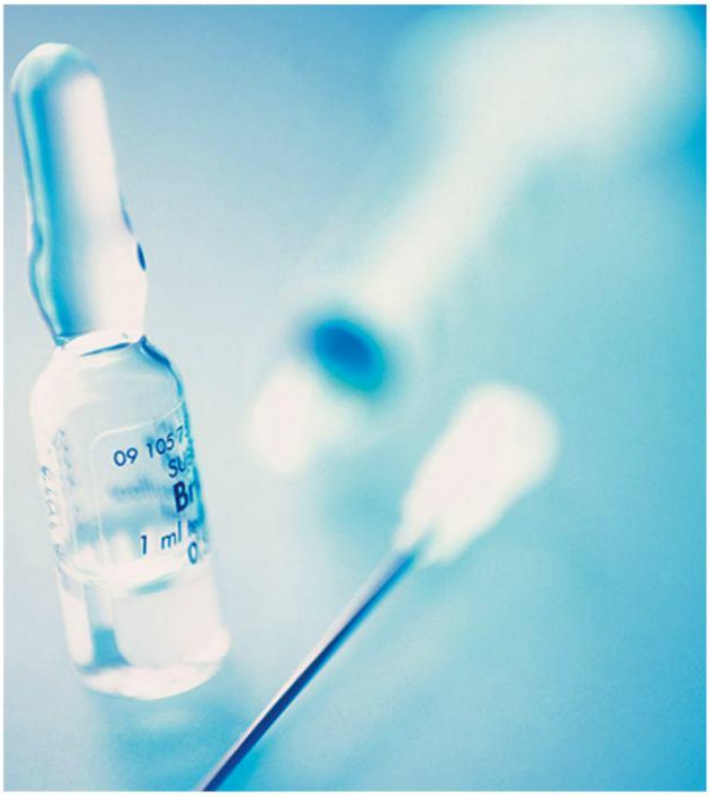

B MEDICAL SYSTEMS COLD CHAIN SOCIAL VALUE

QUANTITATIVE AND QUALITATIVE RESEARCH FINDINGS

MAY 2016

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THOUGHTS IN GEAR

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medical systems

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$4.4 million

in social value in 10 years

The 245 units in Kano, Nigeria will save over

6,000 lives

and prevent over

37,700 cases of illness

EXECUTIVE SUMMARY

THE SOCIAL VALUE OF A B MEDICAL COLD CHAIN UNIT

In 2016, researchers estimated that vaccines would save ***$544 billion in illness costs and $1.43 trillion in broader economic benefits*** in GAVI eligible countries alone. According to these figures, immunisation programmes have the highest return on investment of any development initiative. However, what is often overlooked in the valuing of immunization is the critical role that proper transport and storage of vaccines vis-à-vis cold chains play in this overall value.

Without reliable and accessible cold chain refrigeration the estimated social value from this research cannot be realized. Additionally, the costs of supplying vaccines, when improperly stored, are increased due to wastage and the administration of impotent vaccines. In light of this research, what is the inherent social value of a cold chain?

A single B Medical cold chain unit:

- **Ensures the optimal social return on investment of immunization programs through reliable and consistent temperature control**
- **Enables the effective delivery of vaccines in areas without consistent electricity**
- **And, prolongs the impact of immunization over a 10-year period, ultimately reducing the cost of replacement, repairs and transportation of an alternative refrigeration unit**

According to the case study conducted by surveying 245 health centres in Kano, Nigeria with B Medical cold chain units, the estimated **costs saved** from an average B Medical cold chain unit with the currently reported set of vaccines was **$2,544,061 (PPP)** over its 10-year lifespan, while for a full set of vaccines, as recommended by WHO, the averted social costs would have been **$4,497,356 (PPP)**. This figure was calculated using a per-vaccine prevented illness model, which estimated treatment costs, illness productivity losses, disability productivity losses and mortality productivity losses based on global research and data.

While the social value of the vaccines passing through the cold chain unit can be conservatively estimated and quantified, a greater portion of the cold chain unit's inherent value, including confidence in the reliability of refrigeration, and the broader social value of immunization remains qualitative.

Insufficient or unreliable cold chain infrastructure remains a critical challenge, particularly in the rural areas of developing countries (Ophori et al., 2014, p. 71). According to research from the Gates Foundation, an estimated one-fifth of the 134,000 immunizations points in GAVI-eligible countries have no cold chain equipment, another one-fifth have equipment that is not functioning properly, and two-fifths have equipment with "significant limitations, such as a high freezing risk and/ or the need for expensive gas or kerosene" (PATH et al., 2015, p. 3). Only 29% of countries are meeting minimum standards of temperature control (WHO, 2014, p. 3).[1] As such, to achieve the optimal social value of immunization, it is imperative that adequate planning and funding be allocated to improving cold chain infrastructure.

In addition to the social value of the vaccines passing through a cold chain unit, the inherent value of a B Medical cold chain unit resides in its reliability, longevity and accessibility. **Reliability** depends on a cold chain unit's ability to maintain consistent temperatures, reducing vaccine wastage, maintaining vaccine potency, facilitating timely delivery of immunization, and reducing the risk and cost of breakdowns. As a component of reliability, the **longevity** of a B Medical cold chain unit (i.e. its 10-year lifespan) guarantees that these inherent values, coupled with the avoided costs, are exponentially greater over time. Furthermore, a B Medical cold chain unit, with respect to its durable and transportable design, allows for greater **accessibility** to reliable vaccine storage and administration, particularly in the areas of greatest need and highest disease burden.

In addition to the cost saved to society and inherent value, each cold chain unit ensures that the **broader social value** of vaccines in public health and socio-economic development be achieved, including:

- Disease Eradication
- Herd Immunity
- Reduced Antibiotic Resistance
- Human Capital Development
- Improved Household Economic Behaviours
- Macroeconomic Growth

Ultimately, a B Medical cold chain unit's social value is undoubtedly the vaccines that pass through it, and it is only the manner in which it houses the vaccines that provides it with added social value. It is critical that this value be considered in the planning of immunization programmes, as without a reliable and accessible cold chain, the full social value – illnesses adverted, lives saved, costs avoided and broader benefits – cannot be realised.

[1] Vaccine Wastage & Temp Control results were from EVM Data Analysis

INTRODUCTION

This report was commissioned by B Medical Systems, a manufacturer of cold chain refrigeration units, to measure the social value of their cold chain units. This research developed from a core assumption that each cold chain unit's social value is derived solely from the vaccines it stores and delivers. The term "social value" represents the costs saved to society and the benefits derived from reduced illness and mortality.

To arrive at the full social value of a B Medical cold chain unit, the following research provides an estimated social value of the vaccines passing through an average cold chain in the selected geographic region, as well as a description of the immeasurable social value of that unit, which contribute to broader public health and socio-economic benefits. While the social value of immunisation can be conservatively estimated and quantified, a greater portion of the cold chain unit's intrinsic value from its *reliability*, *longevity and accessibility*, as well as the resulting impact on society of immunization, cannot yet be measured. As such, the broader social value of each cold chain unit must be examined in a qualitative manner.

The state of Kano in Nigeria was selected as the geographic area of focus. Kano, Nigeria was selected as a case study to estimate the social value of a single B Medical cold chain unit. This particular state has a high volume of B Medical cold chain units,[2] which provided an ample sample for surveying the individual productivity vis-à-vis each cold chain unit in an average month, as well as a high burden of disease (Zeeshan, 2014, TBFacts.org, n.d.; Liu et al., 2015).[3]

A per-vaccine prevented illness model was used to calculate the treatment costs, illness productivity losses, disability productivity losses and mortality productivity losses based on global data. The resulting estimated costs saved from an average B Medical cold chain unit were **$4,497,356 (PPP International $)** over its 10-year lifespan. From the case study, a generic model was also developed to support the calculation of the social value of cold chain units in different geographical contexts.

This report outlines the methodology used to arrive at a per cold chain unit social value vis-à-vis the vaccines it stores, the resulting monetary value, and a summary of the immeasurable benefits that each cold chain unit enables.

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[2] Over 1,700 B Medical TCW 2000 SDD units had been distributed in Nigeria between 2014-2015

[3] From Zesshan (2014), see p. 5: it was reported that in 2001, 240 of the 806 polio cases recorded in Nigeria were in Kano: Pg. 5, Polio Cost Effectiveness Nigeria; See also, the high burden of TB in Nigeria at TBfacts.org

METHODOLOGY

QUANTITATIVE ANALYSIS

The measurable component of a B Medical cold chain unit's social value is calculated based on the number of children and adults that were vaccinated from that individual unit and the range of vaccines that are currently available at the surveyed health centres. The total quantified social value only includes the estimated treatment costs, during-illness hourly wage productivity losses, disability productivity losses (at 50%) and mortality productivity losses that could be quantified in relationship to pre-existing incidence and treatment data. Calculations were also run for the recommended "full set" of vaccines as per WHO's recommendations.

To calculate the productivity of each B Medical cold chain unit, 247 health centres in Kano were surveyed. Each centre provided data on

1. the number of cold chain units on site,
2. the vaccines currently being administered from that cold chain,
3. the number of vaccines delivered for children per month in the past twelve months, and
4. the number of vaccines delivered for adults per month in the past twelve months.

Out of those surveyed, 245 health centres that were selected had only one cold chain unit. All units used in the calculation were manufactured by B Medical Systems.

