

Comprehending the Dynamics of Multiple Newer Vaccine Introductions and Uptake in A High-Volume Private-Sector Model Immunization Clinic

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ABSTRACT

Introduction: Besides routine Universal Immunization Program (UIP) vaccines, the Indian Academy of Pediatrics Advisory Committee on Vaccines and Immunization Practices (IAP-ACVIP) has periodically recommended several additional non-UIP vaccines based on updated clinical evidence, for private sector practice in India, procurable out-of-pocket. While there are examples of 'individual new vaccine' post-introduction evaluations into existing immunization schedules, a hypothetical analysis of the dynamics of 'multiple new vaccine' introductions in quick succession - as recommended by the IAP-ACVIP, together with robust statistical data substantiating such analysis, is currently unavailable in India.

Materials and Methods: This paper tracks the chronology of successive introduction of several newer vaccines (as single/multiple doses and routine/optional) into existing IAP-ACVIP schedules, enumerates factors influencing their uptake, and captures data and time trends following their introduction into a high-volume community-level model immunization clinic catering exclusively to pediatric vaccination in a private sector tertiary care institution. All data presented and analysed are from manually entered, internally computed, and computerized records from years 2003 -2019.

Results: Newly introduced vaccines that find timeslots in an already existing schedule would disproportionately affect first, the overall number of injections delivered; whereas those that do not find such timeslots, on the contrary, would first disproportionately affect the overall number of child visits. Successive introduction of multiple vaccines with multiple schedules would shift the progression of the total number of child visits and the total number of injections delivered from the so-called 'first order' towards 'zero order' kinetics.

Conclusion: Understanding vaccine uptake dynamics would facilitate better programmatic preparedness for budget outlines towards vaccine supply and cold chain infrastructure, training and manpower for vaccine delivery and documentation, expected rates of adverse events following immunization, among others.

Keywords: Advisory Committee on Vaccines and Immunization Practices, Dynamics, India, Indian Academy of Pediatrics, New vaccine introduction, Private sector.

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Crossref Doi: <https://doi.org/10.36437/irmhs.2026.9.3.B>

Introduction

The World Health Organization's Expanded Programme on Immunization (EPI), launched in India in 1978 and renamed the Universal Immunization Programme (UIP) in 1985, provides essential vaccines free-of-cost, with its primary focus on public health impact. The National Technical Advisory Group on Immunization (NTAGI) established in 2001, acts as India's apex scientific advisory body, providing evidence-based recommendations to the Government of India on new vaccine introduction into UIP.¹

The Indian Academy of Pediatrics (IAP), the primary professional association for pediatricians in India, was established in 1963. The IAP immunization schedule, designed for private practitioners' office practice, is more comprehensive, covers not only all UIP vaccines but also additional non-UIP vaccines based on updated clinical evidence, and is typically availed of, at personal cost.^{2,3}

The subcommittee of IAP entitled "entitled "IAP Advisory Committee on Vaccines & Immunization Practices (ACVIP)" first formed in 1986, published the "Blue Book of IAP" entitled "Immunity Immunization and Infectious Diseases" in 1994, "Guidebook of Immunization" in 1997 and the IAP Policies, Recommendations and Guidelines in 2001.⁴ Following this, the IAP schedule for pediatric vaccination has been revised several times by the IAP's ACVIP. A plethora of vaccines have been introduced and then made routine in subsequent schedules.

In the UIP prior to 2014, the Japanese Encephalitis vaccine (JE) in endemic districts, Hepatitis-B (Hep-B), and Haemophilus influenza vaccine (Hib) as a Pentavalent vaccine containing DPT, Hep-B and Hib were introduced. Since 2014-18, new vaccines - Pneumococcal Conjugate Vaccine (PCV), Inactivated Poliovirus Vaccine (IPV), Oral Rotavirus vaccine, Measles Rubella (MR) vaccine, and Tetanus with reduced Diphtheria toxoid vaccine (Td) have been introduced into the UIP.²

However, several other newer vaccines such as Human Papilloma Virus vaccine (HPV), Typhoid Conjugate Vaccine (TCV) despite having been recommended for

inclusion into UIP by NTAGI; and Hepatitis A vaccine (HAV), Influenza, Varicella, and others, despite recommendation by the Indian Academy of Pediatrics Committee on Immunization (IAPCOI) with documented high public demand in private sector immunization practice, thus far remain vaccines not included in UIP routine immunization schedule.^{2,3}

Objective

From the perspective of a vaccine provider, there are several examples of post introduction evaluations of individual vaccines such as Hepatitis B (Hep-B) and Haemophilus influenzae type b (Hib) vaccine.⁵ Also, a systematic review has documented the impact of several individual new vaccine introductions, each as a routine or for high-risk group vaccine, mostly in high-income countries, on immunization and health systems.⁶

For a single or a few vaccines introduced programmatically in a defined, circumscribed population/community/country, where data on historical vaccine consumption, birth cohort, immunization coverage, vaccine hesitancy scores, and seasonality, along with campaign rates for epidemics, are readily available and well quantified, vaccine demand forecasts are critical in managing supply, informing manufacturers, and ensuring vaccine availability in low-income countries. For example, Gavi, the Vaccine Alliance, uses two primary types of vaccine demand forecasts: Strategic Demand Scenarios (SDS) for long-term, vaccine-specific planning, and the Base Demand Forecast (BDF) for baseline market needs.⁷

However, a hypothetical analysis of the dynamics of introduction of multiple newer vaccines in quick succession - as optional, routine, single dose or multiple dose schedules into an existing vaccination schedule as recommended by the IAPCOI, or even in a more calibrated manner by the NTAGI, its implications on the overall number of child visits data and the number of injections delivered, together with robust statistical data corroborating such analysis, is currently unavailable in India.

