Towards Vaccine Administration Workload Estimation: Development of a Vaccine Categorization Framework

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Abstract

Finding a right balance between the workload demand for vaccination and healthcare workforce size is key to having vaccination work systems that can support the fulfillment of immunization goals. This load-workforce balance can only be achieved when there is a framework for estimating the workload in various vaccination scenario. The study considers the development of a framework to categorise vaccines based on work requirements for estimation of workload. A framework was developed based on vaccines available for routine immunization schedules in Nigeria. The framework groups the vaccines based on similarity of vaccine administration routes, vaccine preparation for administration, demography of vaccinees and or caregivers in order to define their work requirements. The proposed framework will aid decision-makers in estimating workload of vaccination work system

Keywords
Vaccine, Vaccine administration, Vaccination workload, Work system, Vaccine categorization framework

1. Introduction

1.1 Background of the Study

Balance between health workforce size and the need for care by patient ensures quality of care and safety of patient in terms of patient outcomes and the outcomes of organization in achieving its set goals. The mismatch has been a major challenge in ensuring the desired outcomes of care(Carayon *et al.* 2006; van den Oetelaar *et al.* 2016). This challenge can be addressed by efficient management of workload and deployment of workforce through estimation of workload. Matching health personnel capacity to optimally match the needs of patients is still a challenge particularly in developing countries. There are mismatches between the vaccination workforce and the workload for the vaccination of a target population. This mismatch has resulted in negative outcomes for the patient (wrong doses, wrong vaccine among others), health personnel (job strain, increased level of morale distress, illness and injury) and organization (missed target coverage, resource idleness, absenteeism and overtime).

There is a need for right-sizing of workforce to match the demand for vaccination. The sizing of workforce for vaccine administation is determined by the workload; that is the amount of work available. Several studies have been carried out to estimate workload in health care work system(Faulkner, 2003; Schoo *et al.* 2008; Ly et al. 2014; Shivam *et al.* 2014; van den Oetelaar *et al.* 2016; Azimi Nayebi *et al.* 2019). For vaccination, the workload may differ from setting to setting. While vaccination in many developed countries may be limited to the controlled environment of hospitals and clinics, many vaccinations exercises in most developing countries are, however, carried out in informal environments such as open fields, markets, schools, immigration shelters, internally displaced people's (IDP) camps, and other non-hospital settings. The workload may vary from setting to setting due to different work requirements and one size-fit all may not be applicable.

Also, work requirement for administration of each vaccine differs in terms of the route of administration, vaccine preparation for administration, age of vaccinee, the level of education of vaccinee or caregiver. Delivery and preparation of vaccines are not the same for all vaccines. This calls a framework to group vaccine based on their work requirements and vaccination environment to help in estimating the workload of any vaccination work system

1.2 Rational and Scope of the Study

The target of sustainable development goals (SDGs) of ending preventable deaths of newborn**s** (United Nations, 2015) initiated expanded health program on immunization among others as strategies to be carried out to meet the target**.** Nigeria had gradual and sustained progress but the target was not met. This was reflected in the report of having the highest number of unvaccinated children(Vanderende *et al.* 2018). One of the key factors for this low coverage among others is the ineffectiveness in the service delivery at the vaccination work stations which result from mismatch between available resources in terms of manpower (supply) and target population to be vaccinated (demand) and these have not helped in achieving the coverage rate for all vaccine as spelt out by Vaccine Alliance(GAVI) and other stakeholders(World Health Organization, 2015).Determination of the right configuration of vaccination workforce is important in ensuring high coverage. This calls for development of framework to categorise vaccines based on their work requirements for vaccination workload estimation. The study considers vaccines for routine immunization in Nigeria for the development of the framework.

1.3 Aim, Objectives and Value of the Study

The study aims at developing a framework to categorize vaccine based on their work requirement to aid estimation of vaccination workload and the application of the framework to a case study.

2. Literature Review

2.1 Workforce sizing requirement

Workforce requirement has been identified by(van den Oetelaar *et al.* 2016; Duijzer et al. 2018) as one of the major decision problems for vaccination work system. Several methods have been used in determining the staffing requirements for manufacturing system and services system(Stewart *et al.*1994; Brusco and Johns, 1998; Bard et al. 2007; Ertogral and Bamuqabel, 2008; Corominas et al. 2010; Lim, 2011; Ighravwe and Oke, 2014; De Bruecker *et al.*2015; Qin et. al. 2015). Approaches have been developed in particular for healthcare staffing requirements determination. The need-based approach was reviewed by (Faulkner, 2003) for estimation of psychiatric workforce requirements. (Dreesch *et al.* 2005) identified four traditional methods as given by (Mejia et al. 1978; Markham and Birch, 1997; O'Brien-Pallas *et al.* 2001) as need-based, utilization or demand-based, health workforce to population ratio and target setting approaches. The study gives the advantages and limitations of the approaches.