The calculation model used global data for the following variables for each vaccine that is currently being delivered through the cold chains surveyed in Kano:

1. Morbidity-Mortality Adverted
    a. Estimated Illness Incidence
    b. Estimated Disability Incidence
    c. Estimated Mortality Incidence
    d. Vaccine Effectiveness/Efficacy
2. Productivity Costs
    a. Short-Term Wages
    b. Life-Span Wages
    c. Caretaker Wages
3. Avoided Treatment Costs
    a. Based on Care-Seeking Behaviour
    b. Estimated hospitalization rates
    c. Estimated treatment costs
    d. Estimated treatment time and relationship to caretaker and patient productivity losses

It was assumed that a full set of vaccines (or 12 doses) were delivered to each child immunized based on sites surveyed, which include the following vaccines reported by the surveyed sites and confirmed by the National Programme routine immunization of children in Nigeria is carried out using the following selection:

- BCG (Bacilli Calmette-Guérin)—1 dose

- OPV (Oral Polio Vaccine) – 3 doses
- Hib (Haemophilus influenzae type b) – 3 doses
- Hepatitis B – 3 doses
- Measles – 2 doses
- Yellow Fever – 1 dose
- *Vitamin A—at 9 months and 15 months of age*

For adult immunization rates, Hepatitis B was taken at 100% of adults, however, due to the calculation for HepB being based on DALY estimates, the proportion could be varied depending on the gender context as well. Tetanus Toxoid was only oriented to women who would bear children, and therefore the statistical average of women in Nigeria (49%) was used and then a fraction of them were considered to potentially be covered during pregnancy (see Tetanus Toxoid Methodology for more details). Yellow Fever was not included in the final calculation.

Calculations were also made for the remaining vaccines recommended by WHO to estimate the value added by increased utilisation of each cold chain unit:

- Diphtheria-Tetanus- Pertussis (DTP)
- Pneumococcal Conjugate Vaccine (PCV)
- Rotavirus (Rota) Vaccine
- Meningococcal Conjugate Vaccine (for Men A)
- Human Papillomavirus (HPV) Vaccine

Instead of adopting Value of a Statistical Life Methodology, which is based on an individual's willingness to pay for an extend life-year (Ozawa et al., 2016), this study has followed the more conservative Human Capital Approach that values each life year as the productivity (per capita GDP) of that individual (Deogaonkar et al., 2012; WHO, 2009). Though this provides a more limited view of the measured value of a life, it provides a conservative quantifiable estimate and delineates the additional social values in non-monetary terms to support the wider impact.

Throughout, disability was either calculated as the number of disabled people by 50% productivity over their lifetime (Edmond et al., 2010), or by using the measure of YLD provided from the Global Health Estimates (GHE) for DALYs per country (WHO, DALY & YLD, 2012).

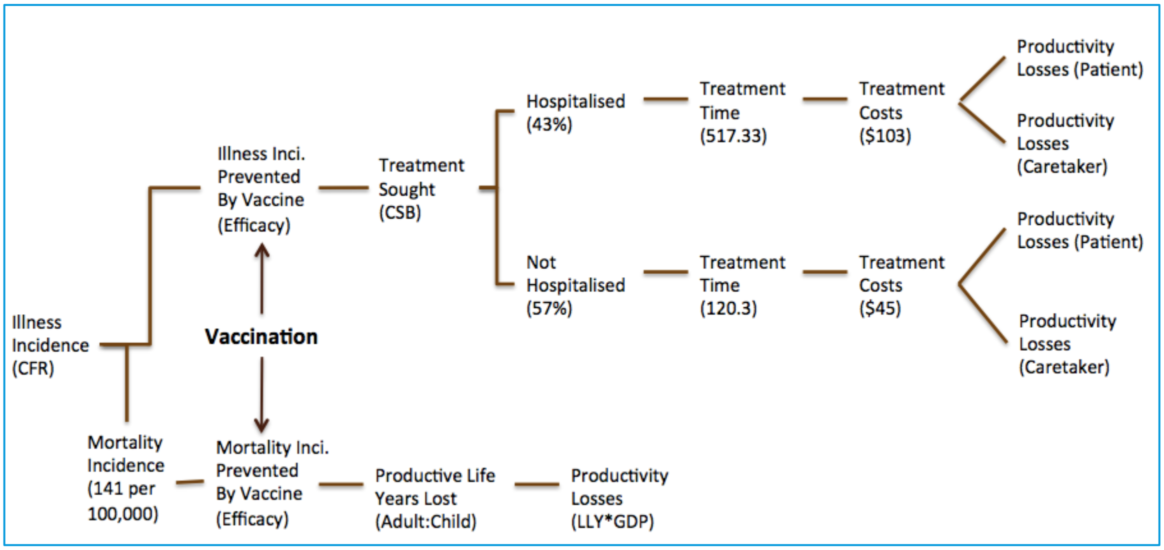
The overall methodology was based on the counterfactual argument, which estimated costs in the absence of vaccination. The reasoning was drawn from similar global research on the social value and return on investment of vaccines (Stack et al., 2011). For all data points, systematic searches for the most relevant data both geographically and temporally. The data points selected had been subjected to rigorous statistical models as determined by the researchers for each analysis, and as such, further statistical modelling was not included in the case study calculation.

For geographical relevance, data was sought first for Kano, although, in light of scarce Kano-specific data, proxy data was used for Nigeria or Sub-Saharan Africa. A more detailed description of the calculation model for each vaccine and illness is included hereafter.

BCG (TUBERCULOSIS)

The Bacillus Calmette-Guerin (BCG) vaccine is used to prevent tuberculosis (TB). The following diagram can best represent the calculation methodology.

Figure 1: BCG Calculation Diagram (Example Figures)



The estimated mortality incidence for Nigeria was taken from the WHO Global Tuberculosis Report (WHO, 2015, p. 164). The incidence rate can either be applied from the same WHO Global Tuberculosis Report, or it can be derived from the case fatality ratio - "In the absence of VR systems or mortality surveys, TB mortality can be estimated as the product of TB incidence and the case fatality rate, or from ecological modelling based on mortality data from countries with VR systems" (WHO, Global TB Report, 2011, p. 16).[4] Both estimates were calculated, but the more conservative figure, using the WHO report, was used in the final calculation. Similar incidence and mortality figures were reported by TBfacts.org, which shows Nigeria as having an incidence of 570,000 (roughly 320 per 100,000) and morality of 170,000 HIV negative and 78,000 HIV positive (roughly 139 per 100,000) (TBFacts.org, n.d.).

The estimation did not separate HIV positive from HIV negative patients, but used the shared estimates for mortality presented by WHO (WHO, 2015, p. 15), and the average efficacy of the vaccine based on both HIV positive and HIV negative efficacy rates (Arbeláez et al., 2015, p. 1085).[5]

The number of patients treated was based on the case notification rate of 15% from WHO data (WHO, 2015, p. 160), and in light of care-seeking behaviour studies (Mesfin et al., 2006). Of those treated, it was estimated that 10.4% of TB cases would arise in children based on WHOs overall incidence estimates - 1 million of the 9.6 million new TB cases (WHO, 2015, p. 1). Separately, WHO has also listed a rate of 11% of TB cases in children (WHO, 2006), and has qualified that by stating, "the actual burden of TB in children is likely higher, especially given the challenge in diagnosing childhood TB" (WHO, n.d. Childhood TB).

[4] See Tiemersma et al. (2011) for alternative global incidence estimates
[5] For further discussion of efficacy and effectiveness measures see Weinberg & Szilagyi (2010)

The hospitalization rate, treatment time and treatment cost were drawn from prior research to give an accurate estimate of cost of treatment and hours spent by the patient and caretaker delivering treatment (Umar et al., 2015, p. 3; Ukwaja et al., 2013, p. 5).[6] Despite TB treatment being provided for free in Nigeria, research has shown that these are the actual costs covered by a family for treatment (Ukwaja et al., 2013). These costs were converted to PPP based on the rates provided in the WHO CHOICE calculator for treatment costs. In the case of the adult, the patient's hourly salary lost due to illness treatment was considered a cost, as well as the proportional caretaker time. For a child, the only treatment productivity losses were derived from the caretaker, who lost their full hourly wages for the child's treatment time (Umar et al., 2012, p. 6).

Mortality costs were taken as the number of prevented deaths based on incidence and vaccine efficacy. A full life's productive years were used to calculate a child's mortality productivity losses, and for an adult, the estimate was half of that - both based on Nigeria's current average life expectancy of 52 years. The average GDP Per Capita PPP for Nigeria was multiplied by the sum of productive life years lost. All final productivity loses were reduced by the average unemployment rate in Nigeria.

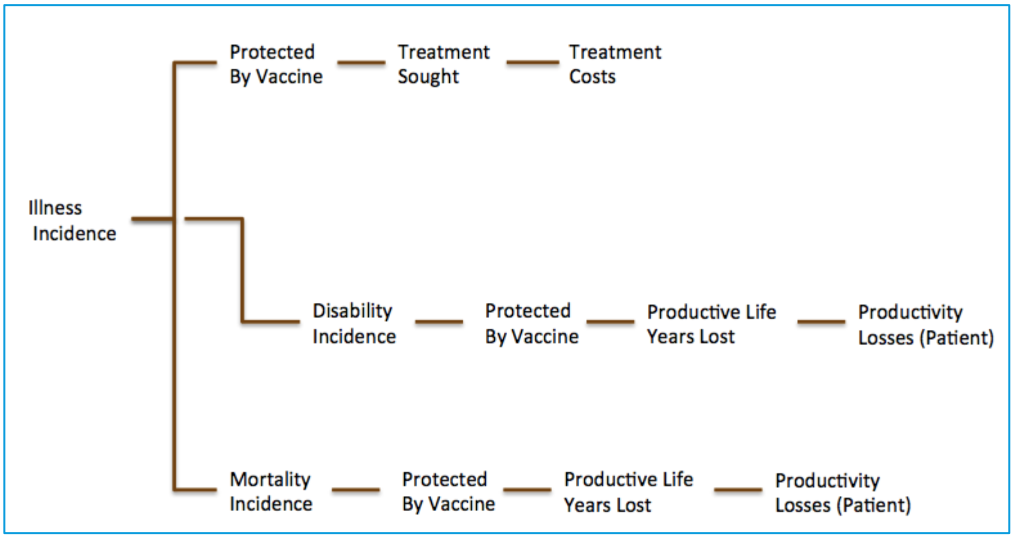
This data likely underestimates both the incidence and costs. According to WHO there is a high level of uncertainty in the estimates of TB incidence due to the lack of widespread studies (WHO, Global TB, 2011, p. 9). Additionally, Nigeria, and Kano state in particular, have historically had a high incidence rates. In fact, Kano has the second highest rate of TB infection of all Nigeria states (United States Diplomatic Mission, 2012), which indicates this is a conservative incident rate for the case study.

