% in Zambia. Designing and building the EIR also made up a substantial portion of the cost, taking up 21% and 14% of total expenses in Tanzania and Zambia or 33% and 26% in the respective countries if learning costs are included. The bulk of rollout costs was attributed to hardware and deployment costs, and recurrent costs only comprised 2.6% and 0.7% of total expenses in Tanzania and Zambia (Mvundura et al., 2019).

Although the expenditure per child obtained from this study may differ from the actual cost as the calculation utilised the projected target population based on the Expanded Program on Immunisation instead of data directly from the EIR, the expenditure breakdown is invaluable as minimal research exists regarding the cost of similar projects in this region (Mvundura et al., 2019). A Californian study from 1998 established that the cost for EIR development was $388,000 (when adjusted to 2018 US$) compared to $867,851 and $486,965 US$ spent on EIR development in Tanzania and Zambia. Also, research from Massachusetts done in 2002 found the cost per child for an EIR registry to be $15.51 if only children less than 8 are considered or $8.46 (adjusted to 2018 US$) if children under 23 are considered as opposed to the $3.30-$3.86 and $8.46 calculated per child in Tanzania and Zambia (Fontanesi et al., 2002; McKenna et al., 2002; Mvundura et al., 2019). The enormous discrepancies in these figures clearly illustrate the necessity for research to be carried out specifically in Sub-Saharan countries regarding implementing EIRs, as conditions and costs vary widely across continents.

Finally, Mvundura et al. project that future EIR implementation costs in related Sub-Saharan African countries could be substantially reduced due to decreased EIR development costs. These reduced development costs would be due to the available open-source EIR software and elimination of learning costs, considering a proven system now exists. Furthermore, rollout costs could potentially be decreased if the lessons learnt from the Better Immunization Data Initiative are implemented in future projects (Mvundura et al., 2019). A topic that would provide immense insight for the future would be the cost savings realized in the sustenance of an Immunization Information System realised when the available open-source software and strategies from this Initiative are applied.

2.4 Cost Savings Due to Replacement of Paper-based Registers with an Immunization Information System.

In addition to the financial records of the cost of implementing an IIS in the Better Immunization Data Initiative, the cost savings realised in the various healthcare facilities and districts where the EIR was rolled out were also documented by Mvundura et al. (Mvundura et al., 2020). The vaccination program's economic costs in these facilities and communities were evaluated before and following the EIR implementation to determine the difference in expenditure and assess whether the EIR led to cumulative savings or a surge in spending.

Specific information on the resources used for managing immunisation logistics and delivering vaccines to patients and the value of these resources were obtained on a facility and district level using questionnaires directly administered by BID staff. This information was then used to conduct a micro-costing study to evaluate annual costs before and post BID initiative EIR implementation (Frick, 2009; Mvundura et al., 2020). Mvundura et al. included five categories of costs in this study. These included the expenditure on personnel, cold chain appliances, transportation, healthcare facility office equipment and recurrent costs (printing, communication, office supplies). Some resources utilised by the immunisation program were shared with other departments, so costs were assigned based on the proportion used by the

BID program. Equipment costs were annualised, and the depreciation was calculated over three years for office equipment, five years for vehicles and ten years for cold chain appliances. All costs were converted to 2017 U.S. dollars (Mvundura et al., 2020). Table 3 below shows the evaluated prices of resources utilised by the healthcare facilities at baseline, before the implementation of the EIR and after the EIR had been implemented, and the cost savings or increment (Mvundura et al., 2020)

Table 3. Average Annual Cost per facility at baseline and post-EIR implementation (in 2017 U.S. dollars)

Parameters	Facilities in Arusha, Tanzania			Facilities in Southern Province, Zambia		
	Baseline	Post	Incremental	Baseline	Post	Incremental
	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)
Personnel costs	16 468 (11 509, 23 175)	6 223 (3 806, 9 127)	-10 245 (-14 048, -7 703)	4 391 (854, 5 974)	3 663 (2 211, 5 693)	-728 (-291, 1 357)
Cold chain appliances	399 (395, 403)	399 (395, 403)	0 (0,0)	313 (255, 371)	313 (253, 371)	0 (0, 0)
Transportation	302 (145, 476)	258 (118, 420)	-44 (-28, -56)	534 (341, 739)	520 (337, 715)	-14 (-24, -5)
Office Equipment	0 (0,0)	138 (138, 138)	138 (138, 138)	11 (0, 22)	149 (138, 161)	138 (138,138)
Recurrent Costs (Printing, Internet and Phone)	148 (63, 235)	63 (49, 78)	-85 (-14, 157)	74 (55, 93)	50 (40, 60)	-24 (-15, -33)
Total Cost	17 318 (12 113, 22 376)	7, 082 (4 056, 10 166)	-10,236 (-14 123, -7 606)	5,324 (1 506, 7 209)	4,695 (2 981, 6 999)	-628 (-209, 1 476)

Source: Author's processing of data from (Mvundura et al., 2020)

The costs per participating healthcare facility in Tanzania and Zambia reduced by 59% and 12%, respectively, post the EIR implementation, and these cost savings were mainly attributed to decreased personnel costs. Personnel costs decreased as the EIR led to an overall increase in the immunisation process's efficiency and decreased required person-hours. A univariate cost analysis was carried out to confirm the significant cost drivers, which corresponded with the questionnaire results, reduced staff time. The transportation costs in Zambia also decreased due to the supply chain component of the EIR software, as the precise inventory eliminated emergency trips to obtain vaccines. On the other hand, the office equipment costs increased as expected due to the purchase of tablets and barcode scanners, while the cold chain appliances cost stayed the same as the EIR did not affect them (Mvundura et al., 2020).

Furthermore, substantial cost savings of 28% were also observed post-EIR implantation at the district level in Tanzania, still majorly due to the decreased personnel time required. In addition, the stock management system reduced the time spent managing logistics for vaccination provision and delivery to healthcare facilities. In Zambia, the cost reduction of 1.3% at the district level was significantly smaller than in Tanzania and was driven by decreased labour and printing costs (Mvundura et al., 2020). However, the price of office equipment also increased as expected in both districts due to the tablets. Table 4 below shows a detailed breakdown of the baseline and post-implementation costs at the district level (Mvundura et al., 2020).

Table 4. Average Annual Cost per District at baseline and post-EIR implementation (in 2017 U.S. dollars)

Parameters	**Districts in Arusha, Tanzania**			**Districts in Southern Province, Zambia**		
	Baseline	Post	Incremental	Baseline	Post	Incremental
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Personnel costs	13 655 (7 121, 21 061)	6 456 (2 452, 10 362)	-7 200 (-10 699, -2 807)	3 693 (1 082, 6 230)	2, 04 (1 043, 6 559)	-789 (-2 116, -276)
Cold chain appliances	2 258 (1 046, 3 847)	2 258 (1 046, 3 847)	0 (0)	855 (470, 1 364)	855 (470, 1 364)	0 (0)
Recurrent Costs (Printing, Internet and Phone)	269 (110, 503)	436 (298, 688)	167 (118, 222)	1 188 (59, 2 416)	1 250 (200, 2 365)	62 (51, 141)
Office Equipment	68 (63, 70)	559 (554, 561)	491 (491, 491)	19 (7, 39)	510 (498, 530)	491 (491, 491)

Transportation	6 751 (2 499, 11 607)	6 751 (2 599, 11 607)	0 (0, 0)	11 823 (2 524, 16 609)	11 823 (2 524, 16 609)	0 (0)
Total Cost	23 001 (11 064, 35 718)	16 459 (8 891, 25 695)	-6 542 (-10 023, -2 173)	17 578 (6 595, 23 724)	17 341 (7 280, 22 178)	-236 (-1 456, 800)

Source: Author's processing of data from (Mvundura et al., 2020)

There were several limitations of this study, like the small sample size, the limited time between the intervention and data collection, possible errors due to recall bias as the data was self-reported, and preliminary evaluation of the benefits of the EIR implemented. However, relevant data for similar future projects can be obtained from this study. First, EIRs result in substantial cost savings compared to paper-based records mainly due to the increased efficiency obtained, leading to a decrease in required personnel time and, hence, costs for human resources. Another observation worthy of note is that the duration of use of EIRs could have considerable effects on cost-saving. For example, the facilities in Tanzania, which had utilised the EIR for an average of 8 months, had significantly more considerable cost savings than Zambian facilities, which had only implemented the EIRs for an average of 3.5 months. This difference can be ascribed to increased learning costs in Zambia as they were still adapting to the novel technology (Mvundura et al., 2020).

2.5 LMIC Case Study Setting, Disease, Economic Evaluation and Modelling

The earlier parts of this chapter explored the theoretical benefits of EIRs in information management over the currently used RHIS, challenges associated with implementing EIRS, and costs and cost savings related to transitioning from RHISs to EIRs in Sub-Saharan Africa. Using the above information as elementary units, the rest of the paper will focus on a comparative analysis between the benefits of EIRs and RHISs and how EIRs impact populations. The objective would be to evaluate the use of EIRs in a specific LMIC and assess how it influences the cost of vaccination, vaccination parameters and disease events of a vaccine-preventable disease and assess if these changes are in accordance with existing literature. To effectively carry out this analysis, the paper would focus on a specific Sub-Saharan African country as a case study, a particular vaccine-preventable disease that has a significant disease burden, and utilise an economic evaluation model that accurately assesses the cost-effectiveness of EIRs compared to RHISs in the chosen country.

A) Tanzania

Tanzania is a country in Eastern Africa with a population of about 60 million people. The population has a median age of 18 years, so it is a predominantly youthful population. The life expectancy is 66 years, and there are about 47 deaths per 1,000 life births of children under age 5. In Europe, the mortality rate for children under 5 is 4 per 1,000 live births. This drastic difference is considerably impacted by child mortality due to vaccine-preventable diseases (VPDs) in Tanzania (World Bank, 2021). Tanzania has been chosen as the focal country due to the extensive documentation on vaccination available in comparison to other Sub-Saharan African countries, mainly due to the considerable vaccination drive in the country by programs such as the Extended Program on Immunisation (EPI) and the GAVI Alliance (MoHSW, 2003).

The vaccination schedule in Tanzania is in line with WHO standards and comprises the Bacille Calmette-Guérin (BCG) vaccine, Oral polio vaccine (OPV), Rotavirus vaccine, Diphtheria and Tetanus and Pertussis and Haemophilus influenza and Hepatitis B vaccine (DTwPHibHepB), Pneumoccocal conjugate vaccine, Measles and rubella vaccine (MR), and the Human Papillomavirus vaccine(MoHSW, 2011; WHO, 2018). The table below illustrates the different diseases the vaccines are preventive against and the administration time.

Table 5. Vaccination Schedule in Tanzania and the diseases they protect against

Vaccine	Target Infection	Schedule
Bacille Calmette-Guérin (BCG) vaccine	Tuberculosis	Birth
Oral polio vaccine (OPV)	Poliomyelitis	Birth; 6,10,14 weeks
Rotavirus vaccine	Rotavirus Infection (Rotavirus-induced diarrhoea)	6,10 weeks
Diphtheria and Tetanus and Pertussis and Haemophilus influenza and Hepatitis B vaccine (DTwPHibHepB)	Diphtheria, Tetanus, Pertussis (whooping cough), Haemophilus Influenzae B infection and Hepatitis B	6,10,14 weeks

Pneumococcal conjugate vaccine	Pneumococcal disease (pneumonia, sinus infections, meningitis, bacteremia)	6,10,14 weeks
Measles and rubella vaccine (MR)	Measles and Rubella	9, 18 months
Human Papilloma Virus (HPV) vaccine		9 years (2 doses)
Tetanus Toxoid vaccine	Tetanus	1st contact; +1, +6 months, +1, +1 year (focused on pregnant women and women of childbearing age

Source: Author's Processing of Data from (MoHSW, 2011)

The rest of this paper will explore how using an EIR instead of a paper-based record influences the cost of vaccination and management of Rotavirus in Tanzania. We would also carry out an economic evaluation which would compare how employing EIRs in place of RHISs would influence parameters that contribute to decreased disease burden; and how this difference in vaccination measures impacts the Tanzanian population in terms of cost and consequences.

B) Rotavirus

The most prevalent vaccine-preventable diseases (VPDs) in children under five are pneumonia and diarrhoea. Diarrhoea is the second most common cause of morbidity and mortality worldwide among children less than five years old, and rotavirus-induced diarrhoea was responsible for 72% of childhood diarrhoea globally before the implementation of vaccinations (Diouf et al., 2014; Munos et al., 2010; WHO, 2017). Despite vaccination implementation, rotavirus is still one of the leading causes of diarrhoea as it is estimated to cause about 40% of diarrhoea-related morbidity and mortality worldwide (Munos et al., 2010). Due to the high disease burden of rotavirus, its vaccine was chosen as the focus of this paper. If we can decrease morbidity and mortality of rotavirus by increasing the efficiency of the vaccination process, it would significantly affect the mortality rate of children under five and lead to a considerable development of the population's overall health.

C) Economic Evaluation

Economic evaluation is a comparative analysis of alternative courses of action in terms of their costs and consequences (Drummond et al., 2005). Resources, especially those allocated to healthcare in developing countries, are limited. Hence, decision-makers must decipher the most efficient allocation of these scarce resources. Economic evaluations provide a method to systematically analyse costs and the consequences of alternatives and assess new technology based on its value. The value can be measured either in terms of financial benefits or natural units like cases detected/averted, years of life gained, and quality of life years (QALY). This practical approach prevents decision-makers from relying only on theoretical expectations.