Dreesch *et al.*(2005) also, give a comprehensive methodology for estimation of health workforce requirement for achievement of Millennium Development Goals. The method gives priority to health problems that are related to Millennium Development Goals in the developing countries and this limits its application. (Hurst, 2006) gave the four categories of workforce planning methods which are professional judgment, case loading analysis, population health records and community patient dependency and acuity. Workforce planning for allied health workers was explored by (Schoo *et al.* 2008) through systematic review. Four methods of workload requirement were identified from literature as ratio-based, procedure-based, care-based and diagnostic-based methods. Each of the approaches has its limitation but procedure-based method is widely accepted of all the four methods. The study also identifies Mixed methodologies which combine two or more of the four methods. Hurst *et al.* (2008) improve the existing approach on dependency workload assessment with introduction of multipliers for widening and strengthening its application.

Musau *et al.* (2008) uses Workload indicator of staffing needs(WISN) which is developed in conjunction with World Health Organization(WHO) to establish optimal workforce for a tertiary health institution. Several studies have applied WISN to staffing needs at perinatal care, maternity ward, HIV clinics, public health centres, general and tertiary health institution(Kitanda, 2008; Mugisha and Namaganda, 2008; Nyamtema *et al.* 2008; McQuide et al. 2013; Ly et al. 2014; Govule *et al.* 2015; Burmen et al. 2017; Azimi Nayebi *et al.* 2019; Okoroafor *et al.* 2019). Existing approaches of determining staffing requirements are historical patterns and professional judgment, population ratio (World Health Organization (WHO), 2016; Burmen et al. 2017; Okoroafor *et al.* 2019). Others adopted methods are acuity measures, case-load profiling, queuing theory, treatment care standards to mention a few. This approaches failed in estimating the staffing requirement in terms of actual workload and does not take into account wide local variations such as demand for services, patterns and levels of morbidity and local economic circumstances(Hagopian *et al.* 2012; Govule *et al.* 2015; Burmen et al. 2017)

Workload indicator of staffing needs (WISN) approach is based on health workers' workload with activity time standards applied to each workload component. It provides evidence-based estimation of staffing levels to meet the actual demand for services in health facility which can be used in workforce planning and management decision making. WISN result can be used to evaluate staffing capacity over previous years and to forecast the likely requirement based on future workloads(Shipp and World Health Organization, 1998; World Health Organization, 2010, 2016). The limitation of WISN as given by Nyamtema et al. (2008) is that the method utilizes statistics from the past data year and gives the estimate of what the staffing levels should be and that the accuracy of the methods depends on the accuracy of the record-keeping of the health institutions. The study which aims at categorizing vaccine based on work characteristics and vaccination environment will aid the application of WISN and other empirical methods of estimating workload requirement in vaccination work system

2.2 Vaccine administration process

Vaccine administration is the act of getting vaccine into the body of the vaccinee through the required site. Proper vaccine administration is critical to achieving successful immunization programme. It is a key factor in ensuring safety and effectiveness of vaccination. It must follow the "Right of Medication Administration" which ensures the right patient is given the right vaccine with the right diluent where applicable at the right time, with right dosage through the right route and at the right site with right documentation(US Centers for Disease Control and Prevention and National Immunization Program , 2005).

Vaccines come as injectable, oral and nasal preparations with three basic presentation strategies which are lyophilized vaccines in vials, pre-filled delivery devices and liquid vaccine in vials or ampoules. The lyophilized vaccines in vials are freeze-dried vaccines which require reconstitution with product specific diluent before administration. This freeze-dried vaccine is packaged in single-dose and multi-dose vials. The pre-filled delivery is ready to use vaccine delivered in manufacturer-filled syringes. Liquid vaccines packaged in vials and ampoules are ready to use vaccines which are packaged in single-dose or multi-dose vials(Papania et al. 2018)