This paper tracks the chronology of the introduction of newer vaccines into the IAP immunization schedule, enumerates factors influencing their uptake, and captures data and time trends following the introduction of several newer vaccines into the Well Baby Immunization Clinic -- a high-volume, community-level model immunization clinic catering exclusively to pediatric vaccination in Christian Medical College, Vellore, South India, from its origin as a provider of 4 EPI vaccines to its current status as the country's largest private vaccine provider by volume of EPI and non- EPI vaccines delivered.^{3,8}

An understanding of the dynamics of such introduction would be fundamental to predict budget outlines, sufficiency of cold and dry storage capacities, vaccine and immunization supply for routine and catch-up campaigns, requirement of training and manpower for vaccine delivery and documentation, expected rates of adverse events following immunization, waste management, among others.

Materials and Methods

All data presented in this manuscript are from manually entered, internally computed, and computerized records maintained in the Well Baby Immunization Clinic since its inception. Special emphasis is ascribed to data from years 2003 -2019 which best capture the time trends of the introduction of newer vaccines as combination, optional and routine vaccines and its repercussions on the overall number of child visits data.

Chronology of Introduction of Newer Vaccines into the IAP Immunization Schedule by the IAPCOI/ACVIP

2001-2006

In the 2001 IAPCOI Guidebook on Immunization, the IAP recommended non-UIP routine vaccines included **Measles Mumps and Rubella vaccine (MMR), Typhoid Vi polysaccharide, Hib, Hep-B, and Tetanus and reduced Diphtheria vaccine (Td)**; while **Varicella** and **HAV** were additional vaccines above one and two years of age respectively.⁹ By 2006, the IAP recommended non-UIP routine vaccines to be given after one-to-one discussion with parents including **PCV 7** and **Diphtheria, Tetanus and acellular Pertussis vaccine (DTaP)**.¹⁰

2008

In its Consensus Recommendations on Immunization (2008), the IAPCOI recommended offering the affordable class.

- (i) **Tdap** vaccine instead of Td/TT vaccine to all children/ adolescents aged 10-12 years;
- (ii) HPV vaccine as a three-dose schedule to all females aged 10-12 years;
- (iii) IPV in addition to Oral poliovirus vaccine (OPV) in all children at the age of 6, 10, and 14 weeks, and a booster at 15-18 months.

The committee also recommended **two doses of MMR** vaccine, the first dose at 15 months and the second at 5 years; and the administration of **Typhoid Vi polysaccharide vaccine** every three years beginning at the age of 2 years till age 18 years.

Vaccines recommended to be given after one-to-one discussion with parents were Oral **Rotavirus vaccine** and PCV 7 beyond 6 weeks of age, Varicella vaccine beyond 15 months as a single dose; and HAV as a two-dose schedule starting at 18 months of age.¹⁰

2009-11

IAP recommended vaccines in the 2009-11 (2011) routine schedule were BCG, OPV, IPV, DTwP/DTaP, DT, Td / Tdap, Measles, Typhoid, Hib, Hep B, MMR, and HPV; with **PCV, HAV, Varicella vaccine and Oral Rotavirus vaccine also finding their place in the schedule as routine vaccines**. The varicella vaccine was made routine with 2 doses: the first at 15 months and the second at 5 years.

The first dose of HAV was moved from 18 months to 12 months of age and the second dose to 18 months from 2 years of age.¹¹

2012

In its 2012 Consensus Recommendations, the IAPCOI abolished the earlier categorization of vaccines into four categories in favour of only two categories: one, the vaccines for routine use; two, the vaccines to be used in special circumstances only.^{12,13} **The third dose of HBV was shifted** from 14 weeks of age to 6 months of age and beyond.¹³

2013

As per the 2013 schedule, the 6 weeks slot included DTwP1, IPV1, Hib1, Hep-B2, Oral Rotavirus and PCV 1; the 15 month slot included MMR1, Varicella and PCV booster and the 5 year slot, DTwP B2 / DTaP B2, OPV5, MMR2, Typhoid Vi polysaccharide 2 and Varicella 2.¹⁴

2014

The 2014 Consensus Recommendations have introduced 'Typhoid Conjugate Vaccine' (TCV) at 9-12 months of age and at 2 years of age, while also advocating two doses of MMR at 9 and 15 months, no standalone measles dose at 9 months or MMR at 4-6 years of age, single dose administration of live HAV vaccine at 12 months and two doses of HPV vaccine for adolescent/preadolescent girls aged 9-14 years.¹⁵

2016

The 2016 IAP ACVIP schedule recommended three doses of MMR vaccine at 9 months, 15 months, and between 4-6 years of age.¹⁶

2018-19

The IAP 2018-19 Immunization schedule accepted four doses of Hep-B vaccine if a combination pentavalent or hexavalent vaccine is used, IPV as at least two fractional doses at a government facility at 6 and 14 weeks or at least one dose of intramuscular IPV at 14 weeks. Inactivated influenza vaccine (either trivalent or quadrivalent) (IIV) was recommended annually to all children between 6 months to 5 years of age. Single dose of Typhoid conjugate vaccine (TCV) was recommended from age of 6 months and beyond, with co-administration with MMR vaccine at age of 9 months.¹⁷

