

Universal Tool for Vaccine Scheduling: Applications for Children and Adults

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- The “universal” catch-up scheduling problem
 - Problem description
 - Current paradigm
 - The need for an automated tool
- An integer programming approach
- A dynamic programming (DP) algorithm
- The tool in practice
- Usage and dissemination



Problem Description: The Recommended Childhood Schedule

Recommended Immunization Schedule for Persons Aged 0 Through 6 Years—United States • 2010

For those who fall behind or start late, see the catch-up schedule

Vaccine ▼	Age ►	Birth	1 month	2 months	4 months	6 months	12 months	15 months	18 months	19–23 months	2–3 years	4–6 years
Hepatitis B ¹		HepB	HepB				HepB					
Rotavirus ²				RV	RV	RV ²						
Diphtheria, Tetanus, Pertussis ³				DTaP	DTaP	DTaP	<i>see footnote³</i>	DTaP				DTaP
<i>Haemophilus influenzae</i> type b ⁴				Hib	Hib	Hib ⁴	Hib					
Pneumococcal ⁵				PCV	PCV	PCV	PCV				PPSV	
Inactivated Poliovirus ⁶				IPV	IPV		IPV					IPV
Influenza ⁷							Influenza (Yearly)					
Measles, Mumps, Rubella ⁸							MMR		<i>see footnote⁸</i>			MMR
Varicella ⁹							Varicella		<i>see footnote⁹</i>			Varicella
Hepatitis A ¹⁰							HepA (2 doses)				HepA Series	
Meningococcal ¹¹											MCV	

 Range of recommended ages for all children except certain high-risk groups

 Range of recommended ages for certain high-risk groups

Approved by the Advisory Committee on Immunization Practices (<http://www.cdc.gov/vaccines/recs/acip>), the American Academy of Pediatrics (<http://www.aap.org>), and the American Academy of Family Physicians (<http://www.aafp.org>).

http://www.cdc.gov/vaccines/recs/schedules/downloads/child/2010/10_0-6yrs-schedule-pr.pdf

Problem Description: The Recommended Adolescent Schedule

Recommended Immunization Schedule for Persons Aged 7 Through 18 Years—United States • 2010

For those who fall behind or start late, see the schedule below and the catch-up schedule

Vaccine ▼	Age ►	7–10 years	11–12 years	13–18 years
Tetanus, Diphtheria, Pertussis ¹			Tdap	Tdap
Human Papillomavirus ²		<i>see footnote 2</i>	HPV (3 doses)	HPV series
Meningococcal ³		MCV	MCV	MCV
Influenza ⁴		Influenza (Yearly)		
Pneumococcal ⁵		PPSV		
Hepatitis A ⁶		HepA Series		
Hepatitis B ⁷		Hep B Series		
Inactivated Poliovirus ⁸		IPV Series		
Measles, Mumps, Rubella ⁹		MMR Series		
Varicella ¹⁰		Varicella Series		

Range of recommended ages for all children except certain high-risk groups

Range of recommended ages for catch-up immunization

Range of recommended ages for certain high-risk groups

Approved by the Advisory Committee on Immunization Practices (<http://www.cdc.gov/vaccines/recs/acip>), the American Academy of Pediatrics (<http://www.aap.org>), and the American Academy of Family Physicians (<http://www.aafp.org>).

http://www.cdc.gov/vaccines/recs/schedules/downloads/child/2010/10_7-18yrs-schedule-pr.pdf

Publicly funded Immunization Programs in Canada - Routine Schedule for Infants and Children (including special programs and catch-up programs)

Province/ Territory	DTaP -IPV- Hib	DTaP -IPV	Td, Tdap or Td-IPV	HB	MMR	Var	MMRV	Men-C	Men-C-A, C, Y, W- 135	Pneu -C-7	Pneu -C- 10	Pneu-C- 13	Inf	HPV	Rot
NACI recom- mendation	2, 4, 6, 18 mths	4-6 yrs	14-16 yrs	Infancy (3 doses) OR Pre- teen/teen (2-3 doses)	12 mths AND 18 mths OR 4-6 yrs	12-18 mths (1 dose)	12 mths AND 18 mths OR 4-6 yrs	Infancy (1- 4 doses) ¹ AND Pre- teen (1 dose) ¹	Pre-teen (1 dose) ¹	2, 4, 6, 12 -15 mths	2, 4, 6, 12 -15 mths	2, 4, 6, 12-15 mths	6-23 mths (1 -2 doses)	Females 9-13 yrs (3 doses at 0, 2, 6 mths) ²	2, 4, 6 mths
BC	2, 4, 6 (DTaP - HB- IPV- Hib); 18 mths (DTaP -IPV- Hib)	4-6 yrs	Tdap, Gr. 9	2, 4, 6 mths (DTaP- HB-IPV- Hib); Catch-up Gr. 6 (HB)	12, 18 mths	12 mths, Catch-up 4-6 yrs, Gr. 6		2, 12 mths; Gr. 6				2, 4, (6 HR), 12 mths	6-23 mths	Females Gr. 6, 9	
AB	2, 4, 6, 18 mths	4-6 yrs	Tdap, Gr. 9	Gr. 5	12 mths, 4-6 yrs	12 mths		2, 4, 12 mths		2, 4, 6, 18 mths			6-59 mths	Females Gr. 5; Catch- up Gr. 9 in 2009- 12	

Province/territory specific recommendations were collected by the Canadian Nursing Coalition on Immunization (CNCI).