Vaccine delivery involves administering vaccine formulations to particular sites of the body and the delivery of the antigen to activate the recipient immune system. Different routes can be used to administer vaccine formulation to particular site of the body(Kallerup and Foged, 2015). Figure 1 gives the route of vaccine delivery. Route of administration is the passage through which vaccine is received into the body. Variation in the route of administration helps in maximising the effectiveness of the vaccine. It could oral through the mouth, or by spraying through the nose and by injecting into the body through the skin. Intranasal vaccines are vaccines administered through the nostrils. It stands the advantage of self-administration and ease of use by different target groups.(Birkhoff et al. 2009; World Health Organization, 2013; Wallis et al. 2019; Madani *et al.* 2020). Figure 2 gives the vaccine administration process which is useful in classifying the work requirements for each of the vaccine.

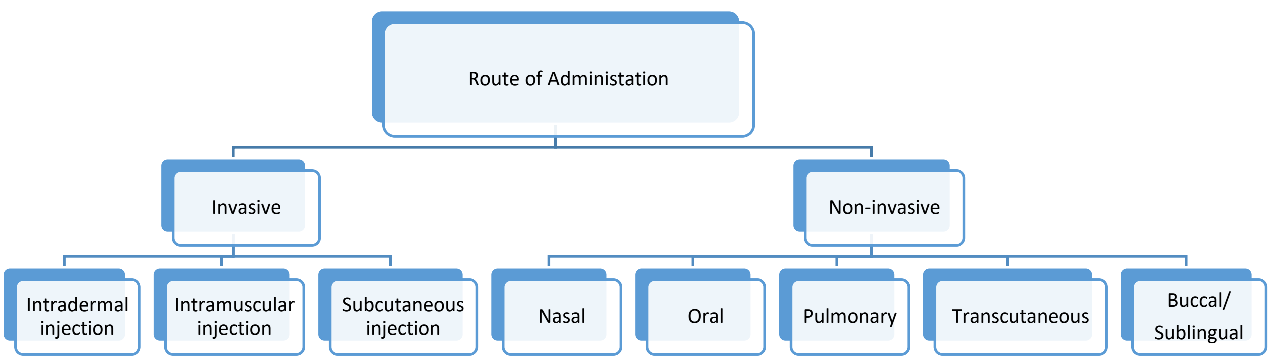

Figure 1. Route of vaccine delivery (Authors 'conceptualization)

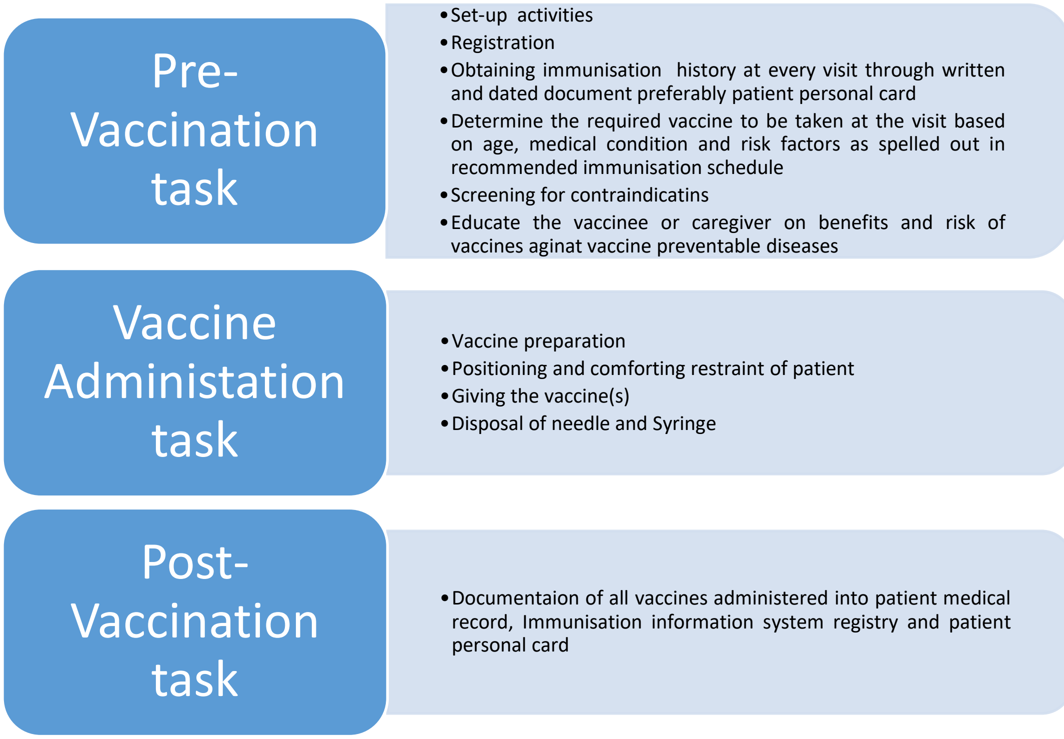

Figure 2. Vaccine Administration Process (Authors 'conceptualization)

3. Methodology

In this section, the definition of parameters and the development of vaccine categorization framework are presented.