Although Tanzania has more available vaccination data than other Sub-Saharan African countries, there is still limited data availability, and many challenges are associated with directly collecting all the required data. Also, evaluating the impact of EIRs on future populations would provide valuable cost-effectiveness information. Hence, a quantitative model can be used to carry out the economic evaluation. A model is a set of activities that lead to the development of a structure that simulates the actual system's behaviour. They are used to replicate processes or decisions in healthcare and their impact in case of uncertainty. In this case, a model would simulate aspects of the vaccination process in Tanzania and how RHISs and EIRs impact these different aspects.

D) UNIVAC Model

The UNIVAC model is a perfect model for this purpose (PAHO, 2019). In 2004, The Pan American Health Organization (PAHO) developed an initiative called ProVac, an acronym for Promoting Evidence-Based Decisions about Vaccine Introduction (Jauregui et al., 2015). The main objectives of this initiative were (Clark et al., 2013; Jauregui et al., 2011, 2015; Robson et al., 2007):

- To re-enforce the ability and infrastructure of developing countries to make informed, evidence-based decisions about whether to introduce a new vaccine by providing them with the technical capacity to carry out economic evaluations.
- To advocate for governments to utilize evidence as a guide when making health policy decisions
- To develop mechanisms for economic analysis and provide education to national multidisciplinary teams
- To obtain data, conduct assessments and construct decision analysis with technical, operational, societal, and financial factors.

- To adequately plan for the introduction of novel vaccines when there is clear evidence it is beneficial for the country

PAHO and the London School of Hygiene and Tropical Medicine developed the UNIVAC Model under the ProVac initiative. It is an adaptation of the TRIVAC Model, which PAHO also developed. UNIVAC means Universal framework for evaluating vaccine policy options in low- and middle-income countries (PAHO, 2019). The UNIVAC model is an Excel-based, decision support, static cohort model that serves as a comprehensive framework for analysing immunization policy options in low- and middle-income countries (Clark et al., 2013; Jauregui et al., 2011). It calculates the incremental cost-effectiveness ratio and other indicators for Rotavirus, Haemophilus Influenza and Pneumococcal Conjugate Vaccines using parameters like vaccine price, healthcare utilization and cost, vaccine efficacy and coverage and disease incidence (Clark et al., 2013). For the model to be used effectively, the users must understand the features and structure sufficiently.

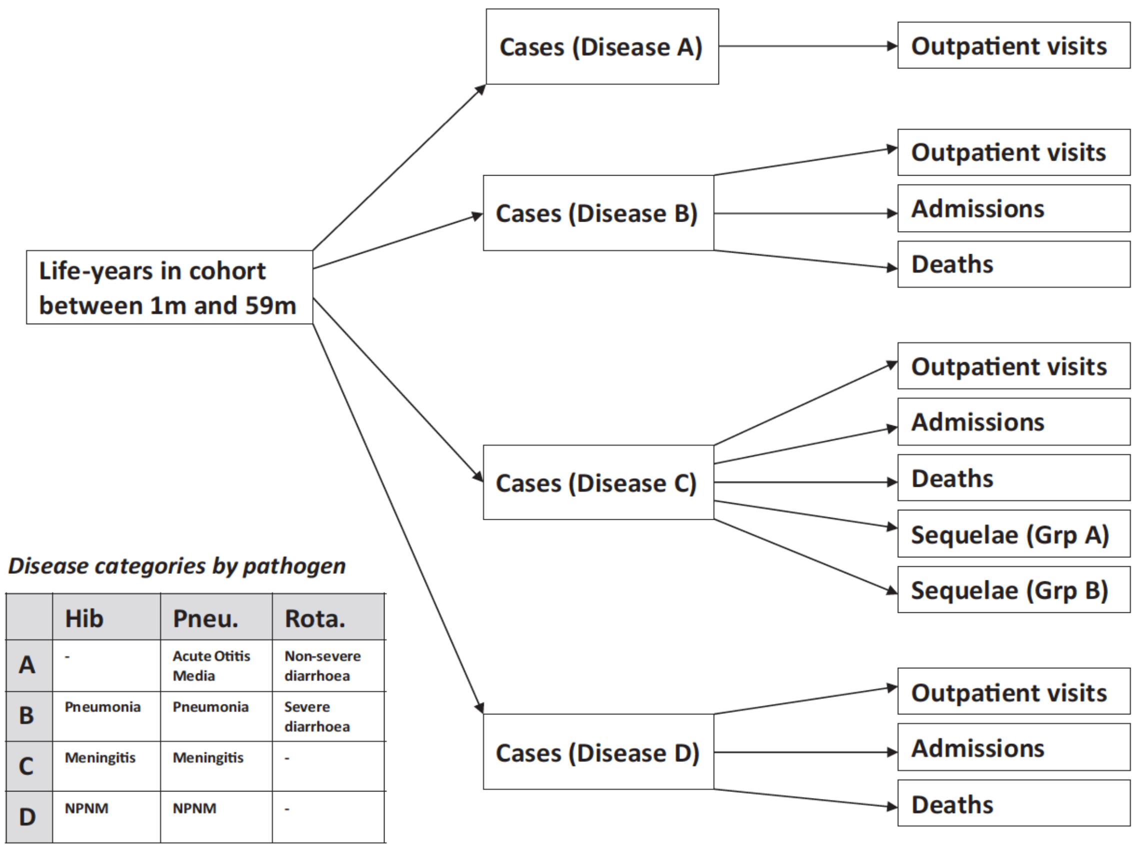
Features of the Univac Model:

Ease of Use: As discussed earlier in this paper, a significant challenge of LMICs is poor data quality and technical capability for economic evaluation. Hence, the UNIVAC model has been adapted for use at multiple levels, from the most simplistic structure requiring fewer data inputs to more complex situations requiring more details. To ensure full accessibility and transparency of the model, it was developed in Microsoft Excel with some features in VBA (Visual Basic for Applications). In addition, it provides multiple languages for end users and has built-in features for scenario and uncertainty analysis. It also contains baseline values for 201 LMICs obtained from global databases, which national teams can alter if they have better, more up-to-date information (Clark et al., 2013).

Outcome Indicators: The primary assignment for cost-effective analysis is the calculation of the incremental cost-effectiveness ratio (ICER). The model calculates multiple indicators, which include the number of cases averted, outpatient cases, number of hospital admissions and mortality, the ratio of under-five mortality prevented, health-care costs averted, life-years gained and vaccination-related costs. In each case, the model estimates the costs and benefits over a specific time, with and without vaccination. The model generates ICERs for multiple outcomes, but the most widely used is the cost per DALY averted (Clark et al., 2013; Murray & Lopez, 1996).

Time horizon and Cohorts: Cost estimates, cost-effectiveness and health benefits are estimated by tracking annual birth cohorts over a while. Most users, however, evaluate birth cohorts over five years (from 1 to 59 months). Program costs are allocated to the first year of each cohort, while the cost of treatment, mortality and morbidity cases are estimated over the 5-year period. Conversely, disability-adjusted life years and all other outcomes are calculated over the lifespan of each cohort population using current and estimated future life expectancies. The model also stacks results of each cohort's estimated costs and health benefits as most decision makers find it more natural to assess in terms of year-on-year trends as opposed to lifetime events in an individual cohort (Clark et al., 2013).

Model Structure: The UNIVAC model is a static model, so it only crudely accounts for indirect effects like herd effect and serotype replacement in unvaccinated children. The structure of the model disease burden is illustrated in Figure 1 below (Clark et al., 2013). Twelve-month projections of birth, neonatal, infant and under-five mortality are used to derive life-years lived between 1 and 59 months for each consecutive birth cohort. For rotavirus, Disease A represents non-severe rotavirus gastroenteritis (RVGE). In contrast, Disease B represents severe rotavirus gastroenteritis, defined by the Vesikari 20-point scale for RV1 (Ruuska & Vesikari, 1990) and the Clark 24-point scale for RV-5 (Clark et al., 1988). Still, the user can redefine the disease categories if there is better country-specific evidence regarding healthcare cost and incidence that supports a different type of categorization.



Disease categories by pathogen

	Hib	Pneu.	Rota.
A	-	Acute Otitis Media	Non-severe diarrhoea
B	Pneumonia	Pneumonia	Severe diarrhoea
C	Meningitis	Meningitis	-
D	NPNM	NPNM	-

NPNM = other non-pneumonia, non-meningitis invasive diseases combined

Outpatient visits and admissions can be divided into ten user-defined categories of healthcare provider e.g. private non-medical (faith healer etc), private pharmacy, private clinic, social security clinic, social security hospital, public clinic, public primary hospital, public secondary hospital, public tertiary hospital.

Figure 1. Structure of UNIVAC Model Disease Burden (Clark et al., 2013)

Healthcare Utilization and Costs: An assumption of the average number of outpatient visits and hospital admissions per case for each disease state is used to estimate the number of outpatient visits and hospital admissions. These visits can be assigned to public, private, or social sectors. Costs for each hospital visit and admission can then be assigned to the appropriate provider (Clark et al., 2013).

Vaccination Program Costs: The price per dose of vaccine, freight costs, handling costs, safety box, syringe and wastage costs are all considered when using the model to calculate vaccination costs. The model also factors the healthcare system's annual incremental costs per vaccine dose. This includes yearly costs like training, cold chain equipment, buffer stock, printing vaccination cards, and atypical recurrent costs like surveillance for unexpected adverse events. Price changes are also taken into consideration as a fixed percentage change per year. Alternatively, specific prices can be given for each year during the 5-

year duration if an irregular price change is expected, as would be the case if GAVI support is provided for a limited time in the form of a co-payment (Clark et al., 2013).

Vaccine Impact: The key parameters for evaluating vaccine impact include vaccine efficacy, vaccine type coverage, vaccine coverage, vaccine timeliness, relative coverage, waning effect of the vaccine per year, and the herd effect of the cohort evaluated (Clark et al., 2013).

Uncertainty Analysis: The model has various built-in sensitivity and scenario analysis tools. One of these is a simple (one-way) sensitivity analysis where the model on request can vary each parameter by a fixed percentage and evaluate the resulting percentage change in cost per DALY averted. A scenario analysis where country teams can create up to 20 hypothetical scenarios involving multiple combinations of parameter values is also included. The sub-group analysis allows the cohort to be split into two groups with different parameter values in each, while the probabilistic sensitivity analysis allows country teams to enter a plausible range of mid, low, and high values for each uncertain parameter value (Clark et al., 2013).

Important Drivers of Cost-Effectiveness for Hib Vaccine, PCV and RV: The herd effect multiplier and relative coverage are the parameters with the most influence. This is because they directly influence health and economic gain without affecting the program cost. Other important parameters include the mortality rate trend in the absence of vaccination, vaccine price and the percentage decline in vaccine price annually. Specifically, for RVGE, the other vital parameters are the incidence and fatality rate of severe RVGE, the efficacy of the vaccine against severe RVGE and the rate of decline of vaccine protection (Clark et al., 2013; Robson et al., 2007).

In general, the main advantages of the model are transparency, flexibility, and response speed. In contrast, the main disadvantage would be the crude way of modelling indirect effects and the fact that each vaccine is modelled separately.

2.6 Summary

The chapter above summarises the focal vaccine-preventable disease and country and the reason the country and the VPD were chosen. It also includes a detailed description of the model used for the cost-effectiveness evaluation and its strengths and weaknesses.

In summary, in the following chapters, the goal of the thesis would be to:

i. Evaluate the cost-effectiveness of EIRs compared to RHISs by comparing facilities in Tanzania that currently utilize the EIRs to facilities that currently use paper-based records.

ii. Use an Excel-based decision support model known as the UNIVAC model to assess how EIRs would influence healthcare costs in the long term.

3 AIMS OF THE THESIS

Research Question and Objective

This research investigates the '*Cost-effectiveness of Electronic Immunization Registries in Low- and Middle-Income countries.'* Primary data is obtained from a Sub-Saharan African country to evaluate if using EIRs is cost-effective in the short term. In addition, predictive modelling is used to assess if EIRs would also be a cost-effective alternative to RHISs in the long term. The study is primarily quantitative with some qualitative elements to describe EIR use.
The research questions below will be answered:

1. *Is using EIRs cost-saving for healthcare facilities in Low- and Middle-Income Countries?*
2. *Compared to paper-based records, will EIRs be cost-effective in the long term for Low- and Middle-Income Countries?*

Also, to provide an in-depth understanding of the research topic using the literature review and new research, the study aims to achieve the objectives below:

- To elaborate on how vaccination information is currently managed in LMICs, particularly Sub-Saharan Africa and establish the benefits of EIR over paper-based records based on existing research.
- To evaluate the difference between immunization-related costs in facilities currently utilizing EIRs and facilities not using them in LMICs using Tanzania as a case study.
- To evaluate the difference between vaccination program effectiveness in facilities currently utilizing EIRs and facilities not using them in LMICs using Tanzania as a case study.
- Assess the impact of EIRs on future health benefits and healthcare costs in LMICs using cost-effectiveness analysis.

Scientific Relevance

The essence of this paper is to highlight the deficiencies in Vaccination Information Management in LMICs and evaluate whether the use of EIRs would rectify these lapses as suggested by existing literature. Dolan et al. (Dolan et al. 2019) focus on how EIRs can be used to improve information management in LMICs, while Mvundura et al. (Mvundura et al., 2019, 2020) discuss the costs of development and implementation of EIRs as well as the cost savings on vaccination-related costs as a result of EIR implementation. This thesis would not only evaluate the operational vaccination-related cost savings resulting from EIR implementation but also predict how the EIR would influence healthcare costs from the societal perspective in the long term. The main contribution is, in this case, we would not just look at the benefits of EIRS from the perspective of healthcare facilities but the overall benefits to the healthcare system, hence generating information that would be more valuable to vaccination policy decision makers.