Factors Influencing the Uptake of a Newly Introduced Vaccine

- **Nature of the recommendation:** Optional or Routine.
- **Cost of the vaccine:** Data from the archives of Well Baby Immunization Clinic, indicate that MMR, Varicella vaccine as a single dose, HAV, IPV, Typhoid and PCV vaccines were more widely accepted vaccines; compared to HPV and PCV in the introductory phase, due to prohibitive costs.
- **Age of administration:** The age of recommendation of these vaccines is an important consideration, with vaccines recommended at younger age groups (HAV, first dose of Varicella vaccine) finding greater acceptance than those recommended for older age groups (HPV, second dose of Varicella vaccine, Tdap). This is similar to the trend seen with routine EPI vaccines in India and worldwide.¹⁸
- **Phenomenon of 'Saturation kinetics':** In practice, the usual maximum number of injections that are given per child per day is TWO. The third injectable vaccine (usually the costliest of the three) spills over to the next or a separate visit¹⁹, either due to parental apprehension or the combined cost of the three vaccines or both. Unlike injectable vaccines, oral vaccines such as Oral Rotavirus vaccine are well accepted during the same visit.
- **Single vaccine integration into combination vaccines:** Hib vaccine, initially available as a single vaccine was widely dispensed in the private sector. The effect of Hib distribution in the private health care sector on Hib meningitis admissions in our institution from 1997 through 2005 during which it was initially dispensed as a single dose and subsequently integrated into combination as pentavalent vaccine has been previously published.²⁰
- **Nonavailability of appropriate combination vaccines:** Unlike in developed countries^{21,22}; in India, during the studied time period, despite instances where the two vaccines appeared at the same timeslot in the IAP routine schedule
 - 1) No combination of DTaP/DPT, Hib, IPV with HBV existed.²²
 - 2) No combination of MMR with Varicella existed.²¹
- **Number of doses and visits:**
Categorisation of newer vaccines: Vaccines that have been added to the IAP schedule at various points to eventually become routine vaccines could be characterised into
 - 1) Those with a double dose schedule (MMR, Varicella vaccine, HAV, Typhoid conjugate vaccine).

- 2) Those with multiple dose schedules (IPV, PCV, Oral Rotavirus vaccine, HPV, Typhoid Polysaccharide vaccine).
- 3) Those whose doses fitted into timeslots already occupied by another single vaccine/combination (IPV, PCV, MMR, Varicella).
- 4) Those whose doses needed an exclusive timeslot for themselves (3rd dose HBV, 2 doses of HAV, 2/3 doses of HPV).
- 5) Those whose doses were practically deferred to a different timeslot despite a shared originally recommended timeslot with another vaccine, due to reasons mentioned earlier (PCV, Varicella 2nd dose).

Predicting the Dynamics of Newer Vaccine Introduction

(a) When vaccines that have a single or double dose schedule, fitting into a slot already occupied by another single vaccine or combination, are added to the existing schedule, the rise in 'individual vaccine data' is disproportionately higher than the rise in the overall number of child visits, which would rise after a time lag.

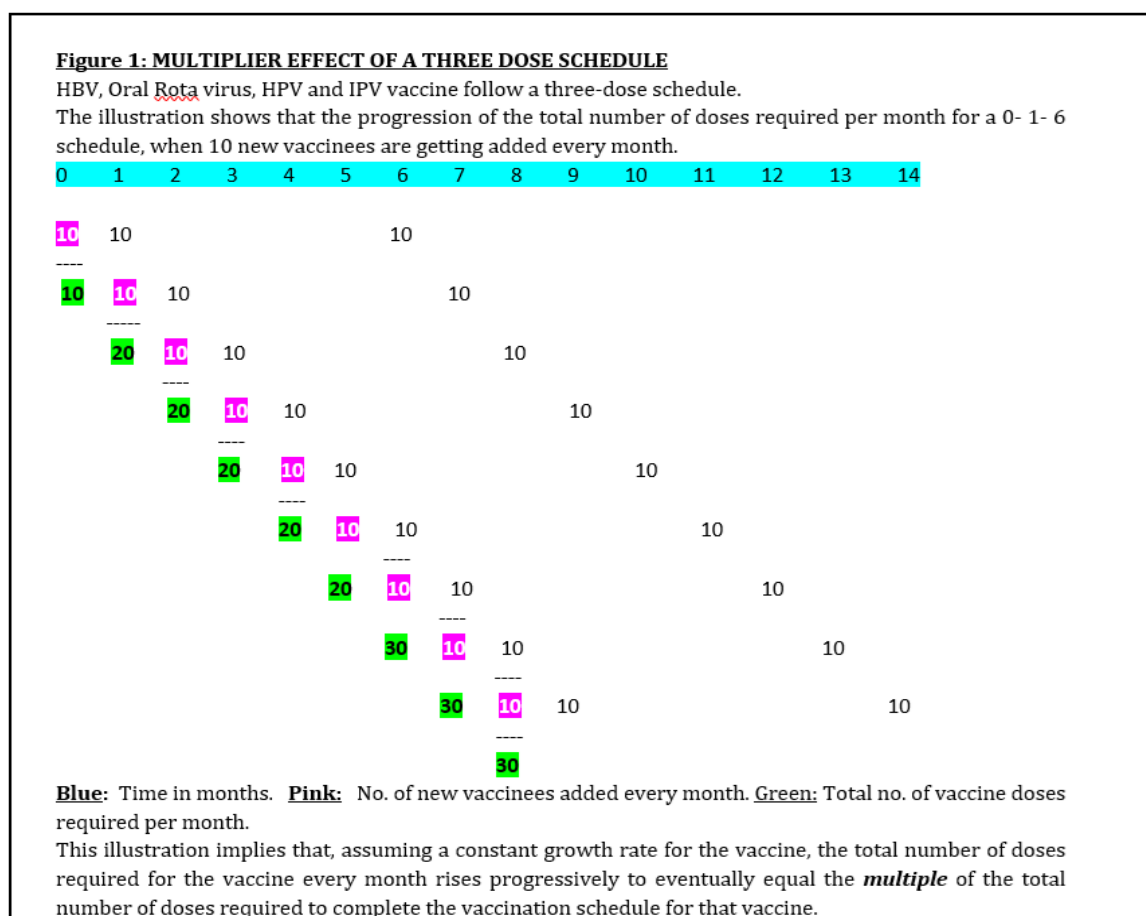
(b) Addition of Newer Vaccines each with a 2 dose, 3 dose or 4 dose schedules in rapid succession would lead to a multiplier effect on the overall number of child visits data and in the number of injections delivered, depending on the slots they occupy within the schedule.