3.1 Vaccine categorization: framework parameters

The vaccine categorization framework is developed to group vaccines based on the three parameters; vaccine types, work requirements and the vaccination environment.

3.1.1 Vaccine types

Vaccines are categorised by the antigen used in their preparation. Their usage, storage and administration are affected by their formulations. There are four major classifications which are live attenuated, killed inactivated, toxoid and subunit. All available vaccine falls into any of these four categories. The vaccine type to be considered will be vaccines available for all diseases. The vaccine types as being defined for this framework will consider all vaccines available for vaccination in any vaccination environment.

3.1.2 Work requirements

Work requirement specifies the component of work, skills and other activities needed to carry out work. Work requirements help to spell out the demand for each vaccination task. The key work requirements for vaccine administration are the route of administration, vaccine preparation, age of vaccinee, the level of education of vaccinee or caregiver. Individual vaccine has a different route of administration and each route of administration has different work requirements. For example, intramuscular injection which administers vaccine into muscle mass requires a certain length of needle and also there is a required positioning of the needle during administration.

Vaccines are package in three basic ways which are lyophilized vaccines in vials, pre-filled delivery devices and liquid vaccine in vials or ampoules. Lyophilized and liquid vaccine could be in single-dose or multi-dose vials or ampoules and each of this packaging requires different preparation for administration and this makes work requirement differs. Age of the vaccinee has a great impact on work requirement for vaccine administration. For example, the positioning of children for vaccination will require different work requirement when compared with adolescent and adult. Level of education of vaccinee or caregiver determines the work requirement for documentation and communication during vaccine administration. Work requirement for attending to a literate vaccinee or caregiver will be different from that of illiterate or semi-literate.

3.1.3 Vaccination environment

The vaccination environment refers to the strategies employed in organizing vaccination. Vaccination strategy selection depends on the knowledge of local cultural attitudes and behaviours to ensure the effectiveness of the delivery system. Availability of fund also determines the choice of strategy. Vaccination strategies employed by the study is based on the location where vaccine is administered and it is referred to in this study as vaccination environment. They are fixed location, outreaches and mobile services. Other environments are immigration outlets where recommended vaccines are given to travellers, IDP camps which require vaccination of refugees from infection or diseases that might erupt from overcrowding and other inherent factors. The choice of vaccination environment determines the type of set-up activities required for administration of vaccine. The set-up activities for each strategy differs as well. One set-up is required per immunisation session that is for all the vaccines that will be administered, it will require only one set-up.

3.2 Development of framework for vaccine categorization

The framework for vaccine categorization employed three parameters which are vaccine types, work requirement and vaccination environment. The framework uses the concept of group technology in categorizing vaccines that have similar work requirements such as route of administration, vaccine preparation and age of vaccinee are grouped for estimation of their work content.

The notation for the framework is given as follows:

J: Set of vaccine type, $j \in J$ for $j = 1, 2, 3, \dots, y$

K: Set of Vaccination environment, $k \in K$ for $k=1, 2, 3, \dots, q$

G: Set of work requirements, $g_m \in G$ for all $m =1, 2, 3, \dots, n$

g_m: Set of work characteristics, $g_{mh} \in g_m$ for all $h=1, 2, 3, \dots, v$

The vaccine categorization based on the three parameters namely vaccine type, work requirement and vaccination environment are illustrated in Table 1

Table 1. Categorization of vaccine type, *j* and work requirement, g for any vaccine environment, *k*