4 METHODS

This Master's thesis aims to compare EIRs to RHISs in Tanzania by evaluating facilities that use EIRs relative to RHISs, and a further cost-effectiveness analysis using the UNIVAC model.

This chapter describes the research method and design as well as the tools and approach for data collection, analysis and processing. The reliability and validity of the data obtained are also discussed in this chapter.

As this paper has two main aims, the methods would be split to

i. Describe how data was obtained and analysed from healthcare facilities in an LMIC to compare the recurrent costs of facilities utilizing and not utilizing EIRs

ii. Detail how the UNIVAC model parameters were obtained and how the model was used to evaluate the impact of EIR on future healthcare costs.

4.1 Cost Comparison of Facilities Using and Not Using EIRs

4.1.1 Research Method and Organization of Study

An observational cross-sectional study was conducted in Tanzania between November to February 2022. The primary data was obtained from Tanzania by a team from SDA Bocconi School of Management in Italy for a research project commissioned by Gavi, WHO, and the Bill and Melinda Gates Foundation to evaluate the economic and programmatic impact of implementing Immunization Information Systems and Electronic Immunization Registries in LMICs. A member of this team served as a consultant on this Master thesis; hence the raw primary data was shared to be analysed for this research.
The primary data was obtained using a questionnaire distributed to healthcare facilities across different regions in Tanzania. The questionnaire included questions that led to qualitative and quantitative data collection. It investigated whether Electronic Immunization Registries had been implemented by the facilities, if there were being used, and the cost of multiple vaccination-related activities.

4.1.2 Population and Sample

Tanzania has thirty-one regions, and primary data was obtained from sixty-one healthcare facilities in ten of these regions, namely Arusha, Dodoma, Kilimanjaro, Mbeya, Mwanza, Njombe, Pwani, Shingaya, Singida and Tanga. Information was obtained from 6 facilities per region except for the Dodoma region, where 7 facilities were evaluated. The questionnaires were given to the staff members in charge of the vaccination department.

4.1.3 Design

The questionnaire included questions about EIR implementation and utilization to establish which of the facilities implemented EIRs and were also currently using EIRs. It also had questions regarding the working conditions of healthcare staff in Tanzania. Questions regarding fourteen vaccine-related activities were also included in the questionnaire. The questions were structured so that the roles of staff members who carried out each activity and how long it took for them to carry out these activities were obtained to facilitate the calculation of staff costs related to each activity. This is in line with the study by Mvundura et al., which outlines staff costs are the vaccine-related costs most influenced by EIRS (Mvundura et al., 2019, 2020). The survey also included questions about the non-staff cost components of these activities to estimate costs exclusive of staff remuneration related to these activities.

4.1.4 Data Analysis

The fourteen vaccine-related activities cost data were collected for were child registration, outreach organization, delivery of outreach, identifying defaulters, contacting defaulters, identifying performance gaps, report generation, report transport, cold chain monitoring, vaccine ordering, vaccine quality monitoring, emergency vaccine replenishment, maintenance, and printing. The cost data collected for these activities were analysed using Microsoft Excel version 16.6 and Program R.

Table 6. Vaccination Activities

ACTIVITY	DEFINITION
Child Registration	The process of collection of a child and guardian's personal information as well as the child's vaccination history
Outreach Organization	Preparations involved in putting together vaccination delivery sessions that take place outside the healthcare facility to reach populations with limited access to vaccination locations
Delivery of Outreach	Delivery of vaccination sessions outside the healthcare facilities
Identifying Defaulters	The process of determining which children have missed a vaccination session
Contacting Defaulters	Reaching out to the guardians of children who have missed a vaccination session
Identifying Performance Gaps	The process of identifying lapses or weak points in the vaccination program
Report Generation	The extraction of relevant vaccination data and organization into reports that provide informative vaccine information
Report Transport	The transportation of vaccination reports from healthcare facilities where vaccination is carried out to district offices
Cold Chain Monitoring	The monitoring of refrigerators used to preserve vaccines
Vaccine ordering	The process of requesting the supply of vaccines to the healthcare facilities
Vaccine Quality Monitoring	This involves checking the vaccines to make sure the vials are intact
Emergency Vaccine Replenishment	The process of requesting for the supply of vaccines to the healthcare facilities due to an unexpected vaccine shortage
Maintenance	All activities related to ensuring equipment used for vaccination are in good condition
Printing	The production of all printed materials used for vaccination-related activities

Source: Author's analysis of primary data from SDA Bocconi

The first step in the analysis was to split the information obtained into staff cost-related data and non-staff cost-related information. Thirteen of the fourteen activities had associated staff costs. Staff cost-related data consisted of the monthly salary of vaccination staff for each role, the roles of the staff members that carried out each activity and the amount of time spent on each activity in hours. The staff costs were processed based on the normal working days and work hours in Tanzania collected from the study. To obtain the hourly staff rate, the monthly staff salary was divided by 20 days and then further divided by 8 hours which are the standard number of working days and hours, respectively. This hourly rate was then multiplied by 0.8 as actual working hours constitute 80% of the entire working day.

$$Hourly\ staff\ rate = \frac{Monthly\ staff\ salary\ (TSh)}{Work\ days\ per\ month(20) * Work\ hours\ per\ day(8)}\ x\ Actual\ Working\ hours(0.8)$$

This hourly rate was calculated for each staff role that carried out a specific activity. The hourly rate was then multiplied by the number of staff members with the same role that participated in that activity and the total number of hours they spent on the vaccination activity yearly. The result was the total staff costs per year of staff members with the same role on that activity. Assuming the first staff role that carried out a specific activity is role A,

$$Total\ Staff\ cost\ for\ role\ A = hourly\ rate\ x\ no.of\ staff\ members\ with\ the\ same\ role\ x\ total\ no.of\ hours\ yearly$$

Afterwards, the total staff costs for each activity were calculated by adding all the staff costs for each role, and the calculation described above was repeated thirteen times for all thirteen activities with a staff cost component. Assuming the first activity is activity A,

$$Total\ staff\ cost\ for\ activity\ A = Total\ staff\ cost\ for\ role\ A + Total\ staff\ cost\ for\ role\ B + \ldots total\ staff\ cost\ for\ role\ N$$

Only outreach, report transport, emergency vaccine replenishment and maintenance had non-staff costs and staff costs components, while printing incurred solely non-staff costs. Outreach non-staff costs were calculated by adding the non-staff outreach service costs and the cost of outreach consumables, and then the result was multiplied by the number of outreach sessions per year. Report transport and emergency vaccine replenishment trips non-staff costs were calculated by multiplying the number of report transport trips and stockout trips yearly by the cost of each transport trip. Maintenance costs were calculated by calculating the sum of the cost of services, consumables and durables associated with maintenance and multiplying the result by the number of maintenance events per year. Lastly, printing costs were calculated by multiplying the total number of pages printed per year by the cost per page. Table 7 below summarizes how all non-staff costs were calculated.

Table 7. Non-Staff Vaccine Related Costs

Activity	Non-staff Cost
Outreach	$(Outreach\ service\ costs + consumable\ costs)\ x\ number\ of\ outreach\ sessions\ per\ year$
Report Transport	$number\ of\ report\ transport\ trips\ per\ year\ x\ cost\ of\ each\ trip$
Urgent Vaccine Replenishment	$number\ of\ stockout\ trips\ per\ year\ x\ cost\ of\ reach\ trip$
Maintenance Costs	$(Maintence\ service\ costs + consumable\ costs + durable\ costs)\ x\ number\ of\ maintenance\ events\ per\ year$
Printing costs	$total\ number\ of\ pages\ printed\ per\ year\ x\ cost\ per\ page$

Following the calculation of all the staff and non-staff costs data for all the activities, the sum of all these costs for each facility was calculated to obtain the total cost for vaccination-related activities per facility.

$$Total\ cost\ per\ facility = Total\ staff\ costs + Total\ non\ staff\ costs\ for\ all\ activities$$

The total costs for all 61 facilities were added and divided by the total number of children registered to be vaccinated in all the facilities to obtain the incremental healthcare costs for vaccine-related activities per child in a year.

$$\text{Total vaccine activity related costs per child} = \frac{\text{Sum of total costs in all facilities}}{\text{Sum of children registered for vaccination in all facilities}}$$

Furthermore, the 61 facilities were split based on the facilities utilizing EIRs and those not using them. Missing data were accounted for using the mean substitution method, where average costs of each activity based on the EIR use and non-use categorization were used to replace missing data in each category (Fox-Wasylyshyn & El-Masri, 2005). The average, standard deviation, median and interquartile range were then calculated for each activity based on EIR use and non-use. Afterwards, in program R, the Wilcoxon rank sum test for independent samples (Bland, 2000; McIntosh et al., 2010) was used to calculate the p-values for each activity and evaluate if the difference in staff and non-staff costs for each activity were statistically significant.

Microsoft Excel and Program R were then used to generate data visualizations in the form of bar charts and box plots to aid the cost comparison between facilities utilizing EIRs and those not using them.

4.2 Cost Effectiveness Analysis Using the UNIVAC Model

4.2.1 Process of Conducting the Study

A comprehensive review of published literature focused on rotavirus vaccination and healthcare costs in Tanzania was done to obtain secondary data sources for the model parameters input. The UNIVAC baseline values for the model parameters were evaluated based on the references, and most of these baseline values were kept for this study. The few baseline values altered were due to the more recent primary vaccination cost data received from SDA Bocconi discussed above, and healthcare-related costs from the societal perspective were not included in the model's baseline values. Details on which parameters were replaced are detailed below, where individual model parameters are discussed. This was done in line with other studies that utilized the TRIVAC model, the predecessor of the UNIVAC model (Sigei et al., 2015; Urueña et al., 2015)

4.2.2 UNIVAC Model

The Excel-based model has seven main sections: instructions, setup, inputs, results, charts, scenarios, and probability sensitivity analysis. The instructions section details how the model should be used, setup provides the avenue for the country of study, in this case, Tanzania, to be set as well as the language preference which was English. The input parameters for the model are demographics, disease burden, immunization schedule, immunization efficacy, vaccine coverage, immunization costs, health service utilization and health service costs. As the selected country option was Tanzania, the model populated baseline values for vaccination parameters for Tanzania and their references. The results section displayed the key outcomes of the cost-effectiveness analysis and associated charts in the charts section. Finally, the scenario segment allows the user to evaluate different possible situations, while the probabilistic sensitivity analysis enables the user to quantify the level of confidence in the analysis output relative to the uncertainty in the model input parameters.

4.2.3 Comparator and Key Outcomes

In this study, vaccination with Rotarix (RV1) using RHISs was compared to immunisation with RV1 utilizing EIRs, which is the new intervention. The model estimates the incremental vaccine costs, healthcare costs averted, disease and adverse events (cases, visits, hospitalizations, death) and disability-adjusted life years (DALYs) that can be averted when vaccination information is managed using EIRs instead of RHISs. DALY is calculated using the model by adding the years lived with disability (YLD) and years of life lost (YLL) for each weekly cycle. YLD and YLL are calculated using the formulas below, respectively.

$$YLD = number\ of\ cases\ x\ duration\ till\ remission\ or\ death\ x\ disability\ weight$$

$$YLL = number\ of\ deaths\ due\ to\ rotavirus\ x\ life\ expectancy\ at\ the\ age\ of\ death$$

DALYs averted would be calculated for each cycle and accumulated over the 260-week duration using the model. This would be done when an RHIS is used to manage vaccination information and when an EIR is used to manage immunization data. Based on similar studies (Sigei et al., 2015; Urueña et al., 2015), cost-effectiveness was estimated based on the incremental cost-effectiveness ratio (ICER) using cost per DALY averted. ICER is calculated by subtracting the cost of the old intervention from the cost of the new intervention and dividing the result by the effectiveness of the old intervention deducted from the effectiveness of the new intervention.

$$ICER = \frac{Cost\ of\ EIR - Cost\ of\ RHIS}{DALYs\ averted\ by\ EIR - DALYs\ averted\ by\ RHIS}$$

Following WHO guidelines, the criteria for cost-effectiveness were dependent on the Tanzanian Gross Domestic Product (GDP) per capita. If the cost per DALY averted is less than the GDP per capita, then EIR implementation and utilization is significantly cost-effective; if it is between one to three times, it is cost-effective, and if it is greater than three times the GDP per capita, then it is not cost-effective (Sigei et al., 2015; WHO. Commission on Macroeconomics and Health. & Sachs, 2001). The difference in ICERs based on cost per DALY and the other output parameters were then evaluated to assess the cost-effectiveness of EIRs compared to RHISs.

4.2.4 Conceptual Framework

The UNIVAC model was populated and run twice to carry out this cost-effectiveness analysis. First, the influence of vaccination when paper-based records are used on UNIVAC model outputs was evaluated compared to no vaccination. Subsequently, how EIR-supported vaccination affects the UNIVAC model outputs compared to no vaccination was also assessed by changing input parameters influenced by EIR use and running the model a second time. The difference between the two model outputs was then compared to evaluate whether there was a significant benefit of utilizing EIRS instead of RHISs for vaccination.

4.2.5 Model Input Parameters

The UNIVAC model required the user to enter set-up parameters with regards to the timeline of the study and the study perspective. Other input parameters are demographic data, disease burden, vaccine timeliness, vaccination schedule and coverage, vaccine efficacy (relative coverage of the vaccine, waning, serotype coverage and herd immunity), vaccine program costs (vaccine price per dose, supplies and wastage, incremental healthcare costs per dose), healthcare service utilization and healthcare costs. The baseline values of the UNIVAC model for Tanzania were used for all the model parameters except vaccine timeliness, incremental health system costs per dose and healthcare costs from the societal perspective. The sources of data for the set-up parameters, vaccine timeliness, incremental health system costs per dose and healthcare costs from the societal perspective are discussed in detail below.