The Multiplier Effects of

(1) A 3-dose schedule

(2) A 2 and 4 dose juxtaposed schedule

are depicted with illustration and explanation. (Figure 1, Figure 2)



The schedule for Hib vaccine and PCV vaccines are shown in the Box below.

Hib	6 weeks to 6 months	3 dose primary series	18 months	Booster
	6 months to 12 months	2 dose primary series	18 months	Booster
	12 months to 15 months	1 dose primary	18 months	Booster
	>15 months	Single dose		
PCV	6 weeks to 6 months	3 dose primary series	15 months	Booster
	6 months to 12 months	2 dose primary series	15 months	Booster
	12 months to 24 months	2 doses	2 months apart	
	>24 months	Single dose		

A simpler approximation for both schedules would be

A <1 year - 3 doses and booster at 18 months (Total 4 doses)

B >1 year – 2 doses 2 months apart (Total 2 doses)

Mean of the total number of doses in schedule A and B = $(4+2)/2 = 3$ doses.

Approximation A – Routine schedule

Approximation B – Catch up schedule

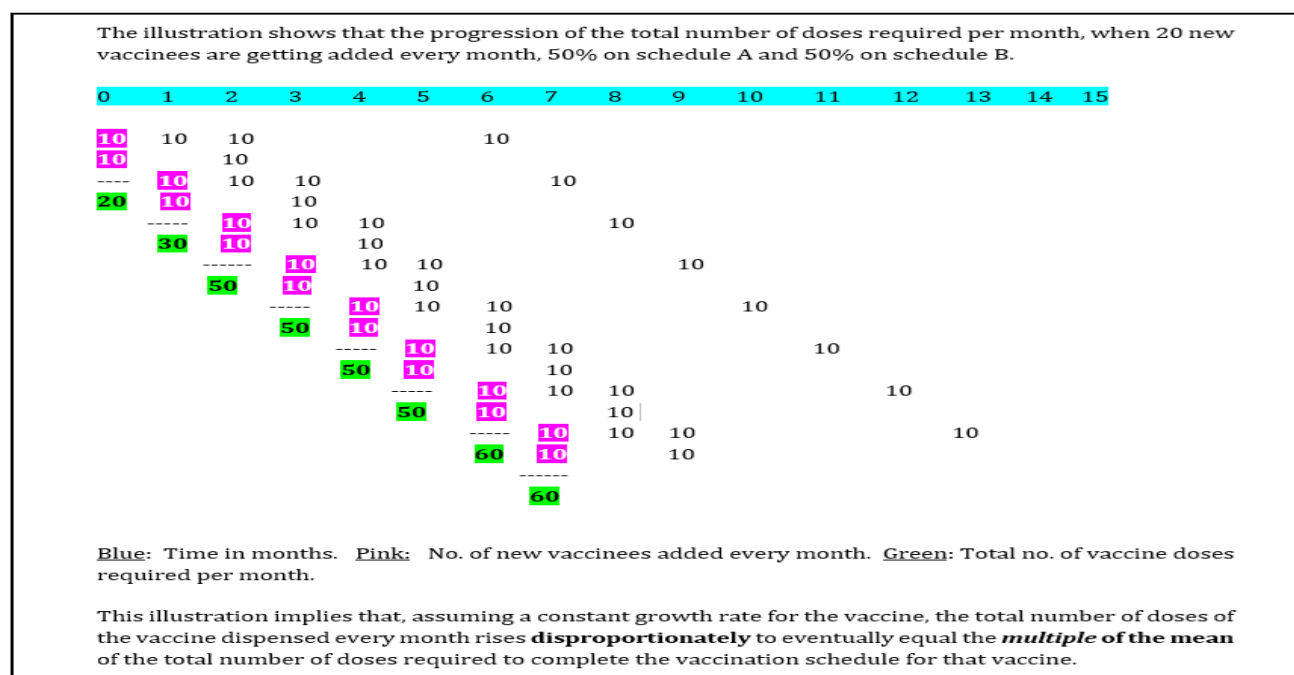


Figure 2: Multiplier effect of A 2-4 Juxtaposed schedule.

Aggregating the factors explained above, it would follow that, as more vaccines with multiple doses are added in quick succession to the existing vaccination schedule and assume significant proportions in the vaccines delivered overall-creating a “multiplier effect”, the time lag between the rise of individual vaccine data and its reflection on the overall number of child visits data and in the total number of vaccines delivered, would be expected to decrease disproportionately with each successive vaccine, to eventually contract into oblivion- akin to the pharmacodynamic shift from the so called ‘first order’ towards ‘zero order’ kinetics.

The above models could be extrapolated to account for a multiplier effect on the number of child visits and injection number data by multiple newly introduced vaccines, each following a multiple dose schedule.