Vaccine j	**Work requirements, G**															**Environment k**	
	g_1				g_2				…			g_n					
1	g_{11}	g_{12}	…	g_{1v}	g_{21}	g_{22}	…	g_{2v}	…	…	…	g_{n1}	g_{n2}	…	g_{nv}	1	
2																	
3																	
…																	
y-1																	
y																	
1	g_{11}	g_{12}	…	g_{1v}	g_{21}	g_{22}	…	g_{2v}	…	…	…	g_{n1}	g_{n2}	…	g_{nv}	2	
2 3																	
…																	
y-1																	
y																	
1	g_{11}	g_{12}	…	g_{1v}	g_{21}	g_{22}	…	g_{2v}	…	…	…	g_{n1}	g_{n2}	…	g_{nv}	…	
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1	g_{11}	g_{12}	…	g_{1v}	g_{21}	g_{22}	…	g_{2v}	…	…	…	g_{n1}	g_{n2}	…	g_{nv}	q	
2																	
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y-1																	
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4. Results and Discussion

4.1 Investigated case and Data Collection

The framework for categorization of vaccine is illustrated with vaccines available for immunization programme in Nigeria which are administered to prevent fourteen targeted diseases such as are tuberculosis, poliomyelitis, tetanus, measles, pertussis, diphtheria. hepatitis B, rotavirus, pneumococcal disease, rubella, yellow fever, meningitis, haemophilus influenza type b disease and cervical cancer. Secondary data were gotten from the guidebook for routine immunization service providers in Nigeria(National Primary Health Care Development Agency, 2017). Routine immunization vaccines and other relevant data were used to illustrate the developed vaccine categorisation framework. The illustrated case study depicts vaccination programme carried out in health facility. Table 2 gives the vaccine, the targeted disease, numbers of doses when to administer each vaccine, route of administration, vaccination site and the vaccine form for routine immunization.

Table 2. Details of vaccines for illustration of the framework

Vaccine	**Disease**	**Number of doses**	**When to give**	**Route of administration**	**Vaccination site**	**Vaccine form**
Bacillus Calmette-Guerin (BCG)	Tuberculosis	1	At birth	Intradermal (ID)	Upper left arm	Freeze-dried powder
Oral Polio Vaccine(OPV)	Poliomyelitis	4	At birth, 6 weeks, 10weeks, 14weeks of age	Oral	Mouth	Liquid
Inactivated Polio Vaccine(IPV)	Poliomyelitis	1	14weeks of age	Intramuscular (IM)	Right anterolateral(outer) thigh in infants and children	Liquid
Hepatitis B vaccine (Hep B)	Hepatitis B infection	1	At birth	Intramuscular (IM)	Left upper anterolateral(outer) thigh in infants and children	Liquid
Pentavalent vaccine (Penta)	Diphtheria, Pertussis, Tetanus, Haemophilus influenzae and Hepatitis B infection	3	6 weeks, 10weeks, 14weeks of age	Intramuscular (IM)	Left upper anterolateral(outer) thigh in infants and children	Liquid
Tetanus Toxoid containing vaccine(Td/TT)	Tetanus	5	1st dose 2nd dose-at least 4 weeks of 1st dose 3rd dose- at least 6 months of 2nd dose 4th dose- at least 1 year of 3rd dose 5th dose- at least 1 year of 4th dose	Intramuscular (IM)	Deltoid muscle (upper arm) of adult	Liquid

Pneumococcal conjugate vaccine (PCV)	Pneumococcal disease	3	6 weeks, 10weeks, 14weeks of age	Intramuscular (IM)	Right anterolateral(outer) thigh in infants and children	Liquid
Rotavirus Vaccine (RV)	Rotavirus gastroenteritis	2	6 weeks, 10weeks of age	Oral	Mouth	Freeze-dried powder
Measles vaccine (MV)	Measles	2	At 9 months, 18 months of age	Subcutaneous(S)	Left upper arm	Freeze-dried powder
Measles Rubella (MR) vaccine	Rubella	2	At 9 months, 18 months of age	Subcutaneous(S)	Left upper arm	Freeze-dried powder
Yellow fever vaccine (YF)	Yellow fever	1	At 9 months of age	Subcutaneous(S) Or Intramuscular (IM)	Right upper arm Anterolateral outer thigh	Freeze-dried powder
Meningococcal Conjugate vaccine (Men A)	Meningococcal Disease(Meningitis)	1	At 9 months of age	Intramuscular (IM)	Left upper anterolateral(outer) thigh in infants and children	Freeze-dried powder
Human Papillomavirus vaccine(HPV)	Cervical cancer	2	At 6 months interval between ages 9 to 14 years	Intramuscular (IM)	Deltoid muscle of upper arm	Liquid