OPV AND IPV (POLIO)

The estimates for the social impact of polio vaccines were based on a combination of oral polio vaccine (OPV) and inactivated polio vaccine (IPV), which are currently being administered to the sites in Kano surveyed for the case study. In accordance with international protocols, it was assumed that all OPV doses would be given to young children (at infancy and a booster at 4-6 years old), and IPV was included in this immunization schedule, though it did not vary the calculation in assuming a full set of vaccination (WHO, February 2015).

[6] See Umar et al. for hospitalization rate in Nigeria, and Ukwaja et al. for treatment time and costs in Nigeria

Figure 2: OPV and IPV Calculation Diagram



Estimating the incidence for polio requires a counterfactual estimation of the pre-vaccine incidence based on prior research studies and accounting for very low levels of case notification (particularly in the pre-vaccine error). The estimates range from 5 per 100,000 to 33 per 100,000 population depending on the source data and analysis. For this calculation, the current estimate is from the higher range and based on a study done in Cameroon (neighbouring Nigeria), which utilized household surveys and hospital reports to determine incidence (Heymann et al., 1983, p. 501). This is the one instance where a conservative number was not selected due to the role that vaccinations and undoubtedly cold chains have played in the eradication of polio from Nigeria over the past decade. This was particularly relevant given that Kano has been identified as a high-burden area for outbreaks of the wild poliovirus in the past – "of the 806 cases of polio recorded in Nigeria in 2001, Kano state had about 240 cases" (Zeeshan, 2014, p. 5).

Mortality incidence was then calculated based on the case-fatality rate of 10% (WHO, 2000). As the reported cases from the survey were those cases, which not just the virus but also the disability was present, the rate of disability was taken by the total incidence reduced by the total mortality – the inverse of the case-fatality ratio.

From incidence and vaccine efficacy figures (Miller & Sentz, 2006, p. 164), care-seeking behaviour was accounted for at 33% to arrive at the total number of individuals that would have been treated for the illness (Bart et al., 1996, p. 38). Illness costs were only calculated for the cost per individual treated, as data on treatment time and caretaker productivity costs were not consistent (Duintjer et al., 2010, p. 337). The same treatment cost was applied across all patients that sought treatment, and in the PPP estimate, the conversion was based on WHO CHOICE rates.

As with BCG, productivity costs for mortality were determined by taking the average GDP per capita per annum multiplied by the total potential productive life years. Disability productivity losses were arrived at by first calculating the survivors disabled by polio, and then for the total disability incidence reducing their productive life years by 50%. The 50% reduction in productivity amounted for the total costs for disability. This did not take into account the losses to caretaker productivity throughout the period of disability, which would also be substantial if appropriate data were available to support it.

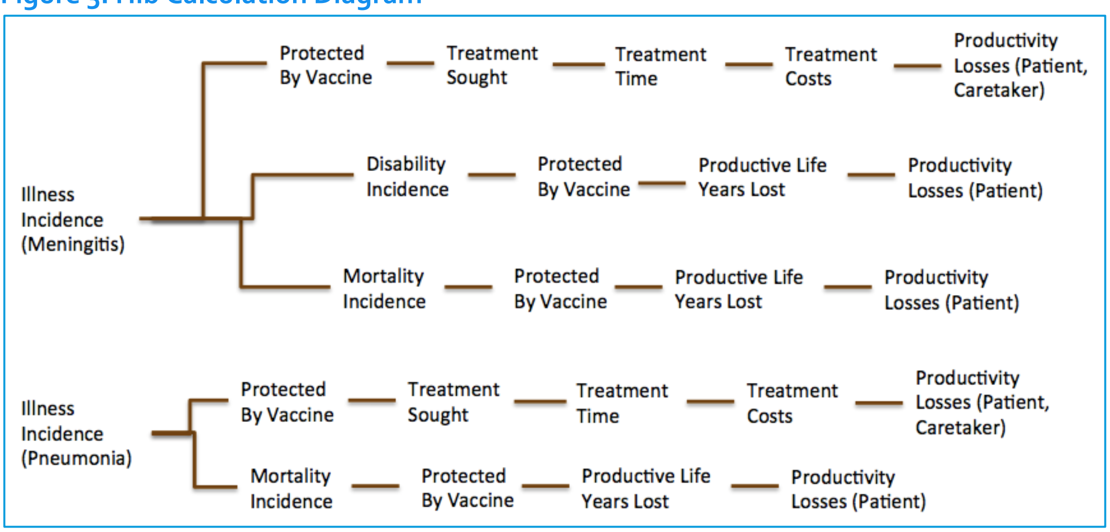
Despite this not being based on the lowest incidence estimates, the resulting figures are conservative in light of other social value findings. According to Polio Eradication Initiative (EPI), "In Nigeria alone this could prevent ~30- 35,000 deaths between 2014 and 2018 and result in an economic benefit of ~$4 billion" (Polio Eradication Initiative [PEI], October 2015, p. 2). If that estimate is doubled to draw it over a 10-year span to 8 billion in cost savings and ~ 60,000 - 70,000 lives saved. Then taking Kano's population as a proportion of the Nigerian population, this would result in ~4,000 - 4,700 lives saved in Kano from the same period. The case study estimates derived from the case fatality rate, were only about a third of that at 1,368 lives saved. Needless to say, the estimated proportional economic benefit of ~ $540 million is nearly double even the PPP estimates for Kano in the B Medical case study. Ultimately, this confirms that for polio, as with the other vaccines, this case study has taken a very conservative approach to measuring both lives saved and economic benefits.

Even though eradication would ultimately nullify the need for the entire population to be vaccinated, research is not definitive on the time period after eradication occurs at which point vaccines would become unnecessary. A model presented by WHO suggests, "there is a 60-70% chance that a cVDPV will emerge during the 12 months immediately following OPV cessation" (Department of Immunization, Vaccines and Biologicals, 2004, p. 18). This is especially true in countries, like Nigeria, where a majority of the adult population still remain unvaccinated.

HIB (PNEUMONIA AND MENINGITIS)

To estimate the impact of Hib pneumonia and meningitis, it was first necessary to calculate the expected percentage of all pneumonia and meningitis cases that were resulting from Haemophilus influenza bacteria (Theodoratou et al., 2010, p. i172). This was used to determine the percentage of pneumonia and meningitis mortality cases provided by the Lives Saved Tool (LiST) that were preventable from by the Hib vaccine (LiST, ret. January 2016). When LiST estimates were used, the vaccine efficacy percentage has already been included in the LiST results, and thus, are not redundantly included in the calculation.

Figure 3: Hib Calculation Diagram



It was assumed that the illness would appear during childhood in a majority of cases, given that the "vast majority of (Hib-preventable) cases occurred in children under the age of five years" (Solarsh & Hofman, 2006, p. 136). Therefore, adult cases were not included in the calculation of illness or productivity costs.

From the LiST mortality estimates, the CFR was used to reverse calculate incidence for both Hib-prevented meningitis and pneumonia cases (O'Brien et al., 2009, p. 897). From the incidence rate, care-seeking behaviour for both meningitis and pneumonia was derived from estimates provided by UNICEF (UNICEF, 2014, p. 51). As there were not specific hospitalization rates, the cost and time for in or out patient was not segregated, rather the treatment time and costs were pulled from two field surveys (Anh et al., 2010, p. 439; Ayieko et al., 2009).[7]

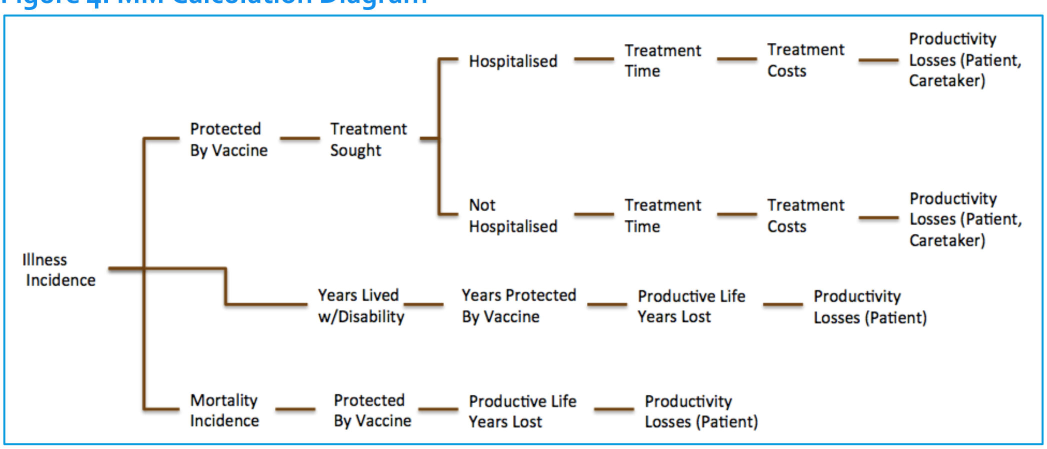
Disability incidence was calculated from taking the percentage of Hib meningitis survivors that experienced neurological sequelae - 34% (Lewis et al., 2008, p. 4).