Set-Up Parameters

2020 was set up as the year of EIR introduction as it aligns with the period after the pilot run of EIR implementation in Tanzania carried out by the BID initiative (Mvundura et al., 2019, 2020). Cost-effectiveness, cost estimates and health benefits were evaluated for five birth cohorts from 2020-2024.

Hence, using the model, the first cohort was followed up for 259 weeks (less than five years). This is because the objective is to assess how EIRs improve the vaccination process compared to RHISs. This would be best evaluated by focusing on how EIRs affect the RVGE morbidity and mortality of children under five years. (Ruhago et al., 2015). Immunization program costs were assigned to each cohort's first year, while the cost of therapy, illness and death were estimated over the 5-year period. Alternatively, DALY and all other outcomes were estimated over the lifespan of each cohort population using current and estimated future life expectancies. The model also stacked results of each cohort's estimated costs and health benefits as it is more logical for decision makers to assess in terms of year-on-year trends as opposed to lifetime events in an individual cohort (Clark et al., 2013). The government and societal perspectives were evaluated, and a cost and benefit discount rate of 3% was used(WHO, Commission on Macroeconomics and Health & Sachs, 2001).

Incremental Healthcare System Costs per Dose

Baseline values of the incremental healthcare system costs per dose used in the model were updated using recurrent cost data obtained from SDA Bocconi. The raw primary data that outlined the recurrent cost of 14 vaccine-related activities were analysed as described in section 2.2.4 to yield the incremental healthcare systems cost per dose per child in Tanzanian Shillings (TSh), when RHISs are used to manage vaccination data and when EIRs are used. The incremental healthcare system costs per child for the facilities that utilized RHISs and EIRs were 4,160TSh and 3,703TSh, which in United States Dollars is USD 1.78 and USD 1.59, respectively based on the 2022 exchange rate (XE, 2022). As these costs were incremental healthcare costs due to all the vaccines, unit costs for each vaccine dose were calculated using the total number of doses for all the vaccines on the Tanzanian vaccination schedule, excluding the doses given at birth. As a result, the increase in healthcare vaccination activity costs due to each dose of rotavirus vaccination when RHISs and EIRs are used is $0.14 and $0.12, respectively.

Vaccine Timeliness

Timeliness is one of the critical factors that affect vaccine effectiveness, and in chapter one, the influence of EIRs on vaccination validity was discussed in detail. Nguyen et al. detailed that the utilization of EIRs increased the vaccination timeliness of the two vaccines evaluated by 23.6% and 21.9%, respectively, compared to RHISs after one year of implementation (Nguyen et al., 2017). The average increase in the timeliness of 22.75% a year post implementation of EIRS was applied to the initial baseline value when the model was run for RHISs to reflect the influence of EIRs on vaccine timeliness.

Healthcare Costs from the Societal Perspective

The UNIVAC model baseline values only include healthcare costs from the government perspective, as the model was developed to inform state governments' vaccine policy decisions (Clark et al., 2013). Healthcare costs from the societal perspective were obtained from a 2019 study of the cost-effectiveness of rotavirus vaccination in 73 GAVI countries (Debellut et al., 2019).

The study estimated healthcare costs from the societal perspective by adding direct medical costs, direct non-medical costs and indirect costs. Direct medical costs were obtained using WHO cost-effectiveness and strategic planning tool, while inpatient costs were calculated using country-specific estimates of daily bed costs, assuming a four-day stay at a secondary level hospital where six oral rehydration and two intravenous solutions are used per day. WHO cost-effectiveness and strategic planning tool were also used to estimate outpatient visit costs where six packs of oral rehydration solution are used over two days in a primary hospital. Non-direct medical costs were calculated by obtaining the proportion of direct medical to direct non-medical costs from literature and combining the proportion of direct non-medical costs with the estimate of direct medical costs. Finally, indirect medical costs were estimated by multiplying the average amount of days lost to caring for a patient with diarrhoea by the average GDP per capita per day with the assumption that inpatient caregivers lost an entire productive day while outpatient caregivers lost 25% of a productive day (Debellut et al., 2019).

The country-specific healthcare costs for Tanzania were obtained from the appendix of the study by Debellut et al. (2019). The total cost, which makes up the average healthcare costs from the societal perspective per outpatient visit, was $12.14 and was comprised of indirect costs of $0.60, direct non-medical costs of $6.62, and direct medical costs of $4.92. Conversely, the average cost per hospital admission from the societal perspective was $37.13. It comprised the indirect costs of $2.41, direct non-medical costs of $5.93 and direct medical costs of $28.79.

Using a combination of the baseline values included in the UNIVAC model for Tanzania, the secondary data obtained from the literature for set-up parameters, timeliness, costs from the societal perspective and processed primary data from SDA Bocconi for incremental health system costs per dose, the model was populated and run a first-time using values for rotavirus vaccination when RHISs are used, and then a second time using values when an EIR is used and the resulting model outputs are compared and discussed in the section below.

5 RESULTS

The results section is also divided to enumerate the results from the cost comparison of facilities utilizing and not utilizing EIRs and the cost-effectiveness analysis using the UNIVAC model.

5.1 Results of Cost Comparison of facilities using and not using EIRs

5.1.1 Characteristics of Study Sample

The 61 facilities that results were obtained from were categorized into facilities that used EIRs and facilities that used paper-based records. The facilities were also described based on the regions they were located in, and the number of children vaccinated yearly, giving an indication of their size. The characteristics of the sample population are described in table 8 below.

Table 8. Summary of Healthcare Facilities in Survey

Characteristics	All facilities, n (%) n=61	Facilities that use EIR, n (%) n=17	Facilities that do not use EIR, n (%) n=44
Region			
Arusha	6 (9.8)	0 (0.0)	6 (13.6)
Dodoma	7 (11.5)	0 (0.0)	7 (15.9)
Kilimanjaro	6 (9.8)	5 (29.4)	1 (2.3)
Mbeya	6 (9.8)	0 (0.0)	6 (13.6)
Mwanza	6 (9.8)	6 (35.3)	0 (0.0)
Njombe	6 (9.8)	0 (0.0)	6 (13.6)
Pwani	6 (9.8)	0 (0.0)	6 (13.6)
Shingaya	6 (9.8)	0 (0.0)	6 (13.6)
Singida	6 (9.8)	0 (0.0)	6 (13.6)
Tanga	6 (9.8)	6 (35.3)	0 (0.0)

N<u>o</u> of children vaccinated yearly			
0-2,000	20 (32.8)	7 (41.2)	13 (29.5)
2,000-5,000	22 (36.1)	5 (29.4)	17 (38.6)
5,000-10,000	14 (22.9)	4 (23.5)	10 (22.7)
>10,000	5 (8.2)	1 (5.9)	4 (9.1)

Of the 61 facilities included in the study, 36 facilities had implemented an EIR at some point, but only 17 facilities were currently using the Electronic Immunization Registries. All 17 facilities were majorly smaller facilities and were localized in three regions, Kilimanjaro, Mwanza and Tanga. None of the facilities outside these three regions were currently using the EIR, despite it being implemented in some of them.

5.1.2 Cost Analysis

The costs of vaccination-related activities were analysed to yield the yearly incremental healthcare costs per child and to compare how the costs for each activity differ between facilities that use EIRs and those that do not. The incremental healthcare system costs because of vaccination per child for the facilities that utilized RHISs and EIRs were 4,160TSh and 3,703TSh, which in United States Dollars is USD1.78 and USD 1.5, respectively, based on the 2022 exchange rate (XE, 2022).

Fourteen vaccination-related activities were analysed, and the staff and non-staff-related vaccination costs were obtained, categorized into EIR users and non-users, and summarised for the 61 facilities. Of these fourteen activities, four had both staff and non-staff components, nine had only staff costs components, and one had only non-staff costs. Hence, 13 activities had staff costs, and 5 had non-staff costs.

Staff Costs

Figure 2 below illustrates how the staff costs varied between facilities currently using the EIR and those not using them.

Of the thirteen activities with staff costs evaluated, there was a reduction in staff costs in nine activities for the facilities that were currently using the EIR. The four activities where the facilities utilizing the EIR had higher costs were child registration, identifying defaulters, cold chain monitoring and staff maintenance costs.

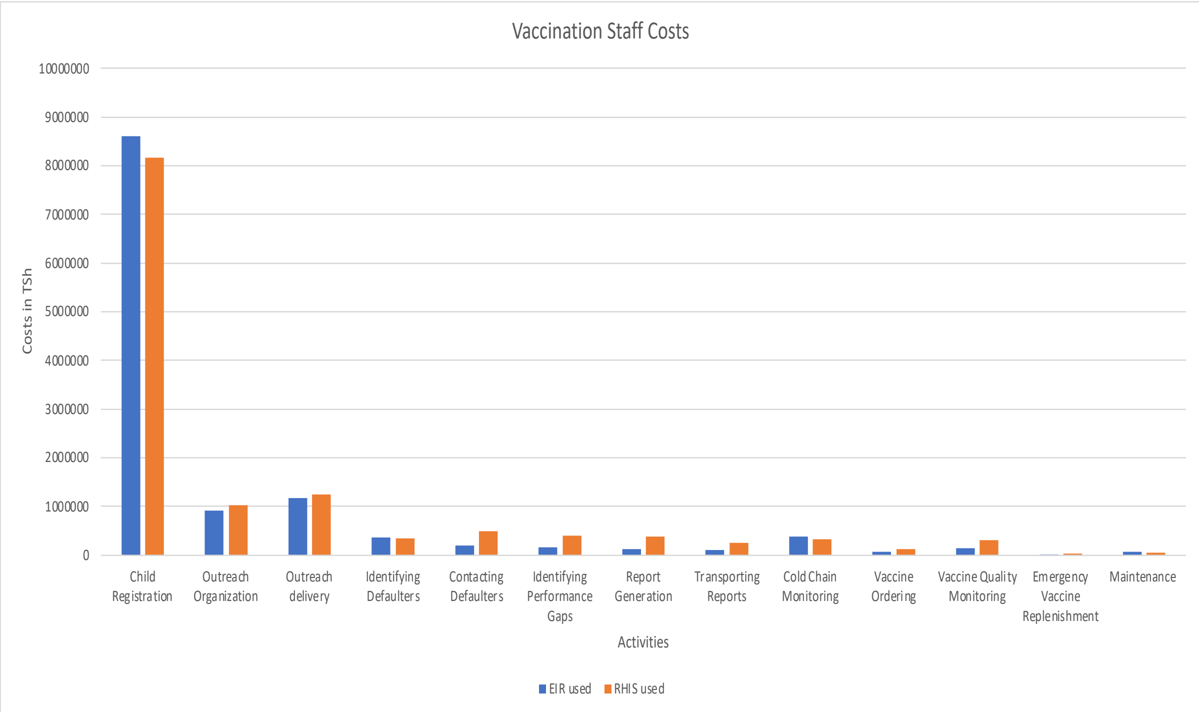


Figure 2. Vaccination Activity Staff Costs

The box plots below in Figures 3-15 further emphasize the difference in staff costs for all 13 activities for EIR users and non-users. In addition, they illustrate the variation in the medians and interquartile range and highlight all the outliers in the facility costs.

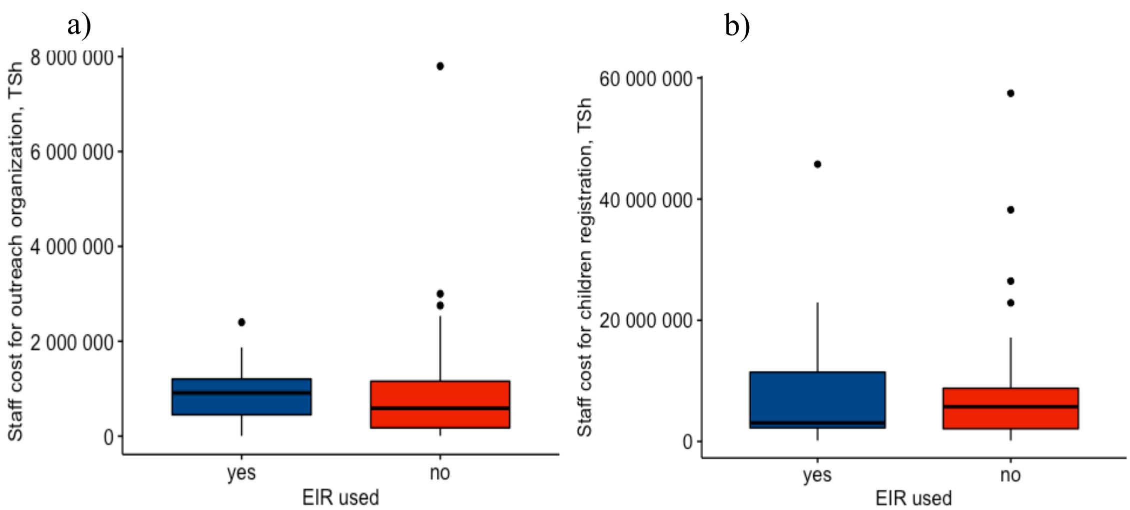


Figure 3. Box plots comparing staff costs for a) registration b) outreach organisation

a) b)