Source:(Immunization Action Coalition, 2009; National Primary Health Care Development Agency, 2017)

4.2 Vaccine categorisation framework for the case study

For the framework development, there are thirteen vaccines and the work characteristics which are elements of work requirements are age of vaccinee and the level of literacy, route of administration, vaccine preparation. Age of vaccine is essential estimating determining the work requirement for "positioning for vaccination" task. Age of vaccinee would be categorized into children(C), adolescent(T) and adult(A). Level of literacy of vaccinee or caregiver determines the work requirement for pre-vaccination tasks such as Registration and education. Level of education is either literate(X) or illiterate(Y). Route of administration for the case study are Intramuscular (IM), Subcutaneous(S), Intradermal (ID), and Oral (O). Vaccine forms determine its preparation for administration. Vaccines are presented for administration as pre-filled manufactured syringes (P), liquid vaccine(L), and reconstituted vaccine(R). The framework for the case study is depicted in Table 3.

Table 3. Framework for categorization of vaccine for routine immunization in Nigeria

Vaccine j	**Work Requirements, G**												**Environment k**
	Route of Administration				**Vaccine Preparation**			**Age of Vaccinee**			**Level of Education**		
	IM	**ID**	**S**	**O**	**P**	**L**	**R**	**C**	**T**	**A**	**L**	**Y**	
BCG		√					√	√					Health facility
OPV				√		√		√					
IPV	√					√		√					
Hep B	√					√		√					
Penta	√					√		√					
Td/TT	√					√				√			
PCV	√					√		√					
RV				√			√	√					
MV			√				√	√					
MR			√				√	√					

YF	√		√				√	√					
Men A	√						√	√					
HPV	√					√			√				

The vaccines grouped based on the age of vaccinee shows that 11 out of 13 vaccines are for children. This helps defines age as a key work characteristic in defining the work requirements of the vaccination task. It suggests the workload for task such as positioning for administration can be estimated for different age group class and this will ease the estimation of workload for such task and in the long run, becomes a useful planning tool for workforce sizing. It was also noted from the framework in Table 3 that majority of the vaccines are for children. This so because the study considers only vaccine for routine immunization which is targeted at preventing death of children under the age of five. The only vaccine for adult is for women of childbearing age to prevent maternal and neonatal tetanus infection and HPV to prevent cervical cancer in girls.

Level of literacy is another key work characteristic that helps in defining work requirements for pre-vaccination task such as registration and education of vaccine and caregiver. The level of literacy determines the work requirement for such task and helps to group patient or caregiver based on their literacy level to estimate the workload for such task for two categories of education. Determination of workload is made easier when the work requirement is defined based on literacy. It is seen from the framework that 8 of the vaccines require intramuscular injection as a route of administration. The vaccines are Hepatitis B, Pentavalent, Pneumococcal Conjugate Vaccine, Inactivated Polio Vaccine, Meningococcal Conjugate vaccine, Yellow fever, Human Papillomavirus vaccine and Tetanus Toxoid containing vaccine. Bacillus Calmette-Guerin is the only vaccine in the schedule that requires intradermal injection. Subcutaneous injection for Measles, rubella and yellow fever vaccine. the route of administration for oral polio vaccine and rotavirus vaccine are oral through the mouth. Vaccines and their route are shown in Figure 3. This grouping of vaccine based on route of administration helps in clearly defining that the vaccines with the same route of administration have similar work requirement and this will aid the estimation of workload for the task.