This estimate is likely conservative given that other incidence rates outside of the LiST data would increase the resulting costs saved by the Hib vaccine. The estimate would increase slightly if the UNICEF care-seeking estimate - 39.7% of cases from 2008-2012 - was used instead of the 2015 estimate - 35% (UNICEF, Nigeria Statistics, n.d.). Additionally, vaccine efficacy rates and the proportion of total meningitis and pneumonia cases that are Hib related vary across the research (Vaccine Assessment and Monitoring Team, WHO, 2002).[8]

MM (MEASLES AND MUMPS)

While the MM vaccine prevents both measles and mumps, this case study only accounted for measles incidence due to the lack of significant data on mumps in this region.

Figure 4: MM Calculation Diagram



[7] See Anh et al. for treatment time; treatment costs from Ayieko et al., which was checked against WHO CHOICE data calculator

[8] See p. 15, reference to "Hib vaccination of infants could prevent over one third of Hib pneumonia cases and approximately 90% of meningitis cases; and higher proportion of 52% of meningitis cases in Africa."

The LiST data for measles indicated total mortality for measles in Kano to be 256. However, the estimate used was calculated from the incidence number from WHO and CFR from a survey of research, which resulted in a slightly lower mortality incidence of 249 (Wolfson et al., 2009, p. 194).

The most accurate incidence estimates for Nigeria appeared in the WHO Weekly Epidemiological record. The estimate for incidence in the whole country was 52,852 cases in 2013 (WHO, 13 Nov 2015, p. 628). From this, the proportion of Nigeria's population living in Kano state was employed for the case study estimates.

Vaccine efficacy was applied to incidence (Miller & Sentz, 2006, p. 166), and then care-seeking behaviour was taken from surveys on fever induced care seeking in Nigeria (NPC, 2014, p. 165). Hospitalisation rates were taken from a separate research endeavour in Bayelsa, Nigeria (Adika et al., 2013). Treatment time for both in-patient and outpatient were calculated based on the average days of treatment per a study in Zambia (Dayan et al., 2004, p. 476). The treatment cost was based on an average across care centres for in-patient and outpatient care per day in the WHO CHOICE model (WHO, CHOICE, 2008). Because these figures are from 2008, the projected estimates would likely be slightly higher.

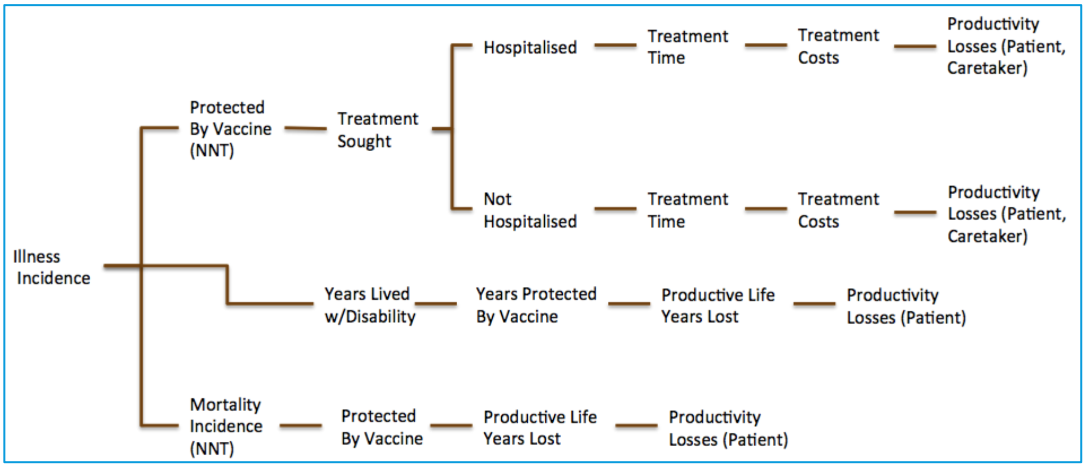
Disability incidence was again was derived from WHO's YLD data (WHO, GHE, 2012). Supplementary research emphasizes the prevalence of blindness as an outcome of measles - "one of the most important preventable causes of blindness in the populations of Sub-Saharan Africa," which is responsible for 27% of blindness cases (Solarsh & Hofman, 2006, p. 131 & 137).

As with the previous vaccines, the incidence rate used for measles in Kano is a conservative estimate. According to GAVI, just the first dose of the measles vaccine prevents 16.5 deaths per 1000 vaccinated (Lee et al., 2013, p. B67). The case study found, based on the incidence and case fatality data, that 237 deaths were prevented in Kano per year, which is nearly half of the figure had this ratio been used. That is not to mention the fact that Nigeria is considered a high-risk country for measles and the incidence estimates could be grossly underreported for Kano (WHO, Measles, 2014; Salako & Sholeye, 2015). Furthermore, some research estimates, – "In the absence of vaccination, measles is estimated to infect virtually the entire population with the exception of isolated communities" (Kuate, 2014), which suggests a prolific incidence rate if the true counterfactual estimate was taken for measles immunization in this case study.

TT (TETANUS)

To quantify the costs that the delivery of the tetanus toxoid (TT) vaccine prevents, the case study focuses on only two components of the TT vaccine – neonatal tetanus (NNT) and disability incidence based on years lived disabled (YLD) data.

Figure 5: TT Calculation Diagram



It was assumed that the likelihood of a vaccinated woman would give birth while the TT vaccine ensured their immunity was high, as the birth rate is 5.7 in Nigeria, and because "the median birth interval in Nigeria is 31 months…the median interval is lowest among mothers age 15-19 (26 months) and highest among mothers age 40-49 (39 months)" (NPC, n.d.). As such, it was taken that 95% of women were immunized for at least one birth, though the likelihood of multiple births being protected is also high.

As 49.09% of the Nigerian population is female (World Bank, Population, 2014), this percentage used to calculate the number of women vaccinated from the total vaccinated adults. However, it is likely that a larger number of women than men would be vaccinated given the set of vaccines administered through the case study cold chain units.

Once the figure of newborns covered by their mother's immunization was calculated, the vaccine efficacy of tetanus toxoid was applied (Borrow et al., 2007, p. 7).

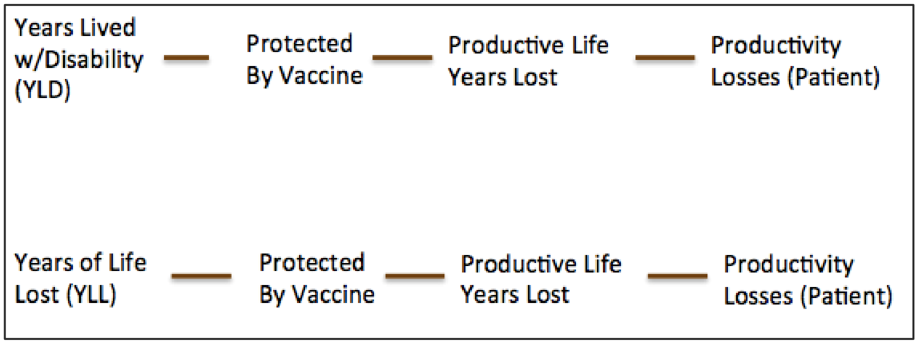
Neonatal tetanus mortality rates and the case fatality rate were drawn from UNICEF, and then used to calculate incidence rate (UNICEF et al., Nov 2000, p. 4 & 27). This, again, is a conservative estimate of 6.77 deaths per 1,000 births in comparison to other studies that show a range from 9 to 20 deaths per 1,000 live births and rates of vaccine efficacy as high as 94% (Babaniyi & Parakoyi, 1991, p. 515; Blencowe, et al., 2010, p. i102).

In addition to the neonatal tetanus estimates, the case study incorporated the YLD data to calculate overall adult and child disability resulting from tetanus in the absence of the tetanus toxoid vaccine (WHO, YLD, 2012).

HEPB (HEPATITIS B)

Reasonable incidence estimates of hepatitis B for Nigeria were not available, and as such, the case study used disability affected life years (DALY) estimates from the WHO (WHO, DALY, 2012). After taking the percentage protected by immunization (Lee et al., 2013, p. B63), years lived disabled (YLD) and years life lost (YLL) estimates from WHO were used to predict the productivity costs of disability and mortality (WHO, YLD & YLL, 2012).

Figure 6: HepB Calculation Diagram



YFV (YELLOW FEVER)

Due to the lack of precise estimates of incidence in Nigeria, a conservative estimate was taken only for the mortality rate. This estimate was based on GAVI's research, which found 0.2 deaths per 1,000 vaccinated against Yellow Fever. The case study only uses rates of illness for children vaccinated under the age of 5 and excludes adult vaccination. This mortality estimate could easily increase when illness incidence is account for - according to research, "approximately 15 to 20 percent of cases, severe disease causes multiple organ failure" (Miller & Sentz, 2006, p. 170).

Vaccine efficacy was taken into account (Lee et al., 2013, p. B64), and the case fatality rate of 23% (Miller & Sentz, 2006, p. 173) was applied in order to calculate estimated illness incidence.