Newer vaccine introduction timelines and the disaggregated numbers of individual new vaccines given from 2003 to 2019 in Well Baby Immunization clinic have been previously published.³

Briefly, the clinic began administering HBV and MMR in the mid-1990s, Typhoid-Paratyphoid (TAB) vaccine in 1996 and Typhoid Vi polysaccharide (Typhoid) vaccine in 2001, Hib

vaccine in 1997, Varicella vaccine in 1999, Hepatitis A vaccine (HAV) in 2000, and pentavalent vaccine in 2003. The Clinic began offering PCV and influenza (Flu) vaccines in 2007, IPV in 2008, Oral Rotavirus and HPV vaccines in 2012, and Typhoid Conjugate Vaccine in 2017 in place of typhoid Vi polysaccharide vaccine.³

The uptake of "New vaccines" increased from 8,333 in 2003 to 1,10,783 in 2015, whereas that of EPI vaccines remained comparatively stable, ranging from 44,684 to 70,499. The most sought-after new vaccinations were MMR, Typhoid, HAV, and Varicella from 2006 to 2012, and then influenza starting in 2014 until 2020.^{3,8}

Observed Impact of the Dynamics of Newer Vaccine Introduction on the Overall Number of child Visits.

Taking into consideration the inferences listed above, the effect of introduction of newer vaccines falling into different categories, in the backdrop of a steadily rising vaccinated cohort, had the following impact on the overall number of child visits and the number of injections delivered in the clinic during the period from 2003-19 in the Well Baby Immunization Clinic. This period is subsequent to establishment of a computerised data capture system (2003) and prior to ‘COVID-19 confounding effect’ (2020).

Year	Total Number of Child Visits	Total Number of Injections Delivered
2003	46451	65729
2004	48101	68631
2005	49090	67307
2006	52383	68948
2007	54426	75002
2008	59255	89840
2009	67768	92057
2010	74583	100380
2011	75945	101804
2012	80248	112466
2013	82499	130587

Table 1: Total number of child visits and total number of injections delivered through years 2003 to 2013.

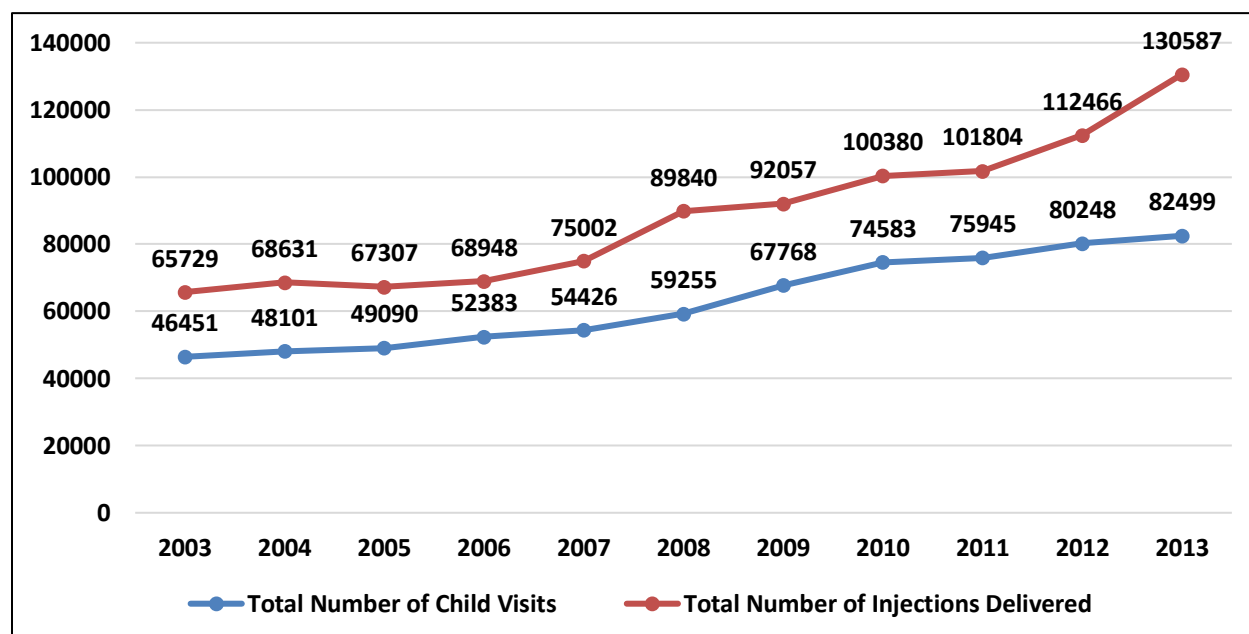


Figure 3: Trendlines depicting total number of child visits and total number of injections delivered from 2003 to 2013.