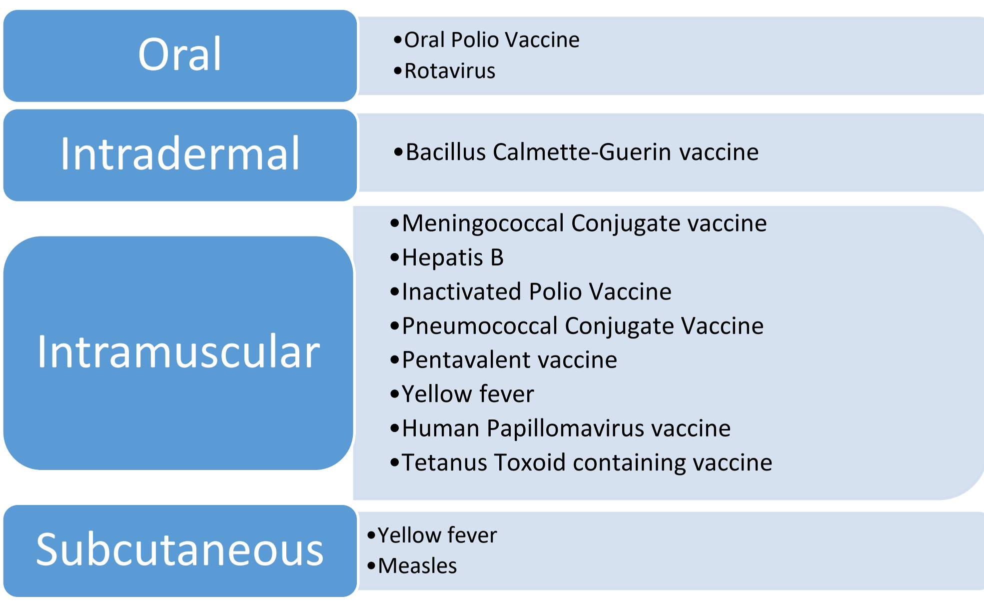

Figure 3. Vaccines and their routes of administration

Another key work characteristic that defines the work requirement is the vaccine preparation. This work characteristics group vaccine based on how it will be prepared for administration. It can be that 6 vaccines require reconstitution before administration and 7 vaccines which are in liquid form are prepared for administration by drawing the required doses into the syringes as shown in Figure 4. This grouping defines the work requirement and this aids the estimation of workload for that task.

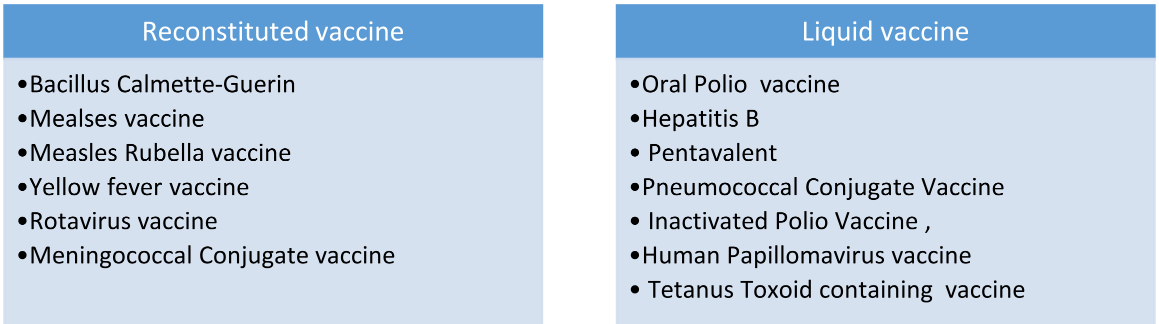

Figure 4. Vaccine classified based on vaccine preparation for administration

It was observed from the framework in Table 3 that no vaccine comes in pre-filled syringes. Non-available of pre-filled syringes for routine immunisation may be due to large space requirements. Pre-filled syringes have many advantages such as simple and easy to use, reduction in workflows for vaccination and it reduces the risk of non-compliance to best practices but the space requirement and other logistics problem in Nigeria might pose a challenge in its deployment for vaccination. It can be seen from the framework that vaccine with the same work characteristics can be grouped in that they will require the same work requirement for any vaccination task been considered for. Vaccine with the same route of administration will have the same procedure for administration of vaccine and the same work requirement except for the difference due to the age of vaccine. And also in some other tasks such as registration and education, the level of literacy of vaccine or caregiver goes a long way in defining the work requirement. This framework will help in quick estimation of workload of vaccination based on the grouping concept of work characteristics. One of the limitation of work content estimation is that it is time consuming but this framework will make the estimation less time consuming**.**

5. Conclusion

The study addresses the mismatch between the demand for vaccination and healthcare workforce size by developing a framework for categorization of vaccine based on work requirement to aid estimation of vaccination workload. The framework is illustrated by vaccines available for routine immunization as a case study which are tuberculosis, poliomyelitis, tetanus, measles, pertussis, diphtheria. hepatitis B, rotavirus, pneumococcal disease, rubella, yellow fever, meningitis, haemophilus influenza type b disease and cervical cancer. The framework helps in the grouping of vaccines with similar work requirements together thus aiding the vaccination workload estimation. It can be seen that the framework employs the concept of group technology in categorizing the vaccines and will be useful in planning and management of vaccination workforce sizing.

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