VAD (VITAMIN A DEFICIENCY)

While Vitamin A Deficiency (VAD) vaccine was reported as being delivered through the case study health facilities, the social value was not used in the quantitative calculation. If it were to be estimated, though, the added value of Vitamin A vaccines is in boosting the effectiveness of other vaccines (Sudfeld et al., 2010). On its own, VAD "results in increased severity of certain infections and an increased risk of disease and death in young children. More severe vitamin A depletion leads to night blindness, which can evolve to irreversible partial or total blindness if the depletion continues" (Solarsh & Hofman, 2006, p. 138).

ADDITIONAL VACCINES

The previously articulated vaccines were included in the current case study calculation. Additional vaccines that should be delivered, as specified by WHO (WHO, Feb 2015), were included in the full set calculation for each cold chain unit's total social value. The treatment cost and illness productivity losses were taken as 0.5% of the total estimated costs saved based on the calculation findings for the currently administered vaccines.

DTIP (DIPHTHERIA, TETANUS, PERTUSSIS)

DTP, though recommended by WHO, was not reported by the field surveys done in Kano, Nigeria. It was therefore only included in the full set calculation.

Diphtheria pre-immunization campaign incidence was taken from an estimate in The Gambia as 6 to every 1,000 children under the age of five (Miller & Sentz, 2006, p. 167). Mortality rates were calculated from the illness incidence and case fatality rate (Besa et al., 2014, p. 797). This was reduced by the vaccine efficacy rate – 95% for diphtheria (Miller & Sentz, 2006, p. 168).

Tetanus was excluded from this vaccine's value to avoid the double counting with the tetanus toxoid (TT) vaccine.

Pertussis, or whooping cough, morality incidence was taken from LiST estimates for 2011-2020 and then taken at a yearly rate (LiST, n.d.). Illness incidence was calculated using the mortality and case fatality rate – 2.8% (Preziosi, 2002, p. 891). As LiST already incorporates efficacy in its calculation, vaccine efficacy was not redundantly applied for pertussis. For disability productivity costs, as with previous vaccines, the years lived disabled (YLD) were taken at half to estimate the reduced productive life years (WHO, YLD, 2012).

Pertussis vaccination is particularly important to develop herd immunity, which was not included in the total costs saved, though, accounts for a substantial reduction in overall illness incidence in any community (Preziosi, 2002).

PCV (PNEUMOCOCCAL PNEUMONIA AND MENINGITIS)

WHO also recommends Pneumococcal conjugate, which prevents pneumococcal pneumonia and meningitis. Pneumococcal disease is one of the primary vaccine-preventable causes of death in children under the age of five (Cochi, 2011, p. 2; Liu et al., 2015). Even though it was not reported by the field surveys done in Kano, it was included in the full set calculation.

Pneumonia incidence, case fatality rate and mortality estimates were taken from Africa-specific figures (O'Brien et al., 2009, p. 897). Then, the percentage of cases that are attributed to pneumococcal bacteria were applied to the illness and mortality estimates (Lee et al., 2013, p. B64)

Pneumococcal meningitis incidence was taken from the same Africa-specific figures (O'Brien et al., 2009, p. 897). In addition to the mortality productivity, disability productivity was calculated using WHO's YLD estimates (WHO, YLD, 2012).

ROTA (ROTAVIRUS)

The rotavirus vaccine, though recommended by WHO, was not reported by the field surveys done in Kano. Rota is the most common cause of severe diarrhoea in children under five.

To calculate morality, the LiST estimate for all forms of diarrhoea was taken and reduced for the percentage of severe diarrhoea caused by rotavirus (LiST, 2011-2020; Lee et al., 2013, p. B64). Due to inconclusive data on case fatality rates, illness incidence was not included in the final calculation.

MCV (MENINGITIS A)

The meningococcal vaccine, though recommended by WHO for meningococcal-risk regions including Nigeria, was also not reported by the centres surveyed in Kano. It was included only in the full set calculation.

Mortality incidence was taken for only meningitis A of 1.04 deaths per 1,000 vaccinated (Lee et al., 2013, p. B64). Illness incidence was reverse calculated using the CFR of 12% (Lee et al., 2013, p. B64). Vaccine efficacy of 85% was then applied (Miller & Sentz, 2006, p. 172). Disability rates were taken from the WHO estimates and included per the other vaccine calculations (WHO, YLD, 2012).

HPV (HUMAN PAPILLOMAVIRUS)

HPV, a vaccine administered to young girls to prevent the development of cervical cancer from the human papillomavirus, was not reported by the field surveys done in Kano. However, the vaccine is recommended by WHO, and although an expensive vaccine, is increasingly delivered in developing countries.

The vaccination rate was reduced to 49% in light of this vaccine being administered to females only. Illness incidence was not used, only the prevented mortality was calculated based on 15.1 deaths per 1,000 vaccinated (Lee et al., 2013, p. B67). The vaccine was taken 100% effective (Lee et al., 2013, p. B64). The disability productivity costs were taken from WHO Global Health Estimates (WHO, YLD, 2012).

COLD CHAIN UNIT PRODUCTIVITY

The productivity of a cold chain unit could not be purely determined by the capacity of a cold chain unit, as the turnover of vaccines passing through the unit was a critical component of the percentage of the population it reached. While data was initially requested per patient, the only available data for Kano, Nigeria was the total vaccines distributed through each centre where a B Medical cold chain unit was installed. Several vaccines require multiple doses to be administered to a single patient to reach full immunization. As such, the number of total vaccines was divided by the average number of doses per child (12 doses) and per adult (3 doses) based on the current vaccine set. Based on those figures, this research utilised the number of individuals vaccinated on average in a given month to determine the impact. The figures for number of individuals vaccinated is conservative based on the improbability that all children and adults would have received a full set of required vaccines. However, this does provide an "optimal" productivity level, which is feasible based on the 99 liter capacity of the TCW 2000 SDD.

The sites surveyed in Kano, Nigeria ranged from community health centres to hospitals. Due to the high birth rate and population in that particular state, the productivity can be expected to exceed cold chain units in less-populated areas. Estimates per cold chain unit will vary based on the population served, and therefore, this case study provides a potential value not an average applicable to all locations.

PPP VALUES AND GROWTH RATES

The first estimation for the case study was run using PPP adjusted GDP per capita from World Bank data and projections (World Bank, GDP Per Capita). The PPP conversion rate for treatment costs was taken from the WHO CHOICE calculator. For the second estimation, nominal GDP per capita in USD was also captured from World Bank data (World Bank, GDP Per Capita). GDP growth rates and consumer price inflation consumer price inflation rates were also taken from World Bank actuals and projections (World Bank, GDP Per Capita & Inflation).

The first estimation did not apply growth rates for consumer prices or GDP due to adoption of PPP estimates. The second estimation with nominal figures applied consumer growth rates and GDP growth rates over the 10-year cold chain lifespan.

All estimates were taken from the 10-year period from 2011-2020, as those were the range available for both LiST and other source data. As each vaccine was supposing the counterfactual argument of non-vaccination, the pre-vaccine estimates were used when available, and when unavailable, estimates from a recent year that was based on the most wide-spread data was incorporated instead. There was no data assuming the current incidence in the absence of vaccination for most illnesses, which is another reason the estimated value is a conservative representation of the real burden to society.

INCREASED VALUE AREAS

This figure could increase substantially based on the following factors:

- The inclusion of currently administered Yellow Fever (YFV) and Vitamin A Deficiency (VAD) vaccines, which were excluded due to a lack of reliable data on incidence and treatment.
- The introduction of additional vaccines to these health centres, including the recommended doses of DTP, Rotavirus, and PCV.
- The introduction of vaccines that are not yet on the market, including Malaria and HIV.
- The calculation of travel costs saved both by the proximity of cold chain units to the populations served, as well as travel costs avoided for illness treatment.
- The use of less conservative estimates for illness incidence and mortality incidence, particularly in the case of polio, measles and tetanus.
- And, most broadly, by quantifying the added social value of the qualitative components described herein.

QUANTITATIVE SOCIAL VALUE

The resulting estimated costs saved from an average B Medical cold chain unit were **$4,497,356 million (PPP)** over its 10-year lifespan, assuming a full set of vaccines.

This figure captures the avoided costs relative to the vaccines passing through a single cold chain unit per annum over the ten-year lifespan of the unit, rather than a cost-benefit analysis or social return on investment (SROI) estimation. These results are conservative in light of other global estimates (Lee et al., 2013).[9] The validity of this figure relies on the assumptions made in global research and data, which is often limited, particularly for the regions with the greatest burden of disease. More accurate data on incidence, when available, could reasonably increase or decrease the resulting value of this research. However, despite those assumptions, this is a conservative estimate.