For the period 2003 to 2013, Figure 3 shows that there is an overall increase seen both the number of injections and in the overall number of child visits due to the increasing number of children entering the vaccinated cohort, in tandem with an increasing number of children in the existing

vaccinated cohort, being vaccinated with optional vaccines. When viewed in context, the percentage rise in the overall number of child visits is comparable to the percentage rise in the number of injections during the first phase prior to 2007 (17.95% vs 14.11%). (Figure 4)

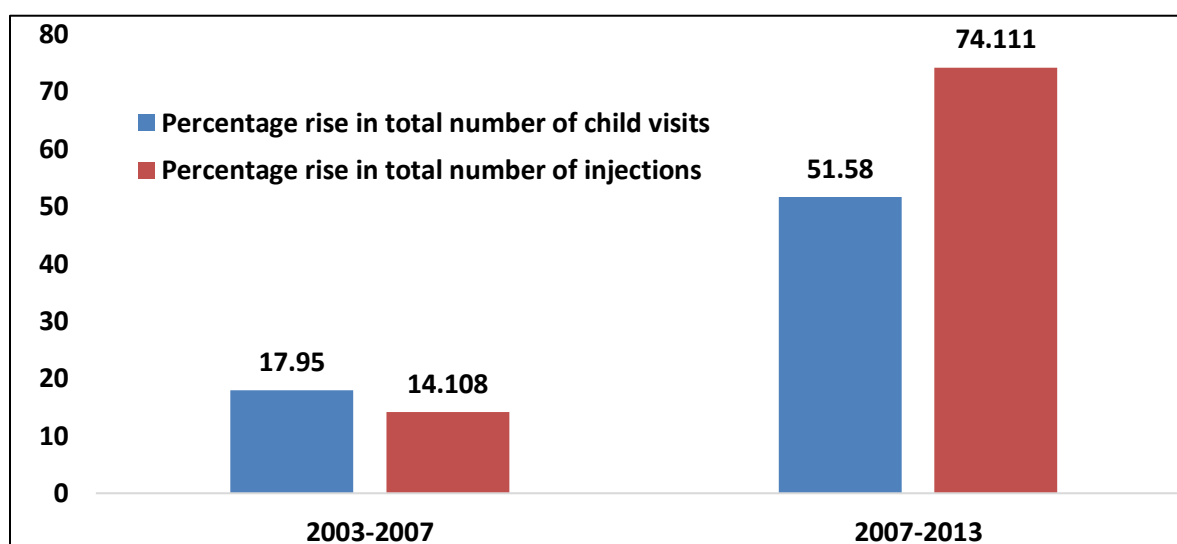


Figure 4: Comparison of percentage rise in total number of child visits with the total number of injections delivered during the period 2003 to 2007 versus 2007 to 2013.

The data for HAV and Varicella vaccine and the overall number of child visits when juxtaposed with the overall number of child visits and compared for the entire time period 2003-2007

shows a mercurial rise for HAV and Varicella Vaccine data from the start, followed by a more sedate rise in overall number of child visits data. (Figure 5, Table 2)

Year	Hepatitis A Vaccine	Varicella vaccine	Total number of child visits
2003	1148	101	46145
2004	1129	715	48101
2005	2169	1697	49090
2006	4284	2671	52383
2007	5657	3175	54426
2008	6182	3492	59255
2009	7150	4544	67768
2010	9869	4549	74583
2011	9176	5487	75945
2012	11031	6191	80248
2013	11467	6287	82499

Table 2: Total number of child visits and disaggregated number of Hepatitis A and Varicella vaccine through years 2003 to 2013.

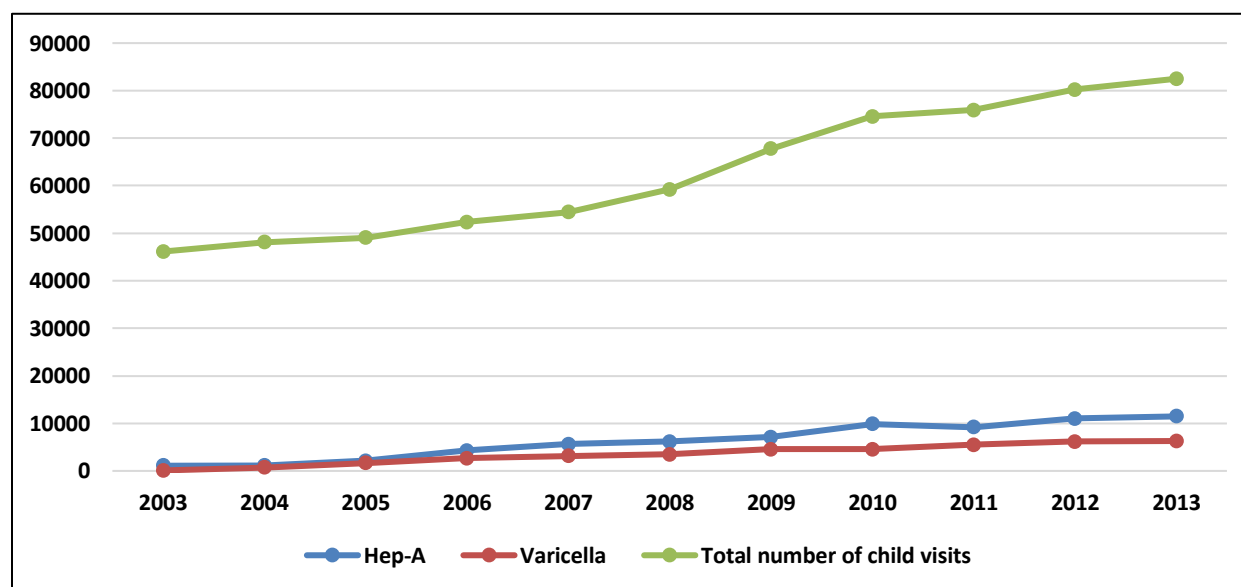


Figure 5: Overall number of child visits versus Hepatitis a Vaccine and Varicella vaccine doses.

This lag could be attributed to the fact that the pre-2007 IAP schedule had only 4 important Non-UIP Routine IAP recommended vaccines HAV, Typhoid, MMR and Varicella.²² A significant proportion of HAV doses were given with Typhoid Vaccine as a 2nd Vaccination on the same day at 2 years of age, and Varicella was mostly given simultaneously with MMR at 15 months.