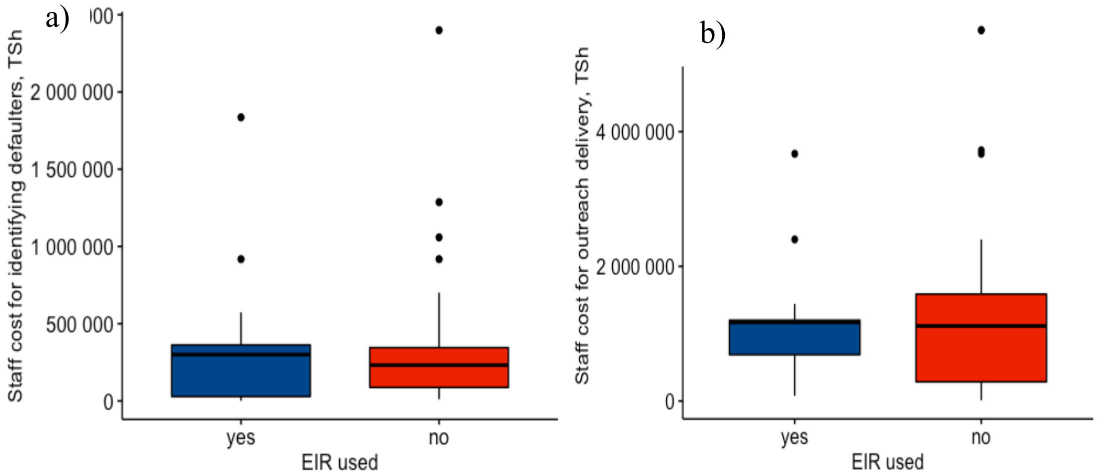


Figure 4. Box plots comparing staff costs for a) outreach delivery and b) identifying defaulters

a) b)

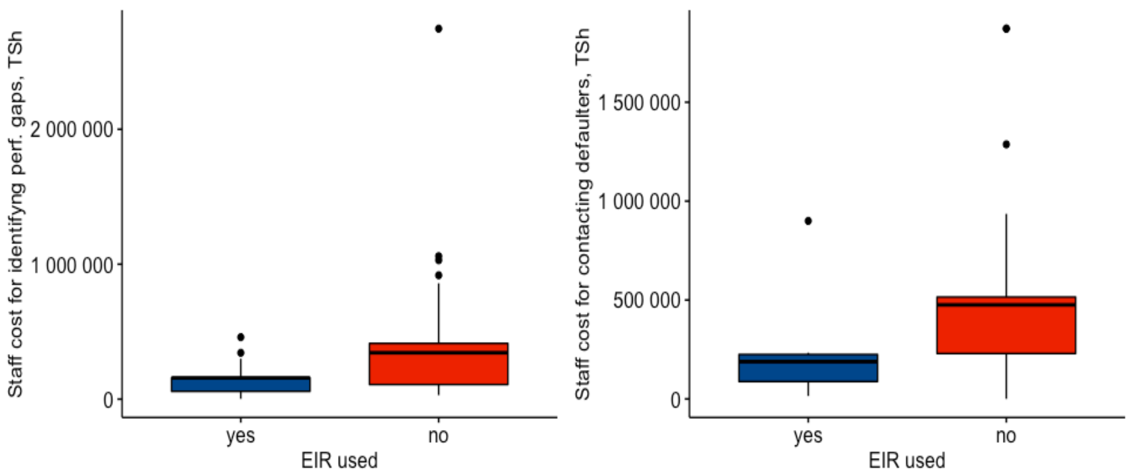


Figure 5. Box plots comparing staff costs for a) contacting defaulters and b) identifying performance gaps

a) b)

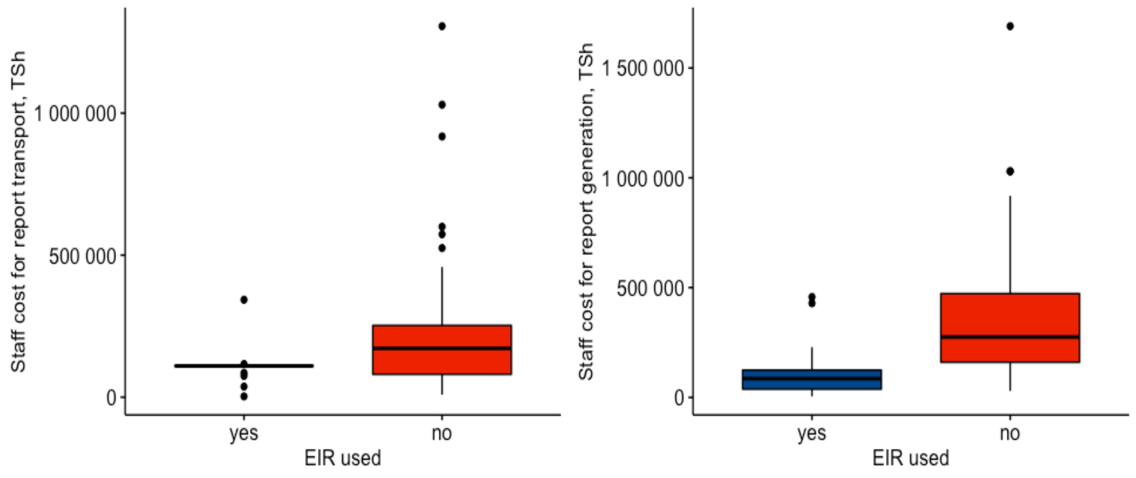


Figure 6. Box plots comparing staff costs for a) report generation and b) report transport

a) b)

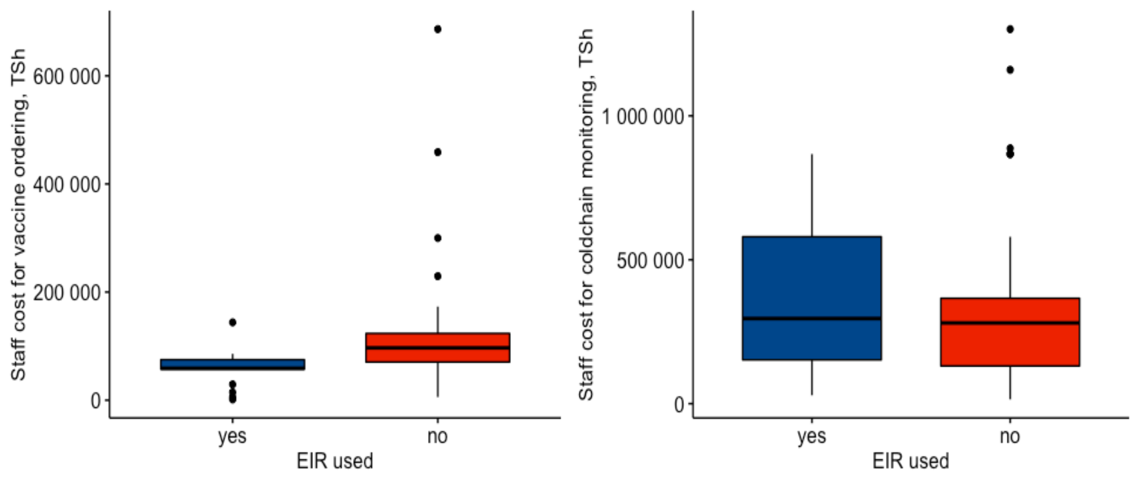


Figure 7. Box plots comparing staff costs for a) cold chain monitoring and b) identifying defaulters

a) b)

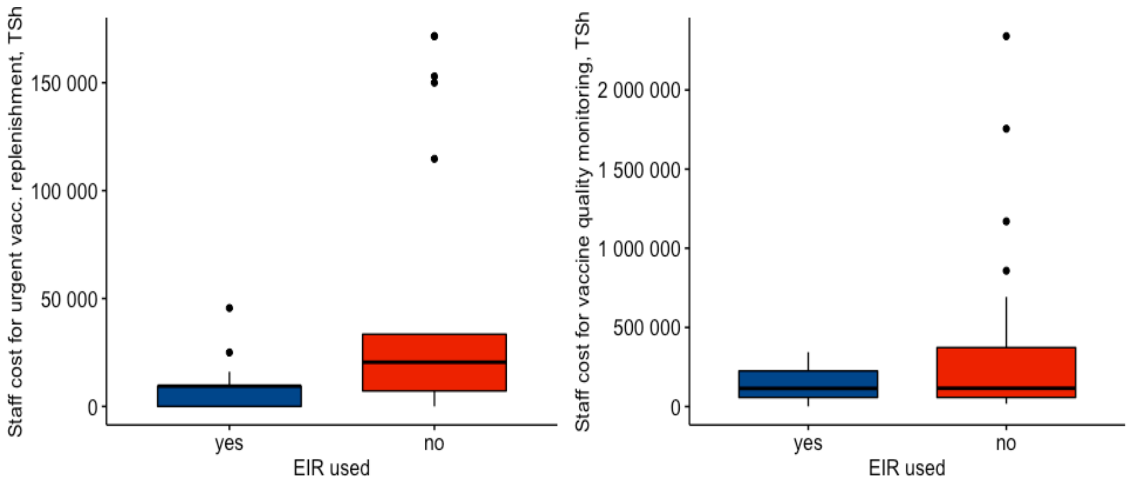


Figure 8. Box plots comparing staff costs for a) vaccine quality monitoring and b) urgent vaccine replenishment

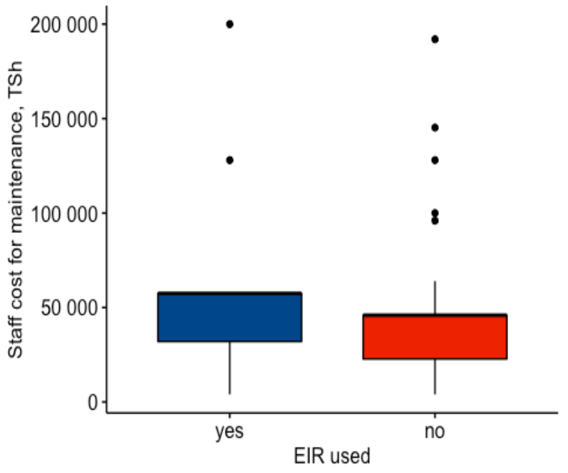


Figure 9. Box plots comparing staff costs for maintenance

Non-Staff Costs

The variation in non-staff costs between facilities utilizing the EIR and facilities currently not using them is illustrated in Figure 10 below.

Of the five vaccine-related activities with non-staff costs, the facilities where EIRs were used had reduced non-staff costs in four activities. The only activity with increased non-staff cost was printing.

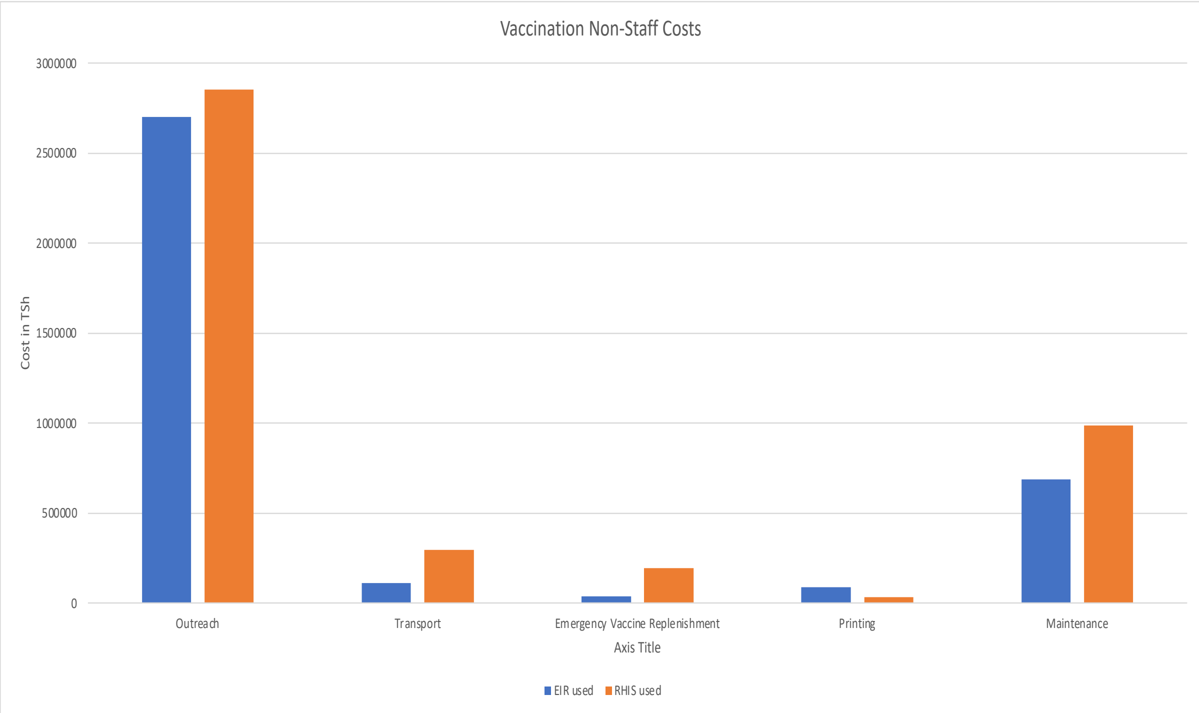


Figure 10. Non-staff vaccination activity costs

The box plots below further demonstrate the difference between the non-staff costs of facilities using EIRs and facilities not using them by illustrating the difference between the median and their range and highlighting any outlier values.