QUANTITATIVE RESULTS (PPP INT. $)

Table 1: Total Kano, Nigeria Results (Per Annum)

Illness/Disease	No. of Deaths Prevented	No. of Illness Cases Prevented	Total Social Costs Saved (PPP, Per Annum)
Tuberculosis	3,742	8,546	$320.972,799
Polio	342	3,425	$292,358,201
Diphtheria (DTP)	2,765	12,922	$429,804,470
Pertussis (DTP)	560	20,012	$89,115,974
Hepatitis B	--	--	$109,212,062
Pneumonia (Hib)	464	4222	$72,684,053
Meningitis (Hib)	107	147	$17,646,505
Measles	237	3390	$37,018,115
Pneumococcal Pneumonia	2,134	20,022	$331,637,947
Pneumococcal Meningitis	165	224	$25,651,554
Tetanus	1,964	2,311	$325,454,845
Yellow Fever	86	375	$13,389,547

Rotavirus	466	--	$72,432,669
Meningitis A (MCV)	401	3,340	$62,296,631
Cervical Cancer (HPV)	--	--	$43,452,768

Table 2: Average Per B Medical Cold Chain Unit in Kano, Nigeria Results (Per Annum)

Illness/Disease	Average Social Costs Saved (PPP, Per Annum)
Tuberculosis	$64,639
Polio	$58,876
Diphtheria and Pertussis (DTP)	$104,502
Hepatitis B	$54,701
Hib Pneumonia and Meningitis	$18,191
Measles	$7,455
Pneumococcal Pneumonia and Meningitis	$71,952
Tetanus	$47,847
Yellow Fever	$2,696
Rotavirus	$14,587
Meningitis A (MCV)	$12,546
Cervical Cancer (HPV)	$4,288
Total (Per Annum)	$449,736

QUANTITATIVE RESULTS (NOMINAL USD $)

Table 3: Total Kano, Nigeria Results (Per Annum)

Illness/Disease	No. of Deaths Prevented	No. of Illness Cases Prevented	Total Social Costs Saved (PPP, Per Annum)
Tuberculosis	3,742	8,546	$188,157,112
Polio	342	3,425	$182,483,731
Diphtheria (DTP)	2,765	12,922	$289,078,848
Pertussis (DTP)	560	20,012	$59,549,482
Hepatitis B	--	--	$52,493,031
Pneumonia (Hib)	464	4222	$48,774,568
Meningitis (Hib)	107	147	$11,764,260
Measles	237	3390	$24,827,974
Pneumococcal Pneumonia	2,134	20,022	$223,053,789
Pneumococcal Meningitis	165	224	$17,252,779
Tetanus	1,964	2,311	$214,741,451
Yellow Fever	86	375	$9,005,572
Rotavirus	466	--	$48,716,926
Meningitis A (MCV)	401	3,340	$41,899,607
Cervical Cancer (HPV)	--	--	$20,885,673

Table 4: Average Per B Medical Cold Chain Unit in Kano, Nigeria Results (Per Annum)

Illness/Disease	Average Social Costs Saved (Current USD, Per Annum)
Tuberculosis	$37,892
Polio	$36,749
Diphtheria and Pertussis (DTP)	$70,208
Hepatitis B	$26,292
Hib Pneumonia and Meningitis	$12,192
Measles	$5,000
Pneumococcal Pneumonia and Meningitis	$48,394
Tetanus	$31,571
Yellow Fever	$1,814
Rotavirus	$9,811
Meningitis A (MCV)	$8,438
Cervical Cancer (HPV)	$2,061
Total (Per Annum)	$281,983

QUALITATIVE SOCIAL VALUE

QUALITATIVE ANALYSIS

Increasingly, studies of immunization value have focused on the broader social value to arm decision makers and policy makers with the full picture of social value, empowering them to make fully informed decisions on the comparative value of interventions (Bärnighausen et al., 2014; Bärnighausen et al., 2009; Bloom et al., 2005).[10] Due to the fact that the quantitative results capture only a fraction of the total social value of each B Medical cold chain unit, it is necessary to explore both the value added directly by each unit, as well as the broader public health and socio-economic benefits enabled by the vaccines delivered through these units.[11]

Table 5: Social Value of Cold Chain Units and Vaccination[12]

CATEGORY	DESCRIPTION	OUTCOMES
	Health Related Benefits	
Health Gains	Reduction in morbidity and mortality	Cases adverted* Deaths adverted*
Health Care Savings	Reduction in cost of health care borne by the public sector or private individuals	Costs saved*
	Cold Chain Specific Value	
Reliability	Ensured temperature control and stable delivery of vaccines	Wastage costs saved Vaccine potency Timeliness outcomes Repair costs and savings
Longevity	The 10-year lifespan of a B Medical cold chain unit extends the benefits over that period	Multiplier of other benefits
Accessibility	Ability to reach a wider population geographically, particularly high disease-burden communities due to adaptability and durability	Increased immunization rates Expands other benefits Productivity (travel time) Reduced epidemics
	Productivity Related Benefits	

[10] See social value chart in Bärnighausen et al. (2009)
[11] See this argument on p. 216 Luyten et al. (2016): "The public-good dimension of a vaccination program is not properly accounted for in cost-effectiveness analysis."
[12] Adapted from the social value table in Deogaonkar et al. (2012)

Productivity gains related to care	Reduction in lost days of work due to sickness or caring for a sick patient	Value of productivity gained*
Productivity gains related to short term outcomes	Reduction in lost days of work due to sickness or death of sick patient	Value of productivity gained*

*Included in the Kano, Nigeria case study calculation model

COLD CHAIN INHERENT VALUE[13]

Insufficient or unreliable cold chain infrastructure remains a critical challenge, particularly in the rural areas of developing countries (Ophori et al., 2014, p. 71). According to research from the Gates Foundation, an estimated one-fifth of the 134,000 immunizations points in GAVI-eligible countries have no cold chain equipment, another one-fifth have equipment that is not functioning properly, and two-fifths have equipment with "significant limitations, such as a high freezing risk and/ or the need for expensive gas or kerosene" (PATH et al., 2015, p. 3). Only 29% of countries are meeting minimum standards of temperature control (WHO, 2014, p. 3).[14] As such, to achieve the optimal social value of immunization, it is imperative that adequate planning and funding be allocated to improving cold chain infrastructure. In addition to the social value that is inherent to the vaccines passing through a cold chain unit, a B Medical cold chain unit has social value in two ways - reliability and accessibility.

Reliability

The reliability of a cold chain unit can be defined in terms of its:

- temperature control,
- energy-dependency,
- rate of failure/breakdown, and
- expected lifespan.

A solar drive powered B Medical cold chain unit exemplifies reliability under these conditions and is guaranteed for a 10-year lifespan. A cold chain unit's reliability results in the following social value:

Reduced wastage: Vaccine wastage commonly occurs either when opened vials have to be discarded because of incomplete use of the doses, but wastage of unopened vials is often due to temperature complications due to improper storage or cold chain failure (Mentay et al., 2015, p. 1). Field research in some regions has revealed vaccine wastage of up to 76% of certain vaccines (Mentay et al., 2015, p. 3). However, poor documentation of wastage figures does not allow us to better understand the proportion of wastage directly due to cold chain-preventable causes (United Nations Children's Fund [UNICEF], 2010). Even so, with the rising costs of vaccines, reliable temperature control via cold chain

[13] The case study is based on a B Medical TCW 2000 SDD model, which is a solar direct drive, non-corrosive unit widely used in Kano

[14] Vaccine Wastage & Temp Control results were from EVM Data Analysis

units is imperative to reducing wastage and ensuring the optimal social return on investment in immunization is achieved.

Ensured potency of vaccines: In conjunction with reducing wastage, reliable cold chain infrastructure is also necessary to maintain the temperatures for a vaccine to be potent when it is administered (Nieburg & McLaren, 2016, p. 8). Particularly live vaccines (e.g. OPV) require specific temperatures, and variations outside that range can reduce the potency of the vaccine (WHO, 2005; Ophori et al., 2014). When invalid doses are administered, not only is the individual not immune, but the cost also increases with the need to revaccinate or treat that individual for a subsequent illness (Luman et al., 2005).

Timeliness of delivery *(PATH et al., 2015, p. 3; Ndiritu et al., 2006)***:** Without the proper infrastructure or in the case of unreliable infrastructure, entire cohorts of infants can miss the optimal window for immunization – "In order to be most effective, primary immunization must be completed before the age when infants are at high risk for contracting these diseases" (Halsey & Galazka, 1985, p. 1162-3). Not only is the timing of delivery key to realizing the full efficacy of the vaccine, but it also, is paramount to preventing outbreaks in particular areas. Essentially, the longer the wait for immunization to reach a population, the higher the social costs will be.

Reduced breakdowns: The avoided wastage and increased potency afforded to having a cold chain unit in place of a household refrigerator is not yet quantified through research, however the reliability of a B Medical cold chain unit intuitively reduces the frequency of breakdowns, time to repair and repair costs often associated with alternatives. The latest models focus on limiting breakdowns caused by installation or user errors as well. This was particularly critical when reviewing the case study of Kano, seeing as the 2012 cold chain assessment in Nigeria had indicated that 43% of cold chain equipment was faulty. Following that assessment 48% of the "faulty" cold chains were repaired, ensuring continuous supply of vaccination to those health facilities (NPHCDA, 2013, p. 15; Yahya, 2007). Cold chain equipment failure has been highlighted as one of the key barriers to the delivery of immunization services (Maurice & Davey, 2009; Ophori et al., 2014). Therefore, it is not just procuring a cold chain that enables the social value of vaccination, but more importantly, procuring a cold chain that will be most reliable in the region's conditions and minimizing the need for repair.

As a component of reliability, the longevity of a B Medical cold chain unit (i.e. its10-year lifespan) guarantees that these inherent values, coupled with the avoided costs, are exponentially greater over time. The cold chain unit's lifespan also reduces the need for replacement infrastructure, planning and transport over an extended period of time, increasing the proportion of social value afforded to each unit and increasing the return on the initial investment as a greater proportion of the population is reached with reliable vaccines.

Accessibility

WHO estimates that there remains 24 million children "difficult to reach with vaccines", which are not receiving their recommended vaccination set largely due to barriers in accessibility (Maurice & Davey, 2009, p. XV). Incomplete and inconsistent immunization coverage due to these challenges, results in large numbers of avoidable deaths (Bärnighausen et al., 2009, p. 3-4). The lack of accessibility is most prevalent when targeting populations in rural areas of developing countries.

A solar direct drive (SDD) B Medical cold chain unit overcomes challenges of accessibility by providing stable temperature control without electricity. The design of the unit is made of a durable plastic to make it reliable in the most remote and harsh climates, which is where, by default, the greatest remaining at-risk populations reside.