However post 2007, with the regularization of Varicella and HAV, addition of newer Vaccines IPV, DTaP, PCV, Flu vaccine, Oral Rota Virus and HPV at various points of time, each with a 2 dose, 3 dose or 4 dose schedule, the displacement of vaccines to form new timeslots such as HBV and HAV, and the increase in frequency of doses of already existing vaccines such as Typhoid and Varicella, the overall number of child visits data and the total number of injections delivered can be seen to be progressively shifting from first order kinetics towards Zero order kinetics, as deduced earlier.

The earlier trend of the overall number of child visits rising in tandem with the overall number of injections delivered, when only a few important Non-UIP Routine IAP recommended vaccines with single or two dose schedules were present before 2007, is seen to reverse in the period 2007-2013.

The overall number of injections delivered during the period shows a rise of 74.11%, which is markedly higher than the 51.58% rise in the overall number of child visits during the same period. These numbers reflect the widespread acceptance of administration of simultaneous multiple vaccines, which were introduced in the period from 2007-2010, within the vaccinated community.

From 2014 to 2019, flu vaccine uptake witnessed a mercurial rise from about 7500 to over 33000. PCV also witnessed a similar spectacular rise from 2016 to 2019. MMR vaccine numbers peaked earlier in 2013, Varicella peaked in 2016, while IPV peaked in 2015 after it was reintroduced in 2014 as a catch-up schedule after one year of age in OPV-primed children²³ -- as two doses two months apart requiring at least one additional scheduled visit. This was followed by an acute short supply of IPV thereafter in 2016. In the infant primary series, PCV programmatically filled in the space vacated by the non-availability of IPV post 2016. Table 3 and Figure 6 show that the overall number of child visits rises in tandem with the Flu vaccine and IPV vaccine uptake from 2014 to 2019, but is relatively less perturbed by the corresponding rise in other vaccines, such as PCV.

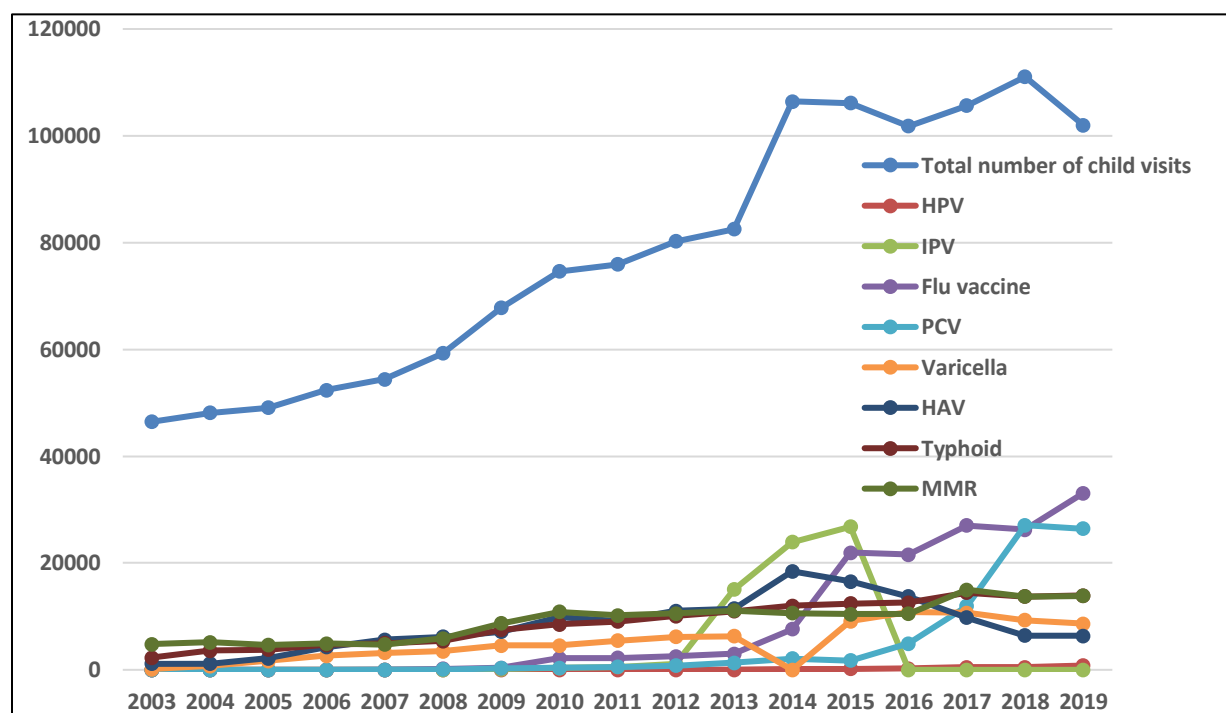
Year	Total number of child visits	HPV	IPV	Flu vaccine	PCV	Varicella	HAV	Typhoid	MMR
2003	46451	-	-	-	-	101	1148	2302	4782
2004	48101	-	-	-	-	715	1129	3579	5157
2005	49090	-	-	-	-	1697	2169	3785	4648
2006	52383	-	-	-	-	2671	4284	4666	4892
2007	54426	-	-	10	26	3175	5657	4964	4730
2008	59255	-	20	198	70	3492	6182	5422	5892
2009	67768	-	135	381	298	4544	7150	7468	8666
2010	74583	-	335	2142	362	4549	9869	8485	10824

2011	75945	-	567	2236	532	5487	9176	9043	10164
2012	80248	6	1065	2499	768	6191	11031	10044	10577
2013	82499	34	15020	3011	1339	6287	11467	10967	11063
2014	106409	116	23920	7589	2075	3907@	18447	11960	10591
2015	106130	167	26785	21945	1742	9085	16528	12382	10439
2016	101808	239	78@	21589	4946	10817	13711	12584	10484
2017	105636	470	0	27007	11936	10691	9756	14428	15004
2018	111045	501	0	26248	27087	9292	6438	13726	13719
2019	102000	801	0	33078	26423	8618	6333	13930	13855

@ Acute short supply throughout India.