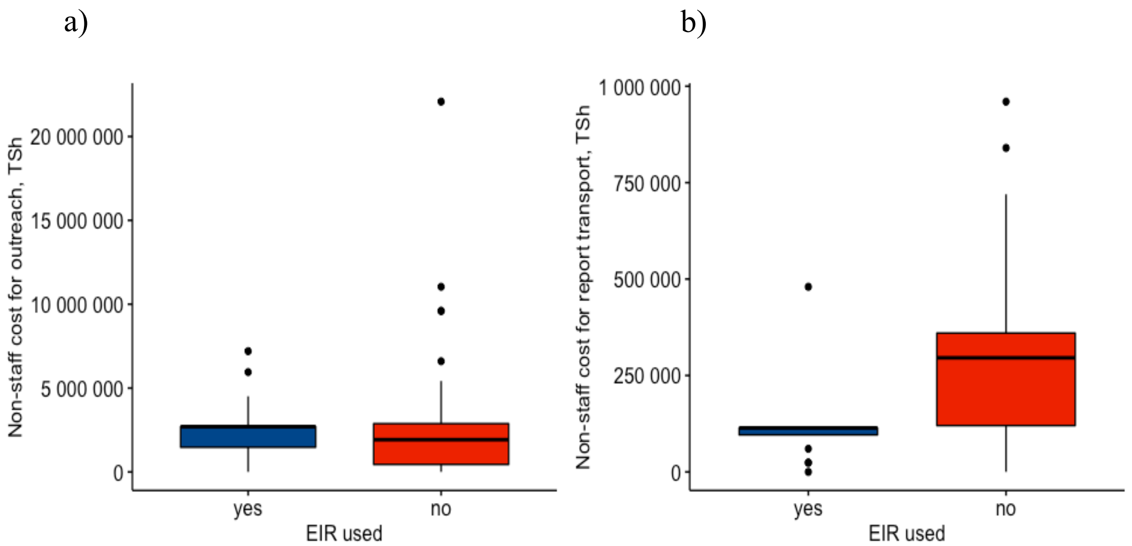


Figure 11. Box plots comparing non-staff costs for a) outreach and b) report transport

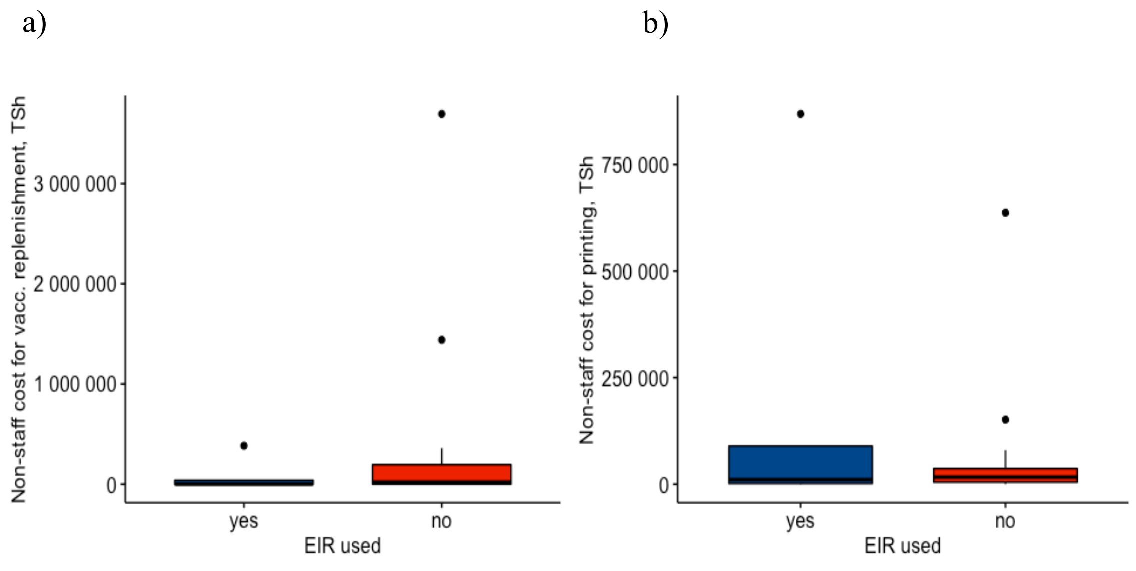


Figure 12. Box plots comparing non-staff costs for a) vaccine replenishment and b) printing

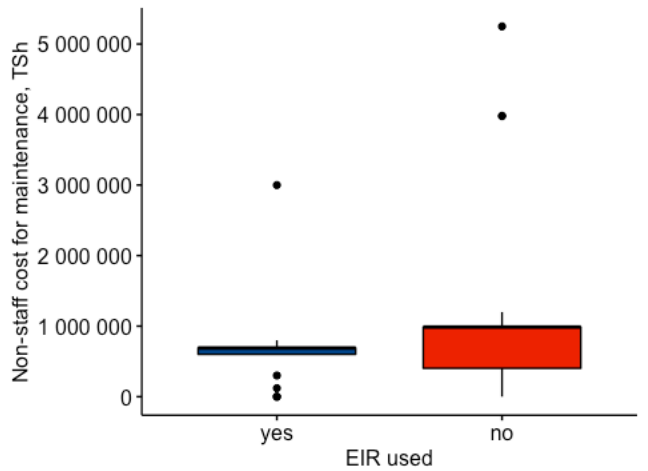


Figure 13. Box plot comparing non-staff costs for maintenance

Cost Analysis Results

The thirteen staff costs and five non-staff costs obtained from all 61 facilities are summarized in Tables 9-10 below.

Table 9. Vaccination-related Activity Staff Costs in Tanzanian Shillings (TSh)

	EIR User		**EIR Non-User**		
Activity	**Mean (SD)**	**Median (IQR)**	**Mean (SD)**	**Median (IQR)**	**p-value**
Child Registration	8 597 956 (1 902 255)	3 059 200 (9 190 000)	8 171 636 (10 718 755)	5 736 000 (6 701 075)	0.612
Outreach organisation	910 669 (668 085)	910 669 (7545 60)	1 020 976 (1 346 229)	586 800 (983 655)	0.872
Outreach Delivery	1 167 829 (838 395)	1 167 829 (512 880)	1 241 929 (1 312 887)	1 114 800 (1 302 968)	0.962
Identifying Defaulters	362 591 (446 857)	300 000 (333 911)	337 722 (421 730)	231 720 (257 400)	0.860
Contacting Defaulters	188 413 (198 379)	188 413 (137 250)	482 910 (406 342)	475 455 (285 765)	**<0.001**
Identifying Performance Gaps	157 451 (129 967)	157 451 (100 091)	397 370 (453 635)	343 680 (305 055)	**0.009**
Report Generation	124 580 (133 262)	85 800 (87 080)	376 732 (330 842)	274 950 (312 745)	**<0.001**
Transporting Reports	110 238 (67 529)	110 238 (0)	251 411 (275 279)	172 080 (172 420)	0.0913
Cold Chain Monitoring	380 278 (265 490)	295 750 (427 873)	325 580 (303 309)	280 410 (235 180)	0.334
Vaccine ordering	59 011 (33 927)	59 011 (17 640)	125 662 (115 655)	96 825 (52 950)	**0.002**
Vaccine Quality Monitoring	132 747 (100 365)	114 720 (167 640)	311 984 (465 842)	115 860 (315 480)	0.4249
Emergency Vaccine Replenishment	9 410 (11 422)	9 410 (9 410)	33 468 (45 337)	20 475 (26 318)	**0.005**

Maintenance	57 464 (46 648)	57 464 (25 464)	45 947 (37 646)	45 947 (23 197)	**0.039**

Table 10. Vaccination-related Non-Staff Costs in Tanzanian Shillings (TSh)

	EIR User		**EIR Non-user**		
Activity	**Mean (SD)**	**Median (IQR)**	**Mean (SD)**	**Median (IQR)**	**p-value**
Non-staff Outreach cost	2 701 164 (1 888 304)	2 701 164 (1 232 364)	2 851 895 (3 970 168)	1 920 000 (2 437 500)	0.562
Non-staff Transportation Costs	114 000 (101 978)	114 000 (18 000)	295 875 (228 163)	295 875 (240 000)	**<0.001**
Non-staff Vaccine Replenishment Costs	38 545 (91 074)	0 (38 545)	194 156 (586 315)	20 000 (194 156)	0.1047
Current cost of pages printed yearly	89 440 (205 395)	10 560 (88 000)	36 529 (9 6250)	16 480 (31 929)	0.7347
Current cost of maintenance yearly	690 000 (651 230)	690 000 (900 00)	986 471 (1 023 218)	986 471 (583 971)	**0.005**

Interquartile range (IQR: Q3-Q1)

The p-value for each activity was calculated to estimate the statistical significance of the difference between the costs of each activity when EIRs are used and not used with a confidence interval of 95% and hence a significance level of 0.05. Six of the thirteen staff costs, namely contacting defaulters, identifying performance gaps, report generation, vaccine ordering, emergency vaccine replenishment and maintenance, had statistically significant differences between EIR users and non-users. For non-staff costs, transportation and maintenance had statistically significant differences between EIR users and non-users.

5.2 Results of Cost-Effectiveness Analysis Using the UNIVAC Model

The UNIVAC model was run twice to evaluate the influence on disease events, economic benefits, and cost-effectiveness of vaccination when paper-based records are used and when EIRs are used.

5.2.1 Rotavirus Disease Events when RHISs are substituted with EIRs

The effects of vaccination with Rotarix on rotavirus-related cases, outpatient visits, hospitalizations, deaths and DALYs when EIRs were used for the vaccination program instead of EIRs were assessed using the UNIVAC model. Figures 14-18 below illustrate how rotavirus cases and rotavirus-related disease events, as well as DALYs due to rotavirus, are averted when EIRs are utilized instead of RHISs.

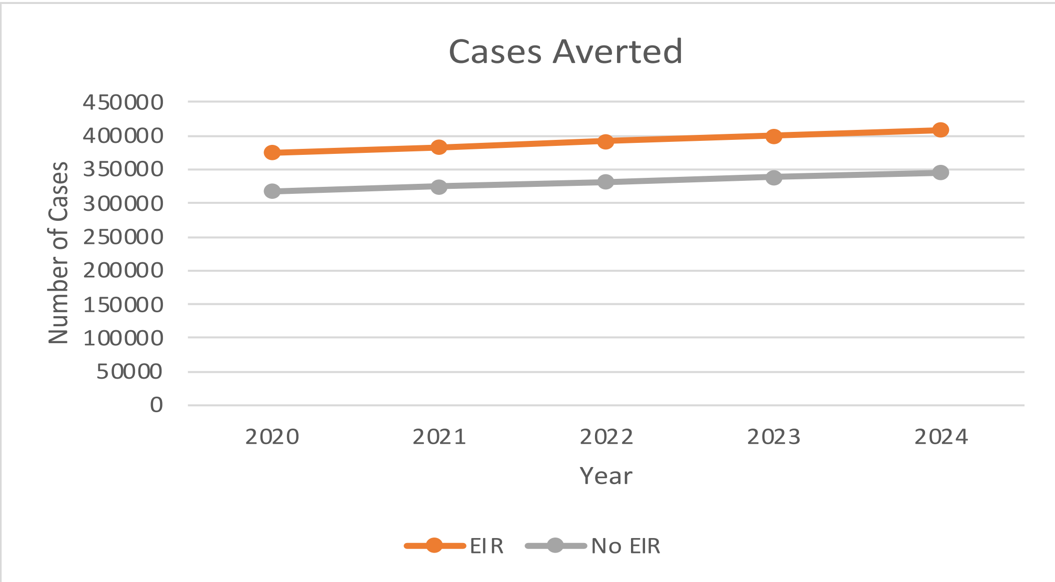


Figure 14. Rotavirus cases averted with EIR utilization instead of RHIS

In figure 14 above, the number of rotavirus cases averted increased over the five birth cohorts evaluated when EIRs and RHISs were used. However, the number of rotavirus disease cases averted is higher when EIRs are used compared to RHISs in every birth cohort.

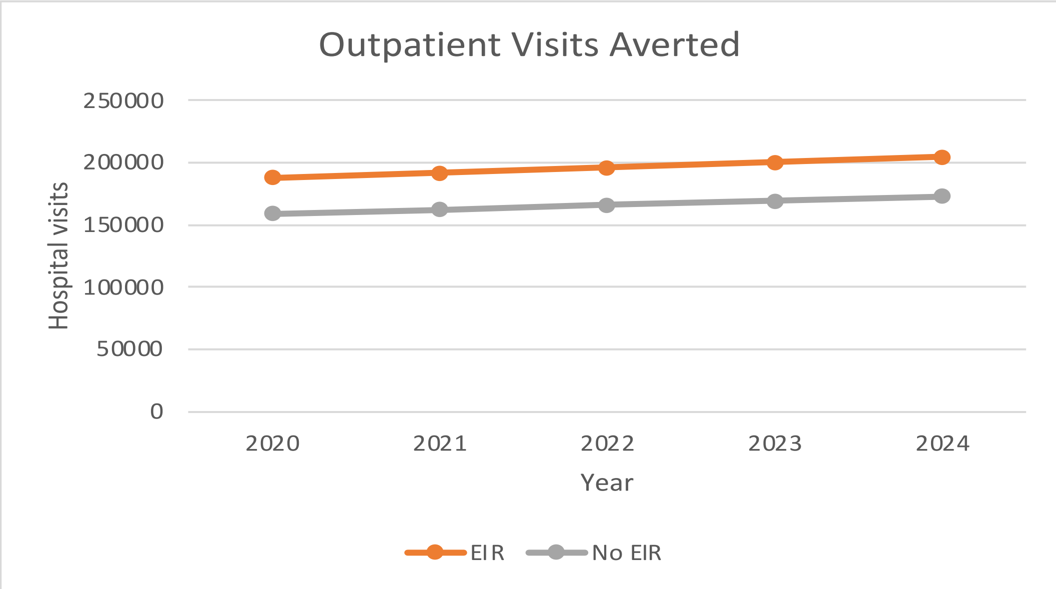


Figure 15. Rotavirus outpatient visits averted with EIR utilization instead of RHIS

In figure 15 above, the number of rotavirus outpatient visits averted increased over the five birth cohorts evaluated both when EIRs and RHISs were used. However, the number of visits averted is higher when EIRs are used compared to RHISs in every birth cohort.