Increased immunization rates: In order for the optimal social value of vaccination to be achieved, particular focus needs to be paid to areas of high disease burden, even though these are often regions with poor infrastructure and limited access to services. Surveys administered in Nigeria show that a large proportion of the rural population find the distance to health facilities too great (National Population Commission [NPC], 2014, p. 153). Increasing accessibility will in turn increase immunization rates, reduced outbreaks and epidemics, and expand the health/social benefits to a wider population regardless of their geographical location.

Expansion of benefits: For example rural populations often face the greatest barriers to access, which leads to unequal distribution of services - "While the bulk of social and health infrastructures and the best equipped hospitals are located in major cities in Africa, the African population is predominantly rural, with the urban population representing only 40 and 37%, respectively, of the total population in Africa" (Kuate, 2014). Due to this the rates of immunization coverage are often substantially lower in rural than urban areas – "in some countries, coverage of measles-containing vaccine in rural areas is 33% lower than in urban areas" (WHO & UNICEF, 2013, p. 19). Research conducted in South Western Nigeria revealed that 16% of mothers surveyed claimed that their child was not vaccinated because the health facility post was "too far" (Bisiriyu & Ojewumi, 2014, p. 138; Ndiritu et al., 2006). The distance to health facilities can incur higher costs associated with travel and lost productivity, which has not yet been accounted for in the quantified value of a cold chain (Bloom et al., 2005).[15]

Reduced Epidemics: Low coverage levels also risk outbreaks and epidemics that could have been avoided through immunization programmes. These outbreaks often effect the most vulnerable populations, especially infants and young children (Ophori et al., 2014, p. 69). In a post-globalization context, the social value of increased accessibility is not only applicable to the populations in question, but rather to the whole international community, as was evident when the 2014 Ebola outbreak in West Africa became an international health crisis. By providing the infrastructure to deliver immunization in these areas, the potential avoided costs and social benefits are far-reaching. It is important to consider, however, that other factors beyond infrastructure, including public awareness and education are just as critical to ensuring the success of these programmes (Roberts, 2004; Miller et al., 2006).

The social value of a cold chain is not only in the types of vaccines that pass through it but also inextricably linked to the particular population that it allows those vaccines to reach. Without providing these units in even the most remote areas, the immediate social value of illness and mortality prevention along with the broader public health and socio-economic benefits will not be fully realized. Beyond the values inherent to each cold chain unit, are the broader social values in public health and socio-economic development that are enabled by reliable and accessible cold chain infrastructure and vaccines.

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[15] See p. 22: "Because these communities are more elusive, the average cost per vaccination has increased," reducing the likelihood of vaccination.

PUBLIC HEALTH BENEFITS

Despite the global push for increased vaccination in the past five years, the burden of vaccine-preventable illness, particularly in children under five, remains high. Researchers estimate that two-thirds of mortality in children is caused by disease, which low-cost interventions, including vaccination, could prevent (Jones et al., 2003). The core public health outcomes that are enabled by reliable and accessible cold chain infrastructure are disease eradication, herd immunity and antibiotic resistance.

Disease Eradication

The global health community has campaigned for the eradication of particular diseases for decades. Cold chain infrastructure plays a critical role in ensuring that vaccines reach even the most remote populations with potent vaccines (Ophori et al., 2014).[16] For example, the oral poliomyelitis vaccine (OPV) is a live vaccine and highly sensitive to heat (Ophori et al., 2014).[17] Without proper cold chain infrastructure, particularly in reference to our Kano case study, the eradication of polio would not have been possible.

Without proper cold chain infrastructure, particularly in reference to our Kano case study, the eradication of polio would not have been possible.

The eradication of a disease, unlike control, requires greater initial investment and effort. However, it results in potentially "infinite" benefits (Luyten & Beutels, 2016, p. 215). In the example of polio eradication - "As long as a single child remains infected, children in all countries are at risk of contracting polio. Failure to eradicate polio from these last remaining strongholds could result in as many as 200,000 new cases every year, within 10 years, all over the world" (WHO, October 2015). Eradication cannot be achieved over night and requires continue immunization efforts until natural immunity is developed for the full cohort, eliminating the reservoirs of disease (Miller et al., 2006). Unless all regions are reached by immunization campaigns, true eradication cannot be reached, and even with small immunization gaps, the risk of disease spreading globally remains a possibility (Miller et al., 2006; Bartlett, 2014; Duintjer, 2005; Nathanson & Kew, 2010; Strebel et al., 2011).

Once again, Kano provides an ideal case study for the extended social value of reaching remote populations to achieve eradication. During the global polio eradication initiative (EPI), large investments were made both in vaccination and cold chain equipment to reach the high-risk population

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[16] See p. 71: "Among the greatest obstacles to polio eradication in Nigeria is the lack of basic health infrastructure."

[17] OPV must be kept between 2-8 degrees Celsius to retain potency

in Kano - 240 of the 806 polio cases recorded in Nigeria in 2001 were in Kano (Zeeshan, 2014, p. 5). Despite EPI efforts in 2004, Kano faced huge obstacles in the uptake of OPV, resulting in the spread of polio to 10 other countries, 9 of which were previously polio-free (Miller et al., 2006, p. 8-12; Wassilak et al., 2011). This demonstrates the "public good" nature of vaccination that extends far beyond the individual vaccinated. Cold chain infrastructure plays a critical role in reaching the last 1% of the population that is pivotal in ensuring the eradication of costly diseases.

Herd Immunity

The accessibility of a cold chain also determines the scope of immunization, which could result in reaching the thresholds of herd immunity. Herd immunity not only has short-term benefits of reducing health care costs and increasing productivity, but in the long-term, it may also reduce the very costs of providing immunization programmes once natural immunities are developed in a community. Unless the infrastructure is provided, though, to reach a greater proportion of the at-risk populations, herd immunity will not be realized.

The accessibility of a cold chain also determines the scope of immunization, which could result in reaching the thresholds of herd immunity.

Immunization supports herd immunity benefits for the unvaccinated members of a community by reducing the exposure of those members to an infectious disease (Stephens, 2008; Brisson & Edmunds, 2003; Claes, 2009). The unvaccinated community members would face varying degrees of risk depending on the proportion of the community that was immune (Neiburg & McLaren, 2016, p. 6). For example, research has shown that when 80% of women in a community have received two doses of tetanus toxoid, "the level of seroprotection coupled with health education is adequate to eliminate tetanus" entirely from the community (Miller & Sentz, 2006, p. 169). In communities where the converse is true and there is an "immunity gap" in the cohort, the risk of epidemics is much higher (Miller & Sentz, 2006). Additionally, because the efficacy of vaccines varies and does not guarantee immunity in every case, herd immunity is an invaluable public good (Luyten & Beutels, 2016, p. 215).

For vaccines like Hib, vaccinating a portion of children in the population leads to indirect protection unvaccinated and partially vaccinated children. This is particularly true for newborns and infants who are too young to receive the vaccine directly, and thus receive the maximum benefit for reduced exposure to pathogens (Theodoratou et al., 2010, p. i181). Even with modest vaccine coverage, the implementation of DTP in regions has led to rapid reduction in overall pertussis (whooping cough) incidence, which once again demonstrates a "strong herd-immunity effect" (Preziosi, 2002, p. 891).

In terms of the social value model used to evaluate cold chain units in Kano, one of the highly relevant but un-captured components was herd immunity. Essentially, the treatment costs, illness incidence, disability incidence, mortality incidence, and productivity costs would be increased exponentially depending the size of the community surrounding the vaccinated and therefore immune individuals (Bärnighausen et al., 2011, p. 2374-5). With increased data on incidence rates, it will potentially be possible to measure the value of indirect immunity in a community vis-à-vis an incidence comparison between the vaccinated and unvaccinated in correlation to the proportion of unvaccinated individuals (Lewis et al., 2008).

Prevention of Antibiotic Resistance

The reliability and accessibility of a cold chain unit also can be leveraged to prevent the development of antibiotic resistant strains of illness. Individuals who are unvaccinated or vaccinated with impotent vaccines frequently receive alternative treatment in the form of antibiotics – "The probability of antibiotic resistance increases with the number of patients treated with an antibiotic (Bärnighausen et al., 2009, p. 14)."Like herd immunity, avoiding antibiotic resistance requires immunization programmes to reach a critical mass of the population.

The reliability and accessibility of a cold chain unit also can be leveraged to prevent the development of antibiotic resistant strains of illness.

Several of today's "super-bugs", including multi-drug-resistant tuberculosis (MDR-TB), could be the results of repeated treatment with antibiotics in the absence of immunization (Otu et al., 2013). Recent global estimates predict that a third of all new TB patients have MDR-TB (WHO, Global TB Report, 2015, p. 2). Not only do these strains pose a greater threat to global health, but also the costs of using second-line antibiotics for treatment are increasingly expensive and a greater burden on healthcare systems (Bärnighausen et al., 2008, p. 7; Bärnighausen et al., 2014). The social value of vaccination in preventing antibiotic resistance could potentially be quantified both in terms of the treatment cost savings but also in terms of the short and long-term costs associated with drug-resistant diseases.

Health Equity

When a B Medical cold chain unit is installed in a facility without prior access to proper vaccine refrigeration, the social value extends beyond the marginal increased cost savings of each person vaccinated. Health equity, not just herd immunity and prevented antibiotic resistance, is an intangible value of a cold chain based purely on its location and the surrounding population. Just as access to electricity and plumbing are associated with bridging socio-economic divides, cold chain equipment bridges gaps in health infrastructure to deliver critical care to a community regardless of their socio-economic status and geographical location.