<http://www.phac-aspc.gc.ca/im/ptimprog-progimpt/table-1-eng.php>

Statistics reported by Luman et al. 2002¹ following the 2000 National Immunization Survey (NIS):

- Only **9%** of children received all recommended vaccines at the recommended ages.
- **55%** of children did not receive all recommended doses by 2 years of age.
- **8%** of children received at least 1 vaccination dose too early to be considered valid.

¹ Luman, E.T., M.M. McCauley, S. Stokley, S.Y. Chu, L.K. Pickering. 2002. Timeliness of Childhood Immunizations. *American Journal of Preventive Medicine* **110**.

Problem Description: Untimely Vaccination

Statistics reported following the 2008 NIS:

For children 19-35 months old ²:

- National coverage rates for the vaccines routinely recommended for children 19-35 months old were reported at **76.1%**
- Coverage among states varied from **59.2%** to **82.3%**.
- Coverage rates for the Hepatitis B birth dose ranged from **19.2%** to **81.4%** between states.

For adolescents aged 13-17 years ³:

- Coverage rates for Tdap, MCV, and at least one dose of HPV were reported at **40.8%**, **41.8%**, and **37.2%**, respectively.
- Only three states had coverage over **50%** for all three vaccines routinely recommended for adolescents.

² CDC. 2009. National, state, and local area vaccination coverage among children aged 19-35 months – United States, 2008. *Morbidity and Mortality Weekly Report* **58** 921-926.

³ CDC. 2009. National, state, and local area vaccination coverage among adolescents aged 13-17 years– United States, 2008. *Morbidity and Mortality Weekly Report* **58** 997-1001.

Reasons often cited for incorrect and untimely vaccination:

- parental **negligence** and **misinformation**
- **incomplete** or **incorrect** schedules constructed by health professionals due to:
 - insufficient knowledge and addition of new vaccines to the lineup, ^{4, 5}
 - problem complexity and tedious process of manual construction.

⁴ LaRussa, P., S. Chen, P. Sternfels, L. Cooper, A. Caesar, M. Ewing, M. Irigoyen, S. Findley. Impact of immunization schedule changes on missed opportunities for vaccination. The 37th National Immunization Conference, Chicago, IL, 2003.

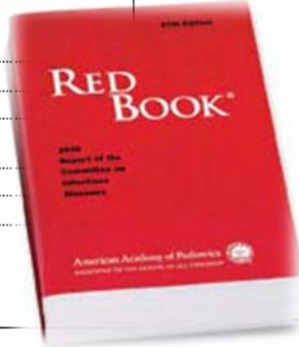
⁵ Cohen, N.J., D.S. Lauderdale, P.B. Shete, J.B. Seal, R.S. Daum. 2003. Physician knowledge of catch-up regimens and contraindications for childhood immunizations. *Pediatrics* **111** 925-932.

Problem Description: The Catch-up Guidelines

Catch-up Immunization Schedule for Persons Aged 4 Months Through 18 Years Who Start Late or Who Are More Than 1 Month Behind—United States • 2010

The table below provides catch-up schedules and minimum intervals between doses for children whose vaccinations have been delayed. A vaccine series does not need to be restarted, regardless of the time that has elapsed between doses. Use the section appropriate for the child's age.