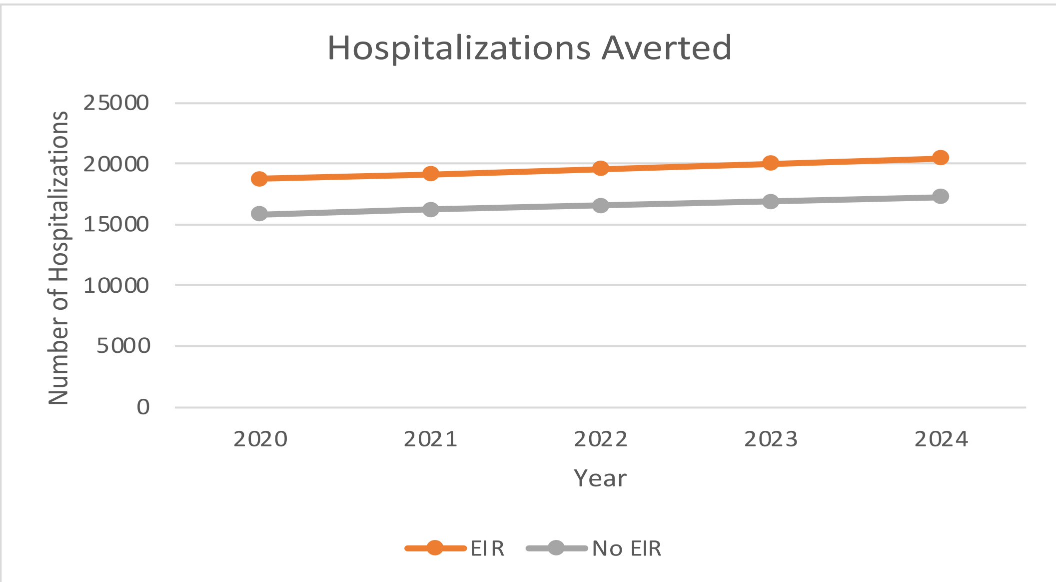


Figure 16. Rotavirus hospitalizations averted with EIR utilization instead of RHIS

In figure 16 above, the number of rotavirus-related hospitalizations averted increased over the five birth cohorts evaluated both when EIRs and RHISs were used. However, the number of hospitalizations averted is higher when EIRs are used compared to RHISs in every birth cohort.

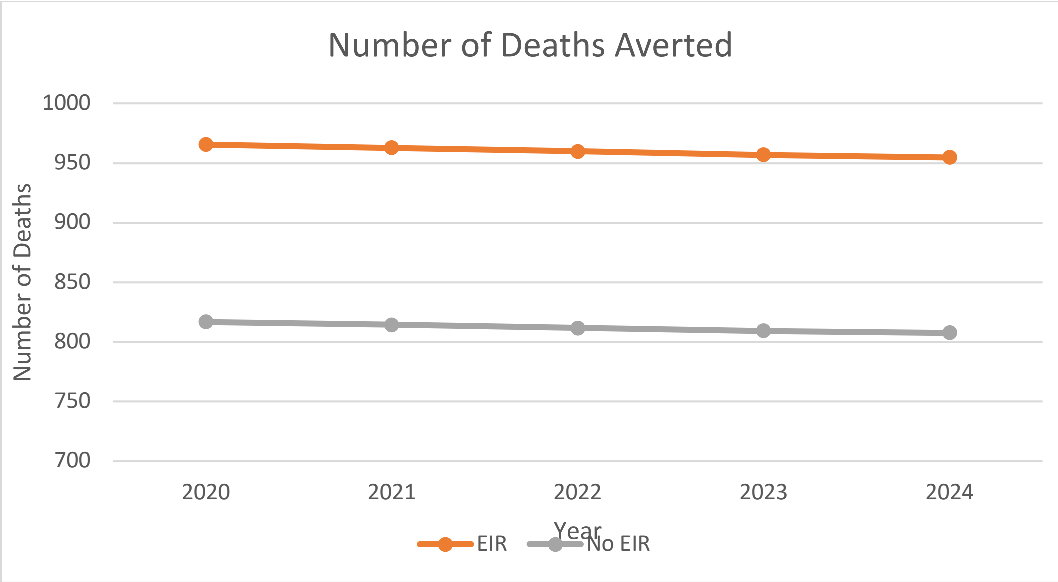


Figure 17. Rotavirus deaths averted with EIR utilization instead of RHIS

In figure 17 above, the DALYs averted decreased slightly over the five birth cohorts evaluated when EIRs and RHISs were used. However, the number of deaths averted is higher when EIRs are used in comparison to RHISs in every birth cohort

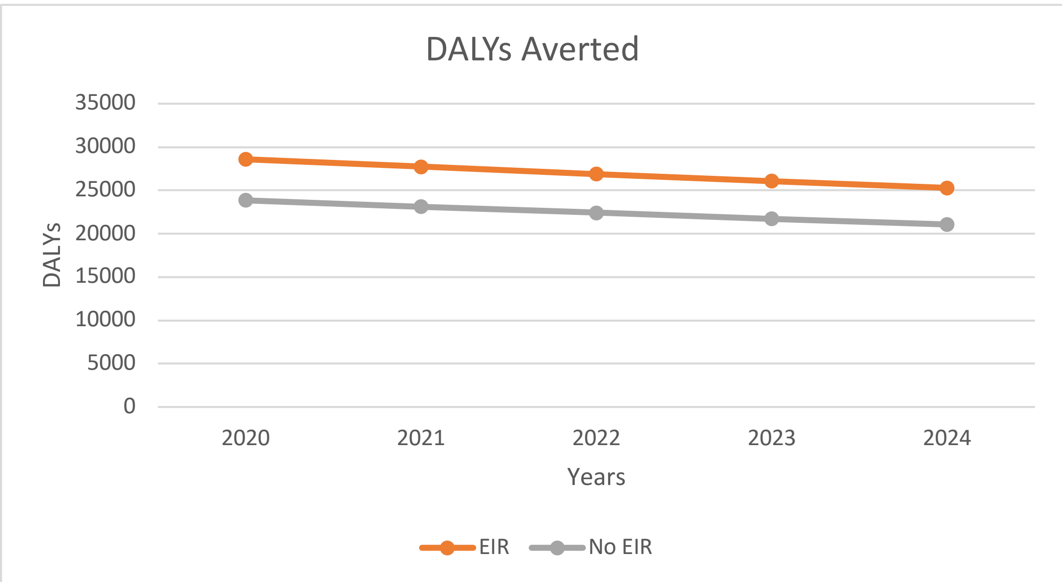


Figure 18. DALYs averted with EIR utilization instead of RHIS

In figure 18 above, the DALYs averted decreased over the five birth cohorts evaluated when EIRs and RHISs were used. However, the number of DALYs averted is higher when EIRs are used compared to RHISs in every birth cohort.

5.2.2 Cost Effectiveness Analysis

RHIS (Paper-based records)

The economic benefits and discounted cost-effectiveness of the Rotarix vaccine when vaccination is done using RHISs compared to no vaccination were evaluated using the UNIVAC model. The results are described in table 11 below. Between 2020 and 2024, the vaccine's introduction could avert approximately 1.7million disease cases, 828,752 hospital visits, 82,080 hospitalizations and 4,060 deaths. 112,136 DALYs are also averted. The study estimated that the vaccination program cost with RHISs would be approximately $52.7 million for the five birth cohorts and would avert approximately $5.7 million in healthcare costs from the government perspective and $12.2 million from the societal perspective. Hence, the net vaccination program costs would be estimated to be $46 million and $40 million from the government and societal perspectives. Conducting the vaccination program using RHISs, the cost per DALY averted was $419 from the societal perspective and $360 from the societal perspective, significantly less than the Tanzanian GDP per capita, $1,135.5 (World Bank, 2021)

Table 11. Cost-effectiveness of RV1 for 5 cohorts vaccinated between 2020 and 2024 in Tanzania using RHISs

No EIR		
Cost-effectiveness compared to no vaccine		
	Government Perspective	**Societal Perspective**
Net cost of vaccine introduction	$46 937 160	$40 375 672
• **Cost of vaccine introduction**	$52 672 304	$52 672 304
• **Health service costs averted**	$5 735 144	$12 296 632
DALYs averted	112 136	112 136
Cost per DALY averted	$419	$360
Healthcare costs averted	$5 735 144	$12 296 632
• **Visits**	$3 730 668	$9 397 373
• **Hospitalizations**	$2 004 476	$2 872 259
Total disease events averted		
• **Disease Cases**	1 657 448	
• **Visits**	828 752	
• **Hospitalizations**	82 820	
• **Deaths**	4 060	

Electronic Immunization Registries

When EIRs were introduced in comparison to no vaccination, the model yielded a new range of economic benefits and discounted cost-effectiveness of the Rotarix vaccine, summarized in Table 12 below. Over the course of the five cohorts, the introduction of the vaccine could avert approximately 2 million disease cases, 980,013 outpatient visits, 97, 921 hospital admissions and 4, 799 deaths. In addition, 134,513 DALYs are also averted, and the cost per DALY averted was $364 from the government perspective and $307 from the societal perspective. Hence, the use of EIRs for vaccination was considerably less than $1,136, the Tanzanian GDP per capita (World Bank, 2021). The model also estimated that the vaccination program cost with EIRs would be approximately $56 million for the five birth cohorts and would avert approximately $6.8 million in healthcare costs from the government perspective and $14.5 million from the societal perspective. Hence, the net vaccination program costs would be estimated to be $49 million and $41 million from the government and societal perspectives.

Table 12. Cost-effectiveness of RV1 for 5 cohorts vaccinated between 2020 and 2024 in Tanzania using EIRs

EIR		
Cost-effectiveness compared to no vaccine		
Net cost of vaccine introduction	$48 991 296	$41 251 530
• **Cost of vaccine introduction**	$55 772 041	$55 772 041
• **Health service costs averted**	$6 780 745	$14 520 511
DALYs averted	134 513	134 513
Cost per DALY averted	$364	$307
Healthcare costs averted	$6 780 745	$14 520 511
• **Visits**	$4 415 224	$11 121 738
• **Hospitalizations**	$2 365 520	$3 393 773
Total disease events averted		
• **Disease Cases**	1 959 944	
• **Visits**	980 013	
• **Hospitalizations**	97 921	
• **Deaths**	4 799	

EIRs, in comparison to RHISs

Lastly, a cost-effectiveness analysis was carried out comparing the use of EIRs to RHISs for the Rotarix vaccination program. The results of this analysis are summarized in Table 13 below. The study estimated that there would be an increase in vaccination program costs by approximately $3 million when EIRs are used instead of paper-based records over the five birth cohorts. The healthcare costs averted increased by an estimated $1 million from the government perspective and $2.2 million from the societal perspective when EIRs were used instead of RHISs. This resulted in an approximate increase in the net vaccination program costs by $2 million and $880,00 from the government and societal perspectives. 22,377 more DALYs were also averted. The ICER was calculated when EIRs were used instead of RHISs, and the costs per DALY averted from the healthcare and societal perspectives were $92 and $39, respectively. These costs per DALY were grossly less than the Tanzanian GDP per capita of $1,136 (World Bank, 2021). Between the years 2020 and 2024, using EIRs instead of RHIs was also projected to avert 302,496 rotavirus-related disease cases, 151,261 hospital visits, 15,101 hospitalizations and 739 deaths

Table 13. Cost-effectiveness comparison between EIR and RHIS utilization for RV1 vaccination for 5 cohorts vaccinated between 2020 and 2024 in Tanzania

EIR utilization instead of RHIS		
Cost-effectiveness of EIRs compared to RHISs		
Net cost of vaccine introduction	$2 054 136	$875 858
• **Cost of vaccine introduction**	$3 099 737	$3 099 737
• **Health service costs averted**	$1 045 601	$2 223 879
DALYs averted	22 377	22 377
Cost per DALY averted	$92	$39
Healthcare costs averted	$1 045 601	$2 223 879
• **Visits**	$684 556	$1 724 365
• **Hospitalizations**	$361044	$521 514
Total disease events averted		
• **Disease Cases**	302 496	
• **Visits**	151 261	
• **Hospitalizations**	15 101	
• **Deaths**	739	

6 DISCUSSION

EIR Utilization

One of the objectives of this study was to bring attention to how vaccination data is currently managed in LMICs and investigate the benefits of EIRs over paper-based records. Of the 61 healthcare facilities surveyed in Tanzania, 36 had implemented EIRs, 59% of the facilities being investigated. However, only 17 of them were currently utilizing the EIRs, 27.9% of all the facilities surveyed, and less than half (47.2%) of facilities that had implemented them.

This goes to show that although there is a slight increase in electronic health record use in LMICs (Akanbi et al., 2012; Namageyo-Funa et al., 2018), the challenges of EIR utilization discussed in existing literature are still ongoing and pose a substantial obstacle to Tanzania reaping the benefits of EIR utilization (Clarke et al., 2019; Namageyo-Funa et al., 2018). It is also noteworthy that facilities in three of the regions where the pilot run of EIR implementation by the Better Immunization Data initiative was carried out, Arusha, Kilimanjaro and Tanga (Mvundura et al., 2019), were also included in the study by SDA Bocconi. Of the three regions, the majority of the facilities in Kilimanjaro and Tanga were currently utilizing EIRs. However, none of the six facilities in Arusha was still using the EIR, and all six fell under the facilities category where EIRs had been implemented but were not currently being used. This is in line with the challenge of EIRs being stopped after pilot programs once researchers move on to another project outlined by Clarke et al. (2019).