Health equity, not just herd immunity and prevented antibiotic resistance, is an intangible value of a cold chain based purely on its location and the surrounding population.

When health equity is increased, as with access to education, individuals have the opportunity to achieve a greater quality of life. In fact, access to effective healthcare programmes, like immunization, is a prerequisite for development on all levels. When it comes to vaccination, the most vulnerable populations are often not reached by immunization campaigns based on cost or infrastructure issues (Cochi, 2011, p. 3), which is where solar-powered and portable refrigeration is most critical to increasing vaccination coverage and health equity. The extent to which this changes the landscape of development will only be fully measurable once the gaps in delivery are overcome (Luyten & Beutels, 2016, p. 214).

In conclusion, the broader social value for public health afforded by a single cold chain is not yet quantifiable. However, policymakers and health officials should not underestimate the tremendous value to public health that vaccination delivered through reliable and accessible cold chains affords the greater population.

SOCIO-ECONOMIC BENEFITS

In conjunction with the public health benefits described previously, there are a multitude of broader socio-economic benefits that have been highlighted by research on the social value of immunization. These benefits include, but are not limited to: human capital development, improved household economic behaviour, and macroeconomic gains. As prior researchers have put it, "in addition to the health benefits of vaccinations, their effects on education and income and benefits for unvaccinated community members are considerable and should be included in calculations to establish their value" (Bärnighausen et al., 2008, p. 2).

Human Capital and Education: Vaccination and the subsequent reduction of illness and mortality results in further social benefits in the form of human capital development. By enabling the effective delivery, a cold chain unit supports this function in the communities it reaches.

"In addition to the health benefits of vaccinations, their effects on education and income and benefits for unvaccinated community members are considerable and should be included in calculations to establish their value."

There are short-term and long-term effects on human capital development vis-à-vis vaccination. In the short term, by reducing illness and mortality incidence, vaccines also reduce the time that would have been spent treating those illnesses. When the illness appears in a child of schooling age, treatment time excludes them from time spent in a classroom. Prolonged illnesses have a particularly detrimental effect, as children are often unable to recoup the time lost during treatment and/or hospitalisation. In the long-term, vaccines prevent learning disabilities that result from preventable-diseases as well as malnutrition arising from repeated infection (Bärnighausen et al., 2009; Solarsh & Hofman, 2006, p. 132).[18] Aside from preventing disabilities in the long-term, research has found a causal link between vaccination and improved cognitive development (Bloom et al., 2007), along with educational attainment (Anekwe et al., 2015). While difficult to quantify, the value of human capital and education underpin a country's economic and social development (Hanushek, 2009).[19]

Household Economic Behaviour: The short-term cost and productivity savings for a household have been captured in the case study calculation. Additional value, though, would only be quantifiable with further data on household data in relationship to each illness. For example and in line with human capital development, the reduced mortality incidence in children has been linked to households having fewer children (Bärnighausen et al., 2009).[20] Reduced fertility rates often result in greater investment in each child's future, including their education and future productivity levels (Bärnighausen et al., 2009, p. 13; Bloom & Canning, 2007). Over time, the behaviour of a household confident in its health changes in terms of consumption, investment and savings as well – "Environments with low life expectancy discourage individuals from investing in health and education due to relatively low payoff periods and high uncertainty" (Bloom & Canning, 2007).

Macroeconomic Gains: Extending the household socio-economic and public benefits one step further, increased immunization contributes to broader macroeconomic trends (Jit et al., 2015). For example, if through immunization, illness incidence is reduced, it can be assumed that there will be a healthier workforce in the future. Because this workforce is healthier and life expectancy is increased, the overall society's productivity increases, fuelling GDP growth at a national and international level (Luyten &

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[18] See Bärnighausen et al., p. 4: "Rotavirus infection can lead to malnutrition in early childhood, potentially resulting in stunted height. Vaccination against these diseases, therefore, can avert both death and impairment."
[19] See Hanushek (2009) for further discussion of the economic value of education
[20] See p. 2: "Reductions in child mortality due to Hib can trigger changes in fertility which in turn may stimulate economic growth."

Beutels, 2016). Similarly, the reduction of illness epidemics promotes stability in a region, leading to opportunities for economic growth through tourism, foreign direct investment (FDI) and greater local investment in the future. The cumulative effect of improved health outcomes, however immeasurable, reinforces the exponential value of investing in immunization programmes.

In summary, the quantified social value of immunization has only captured a small fraction of the avoided costs and productivity gains of each illness. It fails to capture the extensive public health and socio-economic benefits that are also directly linked to reduced illness incidence and increased life expectancy. Investing in vaccines, and therefore the cold chain equipment that enable their delivery, is equivalent to investing in a better future not just for an individual but also for the greater public good.

CONCLUSION

The challenge to evaluating the social value of any good is that it relies on a plethora of assumptions and potentially inaccurate data. It is evident, though, that the ultimate value of a B Medical cold chain unit hinges on the vaccines it stores and the context in which those vaccines are administered.

At the same time, the value of the vaccines themselves is negated without reliable and accessible cold chain infrastructure to deliver them - "If the hundreds of millions of dollars that have been invested in vaccine development are to be translated into the desired transformation in disease burden, vaccine delivery systems must themselves be transformed" (Sabot et al., 2011, p. 3). For the Global Vaccine Action Plan (GVAP) to be implemented and the Sustainable Development Goals (SDGs) to be achieved, the social value of cold chain units cannot be discounted.

It is critical for the global health community and individual nations to roll out sufficient infrastructure to provide sufficient immunisation coverage. It is only once coverage has been optimized that equilibrium can be reached - "As vaccination levels increase, the marginal social benefits of vaccination fall, whereas the marginal social costs rise. Social welfare is maximized where these two relations intersect, which might be called the "optimal" level of vaccination—a level that may or may not achieve cessation of transmission or eradication" (Miller et al., 2006, p. 7).

Drawing from the case study in Kano, Nigeria, investing in a single B Medical cold chain unit could result in over **$4.4 million (PPP)** over the next ten years. Simultaneously, the immeasurable value of that cold chain can only be explained to be central to improved public health and socio-economic development. An investment in a cold chain unit is an investment in the future public good – an untold future of possibilities where life expectancy increases and prosperity grows until decades from now when we reach the optimal global level of immunity.

APPENDIX

APPENDIX I: UNCERTAINTY AND ASSUMPTIONS

There were several assumptions made in order to calculate the social value of a single B Medical cold chain unit in Kano, Nigeria. In the interest of transparency, the main assumptions are outlined below:

- ***Assumptions about productivity:*** Per cold chain unit productivity was calculated based on the survey data gathered from health centres, clinics and hospitals in the state of Kano, Nigeria. If this data was incorrectly reported, the productivity could vary from the estimates used. As a verification measure, the birth rate and under-5 cohort for Kano was used to ensure that the average productivity per month was reasonable. Though reasonable for this case study, it is imperative to remember Nigeria is a "high burden" country, and as such, the value in lower burden countries, even in Sub-Saharan Africa (i.e. Madagascar) would return a significantly lower social value per cold chain. Additionally, we are assuming that individuals are only visiting a centre once in a month - multiple visits in a month would result in double counting and reduce the estimated productivity of a cold chain unit.
- ***Assumptions about vaccination sets:*** For childhood vaccines, it was assumed that each child would receive their full vaccine set. Hepatitis B and Tetanus are the two exceptions to this, as they also include adults and reduced coverage estimates.
- ***Assumptions about accuracy of international data:*** All data on incidence and treatment was drawn from reputable international sources and academic journals. However, it has been conceded by researchers that these estimates are often based on small sets of data, which could misrepresent the reality on the ground – the "black hole" of statistics as some have coined it (Botha & Bradshaw, 1985). As the former VP Africa Region of the World Bank, Callisto Madavo wrote, "Notwithstanding these advances in health statistics, a theme that emerges…is that too little is known about trends in the diseases and conditions included here in order to monitor and evaluate the effectiveness of programs intended to produce better health outcomes" (Jamison et al., 2006, p. xiii). Assumptions for individual vaccine data were mentioned in the per vaccine methodology descriptions.
- ***Assumptions about counterfactual incidence:*** For most vaccines, counterfactual data for the illness and mortality incidence that would have occurred in the absence of vaccines was unavailable or unreliable. As such, the estimates used often represent the current incidence even with immunization programmes actually running. The social value, therefore, in a true counterfactual calculation would be even greater.
- ***Assumptions about time period:*** The case study focused on a time period from 2011-2020 purely based on the available data within that period. It is assumed that this is a fair representation of the current and future social value of a cold chain unit with a ten-year lifespan.
- ***Assumptions about other mortality causes:*** The social value estimates are assuming that by not succumbing to a vaccine-preventable illness that individual would live accordingly to the average life expectancy in Nigeria. Though this accounts for all mortality factors, the individual cases do not account for death from other causes (i.e. conflict, injury, etc.), which does play a significant role in the low life expectancy and high mortality rates in Nigeria.
- ***Assumptions about future vaccine development:*** There is the potential for 'heat-resistant" vaccines to impact the social value of cold chain units drastically once they are developed.

However, this development is a “long way from being realized” and would likely not apply to all vaccine types (Maurice & Davey, 2009). This social value case study assumes that cold chain refrigeration for vaccines will still be required for the coming decade.

For several assumptions, including productivity, the results of the case study were triangulated with external research estimates. For the 2011-2020 period, it was estimated that 2,146,905 lives would be saved by immunization (Lee et al., 2013, p. B67). The total deaths avoided per the full set model for the state of Kano were 134,350, which is 6.2% percent of total deaths. Kano represents 6.7% of the population and is a high burden region of the overall country.

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