Table 3 depicts the total number of child visits and disaggregated numbers of newer vaccines: HPV (Human Papillomavirus Vaccine), IPV (Inactivated Poliovirus Vaccine), Flu (Killed Influenza Vaccine), PCV (Pneumococcal Conjugate Vaccine), Varicella vaccine, HAV (Hepatitis A Vaccine), Typhoid and MMR (Measles Mumps Rubella)

Table 3: Total number of child visits and newer vaccines through years 2003 to 2019.



The annual disaggregated numbers and trendlines of individual 'newer vaccines'- HPV (Human Papillomavirus Vaccine), IPV (Inactivated Poliovirus Vaccine), Flu (Killed Influenza Vaccine), PCV (Pneumococcal Conjugate Vaccine), Varicella vaccine, HAV (Hepatitis A Vaccine), Typhoid and MMR (Measles Mumps Rubella) administered from 2003 to 2019.

Figure 6: The annual disaggregated numbers and trendlines of individual 'newer vaccines' from 2003 to 2019.

Discussion

Newer vaccines' uptake has progressively rivalled and exceeded EPI vaccines' uptake in the Well Baby Immunization Clinic since the last two decades.^{3,8} Given the increasing awareness of the benefits of vaccination in the community leading to widespread acceptance of newer vaccines over relatively short periods of time, introduction of such vaccines should be in consonance with a better understanding of its dynamics on the overall vaccinated cohort.

The vaccines introduced or made routine as per successive IAP schedules post-2007 have mostly found their niche in spots in the schedule where one vaccine already existed or where two of these could be administered simultaneously (HAV with Typhoid first dose, Varicella first dose with MMR, Typhoid second dose with MMR second dose, IPV with penta/quadra valent vaccines). This can be seen to manifest as a disproportionate rise in the year-on-year percentage rise in the number of injections delivered, when compared with the overall number of child visits, notwithstanding a significant rise in both.

Vaccine that would create new slots in the existing schedule, or would need to be given as a separate vaccine due to parental apprehension of delivering more than two injections at the same time (Influenza, PCV) would instead produce a more disproportionate effect in the year-on-year percentage rise in the overall number of child visits than in the year-on-year rise in the number of injections delivered. Other new vaccines such as HPV, which have two/three dose schedules and are currently rising steeply on a low base could be expected to similarly influence the overall number of child visits in the coming years.

Proactive planning across several operational aspects can be made possible by accurate vaccine demand forecasts, which is a fundamental component of an effective immunization program. While predicting the dynamics of successive or simultaneous multiple optional or routine newer vaccine introduction as single or juxtaposed multiple dose schedules can be extremely

challenging, supply chain management could become pre-emptive and cut logistical costs by putting in place a strong forecasting system, powered by data-driven predictive modelling from hitherto available data. The deployment of Artificial Intelligence (AI) technologies presents a promising avenue to enhance the efficiency and effectiveness of vaccine distribution systems.²⁴

Reliable forecasting improves immunization programs by supporting efficient budgeting, preventing vaccine shortages or overstocking, and strengthening cold chain and storage capacity. It also ensures the availability of essential supplies such as syringes and diluents while maintaining stable vaccine distribution across the supply chain.²⁵

Forecasting additionally helps health systems plan workforce requirements by identifying staffing and training needs in advance. It also supports proactive monitoring of Adverse Events Following Immunization (AEFI) by preparing surveillance systems for expected vaccination volumes. Overall, effective forecasting reduces vaccine wastage, improves service delivery, and increases public confidence in immunization programs.

Conclusion

Newly introduced vaccines that find timeslots in an already existing schedule would disproportionately affect first, the overall number of injections delivered; whereas those vaccines that do not find such timeslots, on the contrary, would first disproportionately affect the overall number of child visits. Successive introduction of multiple vaccines with multiple schedules, of both types as stated above, would shift the progression of the number of child visits numbers and the total number of injections delivered from the so called 'first order' towards 'zero order' kinetics.

Comprehending the dynamics of successive newer vaccine introduction as single or juxtaposed multiple dose schedules would facilitate better preparedness for budget outlines, sufficiency of cold and dry storage capacities, vaccine and

immunization supply, requirements for training and manpower for vaccine delivery and documentation, and expected rates of adverse events following immunization, among others. The deployment of Artificial Intelligence (AI) technologies for predictive modelling presents a promising avenue.

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<https://doi.org/10.1016/j.vaccine.2016.05.027>

How to cite this Article: Durai. B, Sherin. V. Cynthia, Saravanarajan, N. A, Kiruthika. S, Sharon Jessica A, Richard. J. P, Robert. M, Kompithra. R. Z; [Comprehending the Dynamics of Multiple Newer Vaccine Introductions and Uptake in A High-Volume Private-Sector Model Immunization Clinic](#); Int. Res. Med. Health Sci., 2026; (9-3): 20-34; doi: <https://doi.org/10.36437/irmhs.2026.9.3.B>

Source of Support: Nil, **Conflict of Interest:** None declared.

Received: 12-06-2026; **Revision:** 15-08-2026; **Accepted:** 28-08-2026