As these countries already have limited resources and would be better off without these sunk costs (Debellut et al., 2019), the challenges of EIR use need to be addressed to ensure the benefits of EIR use are harnessed by LMICs (Debellut et al., 2019; Dolan et al., 2019; Nguyen et al., 2017). Also, considering that all the facilities in our study currently using EIRs are concentrated in the same region, and a region like Arusha had EIRs implemented in all six facilities redundant, regional health commissioners and governments have a role to play in the sustainable use of EIRs. Carnahan et al. proposed a potential solution to this challenge would be to have built-in indicators of engagement and utilization included in the system, so its utilization can be monitored, and any obstacles to use can be adjusted accordingly (Carnahan et al., 2020). The suggestion by Clarke et al. for governments to take ownership of programs like this and plan for the long-term instead of time-limited pilots could be a feasible step towards ensuring the longevity of EIR utilization and maximization of EIR benefits (Clarke et al., 2019)

Cost Analysis

Another objective was to discuss the cost of implementation of EIRs and the cost savings associated with their utilization. Mvundura et al. addressed the cost of implementation of EIRs, including the cost of developing EIR software and initial capital investments of hardware related to EIR use. This was discussed extensively in the state of the art (Mvundura et al., 2019, 2020). As Mvundura et al. discussed software and equipment cost in detail and led to the development of an open-source software as well as learning strategies; and a substantial amount of LMICs receive funding for EIR development and initial equipment costs from organizations like GAVI (Debellut et al., 2019; GAVI, 2015, 2019; Mvundura et al., 2019) this Master thesis focused on analysing the operational cost savings realized from day-to-day vaccination activities, and the effect of these cost savings on the vaccination program.

Staff Costs

Fourteen routine vaccination-related activities were analysed; thirteen had staff cost components, while five had non-staff cost components.

Nine out of the thirteen activities with staff costs recorded a decrease in staff costs after an EIR was implemented instead of paper-based records, and this is in line with existing studies by the Better Immunization Data that enumerated a significant portion of the reduction vaccination program costs after EIR implementation is due to decrease in personnel costs as a result of increased efficiency and less staff time being spent on routine vaccination activities (Mvundura et al., 2020), especially when the EIRs are not being used in tandem with paper-based records (Glazner et al., 2004)

Five of these activities, namely contacting defaulters, identifying performance gaps, report generation, vaccine ordering, and vaccine replenishment, had statistically significant differences after the EIR was implemented compared to RHIS. The decrease in staff costs related to vaccine ordering and emergency vaccine replenishment is in accordance with the study by Mvundura et al. as it discusses how better management of vaccine stock using the IIS reduces emergency vaccine replenishment time and eases the vaccine ordering process (Mvundura et al., 2020). Furthermore, the decreased staff cost due to report generation is also in line with the study by Dolan et al. as it describes how using EIRs can improve the ease with which vaccination parameters can be calculated hence the efficiency of generating vaccination reports (Dolan et al., 2019).

Four of the staff costs increased when EIRs were used instead of RHISs, but only the increase in staff-related maintenance costs was statistically significant. This buttresses the findings by Mvundura et al. that using EIR increases staff-related maintenance costs due to the equipment required when EIRs are utilized that would not be used if paper-based systems were still in place (Mvundura et al., 2020).

Non-staff Costs

Regarding the non-staff costs of the vaccine-related activities, there was a decrease in four out of five non-staff costs when EIRs were used instead of paper-based records. Of these four, the decline in transportation and maintenance costs was statistically significant. The decrease in transportation costs further emphasizes how EIRs can decrease transportation costs related to vaccination. With regards to the decrease in non-staff maintenance costs, we postulate that the majority of maintenance costs when EIRs are utilized are staff costs, and if replacement equipment needs to be purchased due to non-function, those will fall under equipment costs, leaving the non-staff component of maintenance costs as a minimum. However, more in-depth research on this would be ideal.

The only non-staff cost that increased when EIRs were utilized was printing costs, and this is contradictory to the study by BID that stipulated a significant activity costs were expected to be saved on were printing costs, as EIRs require considerably less paper than RHISs (Mvundura et al., 2020). The observed difference was because one facility that is an EIR user had abnormally high printing costs, which skewed the results as the mean substitution was used to treat missing data. When this outlier facility is not taken into consideration, the average printing cost in facilities utilizing EIRs is substantially less than the average printing cost in facilities using paper-based records.

Disease Events when EIRs Substitute RHISs

In addition to the objectives discussed above, this thesis also aimed to evaluate the difference between the effectiveness of vaccination programs when EIRs are used instead of RHISs. This evaluation was done using the UNIVAC model. After these input parameters were altered based on EIRs effects on vaccination costs obtained from the data analysis of primary data from SDA Bocconi, healthcare costs (Debellut et al., 2019) and timeliness (Nguyen et al., 2017), a change in rotavirus-related disease events was observed. First, the rotavirus cases, outpatient visits and hospitalizations averted due to Rotarix vaccination continue to increase when both RHISs and EIRs are used. However, the number of rotavirus-related disease events averted when EIRs are utilized instead of RHISs is higher. This decrease in disease events can be attributed to increased timeliness (Nguyen et al., 2017), which increases dose validity and hence increases the direct benefits of vaccination (Dolan et al., 2019).

As the study used to investigate the effect of EIRs on the timeliness of vaccination was carried out in Vietnam, which is still an LMIC but not in Sub-Saharan Africa and could have peculiar conditions not applicable to Sub-Saharan Africa, we carried out a threshold analysis to determine the minimum percentage increase in timeliness that would make EIR utilization cost-effective in comparison to paper-based records. The input parameters except timeliness were altered based on the influence of EIRs. The timeliness of vaccination when paper-based records were used was increased by 1% until we obtained the cost-effectiveness threshold, which was 6%. Hence, provided the EIR increases timeliness by 6%, which is considerably less than 22.75% estimated by Nguyen et al. (2017) and used in this study, the EIR would still be cost-effective (the cost per DALY averted by EIR use is still less than the GDP), and positively influence the outcome of the vaccination program.

In addition to timeliness, the decrease in disease events can also be attributed to indirect effects of vaccination like relative coverage. Relative coverage refers to the children who are protected from a vaccine-preventable disease that would have become diseased or dead if the rest of the population had not been vaccinated (Clark et al., 2013). This is also known as herd immunity and was only minimally taken into consideration using the UNIVAC model as a dynamic model is required to take herd effect into consideration adequately. This means the benefits of EIRs regarding decreasing rotavirus-related disease events discussed in this paper are conservative estimates.

Conversely, the number of deaths and DALYs averted decreased over the course of the five cohorts examined both with EIR and RHIS, however, EIRs still averted a larger number of deaths and DALYs compared to RHISs. Disability Adjusted Life Years (DALYs) is a combination of years of life lived with disability, hence a measure of morbidity due to rotavirus-related illnesses and the years of life lost. The reasons for this decline include the fact that as more disease cases of rotavirus are being averted, fewer patients are getting severe rotavirus diarrhoea which could potentially lead to death. This results in a decrease in the years of life lost component of DALY. Also, the higher the number of cases averted by vaccination, the fewer years lived with disability due to rotavirus. Hence, this results in an overall decrease in the DALY, as seen in the study. Lastly, the fact that vaccination with EIRs had a greater effect on all the disease events in comparison with RHISs further emphasizes the study by Dolan et al. that suggests

EIRs increase the effectiveness of vaccination programs when used instead of paper-based records (Dolan et al., 2019).

Cost- Effectiveness Analysis

The final objective of this study was to carry out a cost-effectiveness analysis of EIRs compared to RHISs and assess the impact of EIRS on future healthcare costs in Low -and Middle-Income Countries. Based on our study, rotavirus vaccination, when using paper-based records, has a cost per DALY averted of $419 from the government perspective and $360 from the societal perspective. These costs per DALYs are less than the Tanzanian GDP per capita, which is £1,136 (World Bank, 2021), and so according to the WHO standard, vaccination using RHISs is very cost effective (Sigei et al., 2015; WHO, Commission on Macroeconomics and Health. & Sachs, 2001). When vaccination using EIRs is compared to no vaccination, the cost per DALY averted is $364 from the government perspective and $307 from the societal perspective. As these costs are substantially less than the Tanzanian GDP per capita of $1,136, EIRs are very cost-effective compared to no vaccination. This is in accordance with existing studies that estimate that for LMICs with a high under-5 mortality rate, vaccination would also be more beneficial than no vaccination, whether paper-based records or EIRs are used (Debellut et al., 2019; Ruhago et al., 2015; Sigei et al., 2015).

However, this thesis's main aim is to compare EIRs' cost-effectiveness to RHISs. The incremental costs per DALY averted when EIRs are used for the rotavirus vaccination program instead of RHISs were $92 and $39 from the government and societal perspectives, respectively. These costs are less than $1,136, the Tanzanian GDP per capita; hence, using EIRs instead of RHISs is very cost-effective. However, it is essential to note that this study only takes into account the operational costs of carrying out day-to-day vaccination activities, as most LMICs have capital costs of vaccination programs covered by organizations like GAVI (Debellut et al., 2019; GAVI, 2015, 2019; Mvundura et al., 2019), and this thesis preferred to focus on the benefits of EIRs to LMIC governments if they were not just to implement but also sustain the use of EIRs in their regions and the country as a whole. Furthermore, the study by Mvundura et al. still records cost savings when EIRs are used instead of RHISs when taking EIR development and capital costs into consideration(Mvundura et al., 2020). Hence, as the costs per DALY averted when EIRs are used instead of RHIs are less than a tenth of the Tanzanian GDP per capita, it would be reasonable for us to suggest that replacing paper-based records with EIR use would still be very cost-effective even when capital costs and EIR development costs are taken into consideration in situations where an LMIC may not have the support from an organization like GAVI. In addition to the cost-effectiveness of EIRs compared to RHISs, over the five cohorts evaluated, using EIRs instead of RHIs was also projected to avert 302,496 rotavirus-related disease cases, 151,261 hospital visits, 15,101 hospitalizations and 739 deaths.

Based on the results of our cost-effectiveness analysis, this paper is in line with studies that suggest the use of EIRs results in cost savings for the healthcare facilities and populations that implement and utilize them (Mvundura et al., 2020), and that improved vaccination data management results in improved efficiency and effectiveness of vaccination programs which in turn leads to a decrease in morbidity and mortality caused by vaccine-preventable diseases (Dolan et al., 2019).

Limitations of the Study and Proposed Future Research

A major limitation of this study is that the UNIVAC model utilized is a static model, and hence it does not take into account factors like herd immunity or change in seroprevalence. It was not something that could be changed for the purpose of this study, as dynamic models are highly technical and challenging to build. However, for future research, it would be worth analysing the cost-effectiveness of EIRs in comparison to RHISs with a dynamic model, taking these factors into consideration for more accurate cost-effectiveness estimates.

Another limitation of this study is the fact that EIR development and equipment costs were not taken into consideration, hence limiting its relevance to GAVI-supported countries, although inferences on how this could apply to non-GAVI-supported LMICs were briefly mentioned. A cost-effectiveness analysis study incorporating EIR development, equipment and operational costs would benefit LMICs with limited support from international organizations.

Lastly, none of the economic and health benefits discussed above will ever be achieved if LMICs do not sustainably utilize EIRs for their vaccination programs. Hence, a study that investigates the potential solutions to the challenges of EIR utilization like the influence of government planning and ownership of EIR programs on EIR use (Clarke et al., 2019); or having in-built systems that monitor engagement and EIR utilization so any hindrances can be identified and rectified promptly (Carnahan et al., 2020) will be worthwhile.

7 CONCLUSION

Vaccination data is currently poorly managed in Low -and Middle-Income countries, and replacing currently used paper-based records with electronic immunization registries could improve vaccination data management and, in turn, enhance vaccine program outcomes. However, certain obstacles prevent sustainable use of these EIRs even after they are implemented in LMICs, like increased staff workload due to paper-based records being used alongside EIRs, lack of technical know-how and technical support to manage EIRs, power cuts, and temporary pilot projects that are not sustainable and end shortly after research projects are completed. Existing studies also outline that EIR implementation and use instead of paper-based records is cost-saving for healthcare facilities.

We have evaluated that the challenges associated with EIR utilization in healthcare facilities in LMICs are still prevalent and limit these populations from harnessing the full benefits of EIRs. The thesis also assessed the costs of vaccination-related activities in facilities that utilized EIRs and those that did not. In line with existing literature, the results showed facilities that used EIRs had lesser vaccination-related activities costs and hence lesser incremental healthcare costs per child due to vaccination. In addition, this study also affirmed that the effectiveness of vaccination programs after EIR implementation increased, as illustrated by the decrease in vaccine-preventable disease events. Lastly, this research carried out a cost-effectiveness analysis that revealed EIRs are very cost-effective compared to paper-based records and lead to long-term healthcare cost savings and health benefits for the population.

In summary, using electronic immunization registries for vaccination programs in low -and middle-income countries improves vaccination data management and vaccination program outcomes, decreases healthcare costs, increases population health benefits and is highly cost-effective compared to paper-based records. However, there are challenges to sustainable EIR utilization in LMICs which need to be resolved to enable the widespread adoption of EIRs in LMICs.

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