PERSONS AGED 4 MONTHS THROUGH 6 YEARS					
Vaccine	Minimum Age for Dose 1	Minimum Interval Between Doses			
		Dose 1 to Dose 2	Dose 2 to Dose 3	Dose 3 to Dose 4	Dose 4 to Dose 5
Hepatitis B ¹	Birth	4 weeks	8 weeks (and at least 16 weeks after first dose)		
Rotavirus ²	6 wks	4 weeks	4 weeks ²		
Diphtheria, Tetanus, Pertussis ³	6 wks	4 weeks	4 weeks	6 months	6 months ³
<i>Haemophilus influenzae</i> type b ⁴	6 wks	4 weeks if first dose administered at younger than age 12 months 8 weeks (as final dose) if first dose administered at age 12–14 months No further doses needed if first dose administered at age 15 months or older	4 weeks ⁴ if current age is younger than 12 months 8 weeks (as final dose) ⁴ if current age is 12 months or older and first dose administered at younger than age 12 months and second dose administered at younger than 15 months No further doses needed if previous dose administered at age 15 months or older	8 weeks (as final dose) This dose only necessary for children aged 12 months through 59 months who received 3 doses before age 12 months	
Pneumococcal ⁵	6 wks	4 weeks if first dose administered at younger than age 12 months 8 weeks (as final dose for healthy children) if first dose administered at age 12 months or older or current age 24 through 59 months No further doses needed for healthy children if first dose administered at age 24 months or older	4 weeks if current age is younger than 12 months 8 weeks (as final dose for healthy children) if current age is 12 months or older No further doses needed for healthy children if previous dose administered at age 24 months or older	8 weeks (as final dose) This dose only necessary for children aged 12 months through 59 months who received 3 doses before age 12 months or for high-risk children who received 3 doses at any age	
Inactivated Poliovirus ⁶	6 wks	4 weeks	4 weeks	6 months	
Measles, Mumps, Rubella ⁷	12 mos	4 weeks			
Varicella ⁸	12 mos	3 months			
Hepatitis A ⁹	12 mos	6 months			
PERSONS AGED 7 THROUGH 18 YEARS					
Tetanus, Diphtheria/ Tetanus, Diphtheria, Pertussis ¹⁰	7 yrs ¹⁰	4 weeks	4 weeks if first dose administered at younger than age 12 months 6 months if first dose administered at 12 months or older	6 months if first dose administered at younger than age 12 months	
Human Papillomavirus ¹¹	9 yrs	Routine dosing intervals are recommended ¹¹			
Hepatitis A ⁹	12 mos	6 months			
Hepatitis B ¹	Birth	4 weeks	8 weeks (and at least 16 weeks after first dose)		
Inactivated Poliovirus ⁶	6 wks	4 weeks	4 weeks	6 months	
Measles, Mumps, Rubella ⁷	12 mos	4 weeks			
Varicella ⁸	12 mos	3 months if person is younger than age 13 years 4 weeks if person is aged 13 years or older			



Problem Description: Causes of Untimely Vaccination

Reasons often cited for incorrect and untimely vaccination:

- parental **negligence** and **misinformation**
- **incomplete** or **incorrect** schedules constructed by health professionals due to:
 - insufficient knowledge and addition of new vaccines to the lineup, ^{4, 5}
 - problem complexity and tedious process of manual construction.
- **missed opportunities** for vaccination ⁶
- environmental and socioeconomic standings.

⁴ LaRussa, P., S. Chen, P. Sternfels, L. Cooper, A. Caesar, M. Ewing, M. Irigoyen, S. Findley. Impact of immunization schedule changes on missed opportunities for vaccination. The 37th National Immunization Conference, Chicago, IL, 2003.

⁵ Cohen, N.J., D.S. Lauderdale, P.B. Shete, J.B. Seal, R.S. Daum. 2003. Physician knowledge of catch-up regimens and contraindications for childhood immunizations. *Pediatrics* **111** 925-932.

⁶ Szilagyi, P.G., L.E. Rodewald, S.G. Humiston, R.F. Raubertas, L.A. Cove, C.B. Doane, P.H. Lind, M.S. Tobin, K.L. Roghmann, C.B. Hall. 1993. Missed opportunities for childhood vaccination in office practices and the effect on vaccination status. *Pediatrics* **91**.

Recommended Adult Immunization Schedule


UNITED STATES • 2010


Note: These recommendations *must* be read with the footnotes that follow containing number of doses, intervals between doses, and other important information.

Figure 1. Recommended adult immunization schedule, by vaccine and age group

VACCINE ▼	AGE GROUP▶	19–26 years	27–49 years	50–59 years	60–64 years	≥65 years
Tetanus, diphtheria, pertussis (Td/Tdap) ^{1,2}		Substitute 1-time dose of Tdap for Td booster; then boost with Td every 10 yrs				Td booster every 10 yrs
Human papillomavirus (HPV) ^{2,3}		3 doses (females)				
Varicella ^{2,4}		2 doses				
Zoster ⁴					1 dose	
Measles, mumps, rubella (MMR) ^{5,6}		1 or 2 doses		1 dose		
Influenza ^{6,7}		1 dose annually				
Pneumococcal (polysaccharide) ^{7,8}		1 or 2 doses				1 dose
Hepatitis A ⁹		2 doses				
Hepatitis B ^{10,9}		3 doses				
Meningococcal ^{11,7}		1 or more doses				

*Covered by the Vaccine Injury Compensation Program.

 For all persons in this category who meet the age requirements and who lack evidence of immunity (e.g., lack documentation of vaccination or have no evidence of prior infection)

 Recommended if some other risk factor is present (e.g., on the basis of medical, occupational, lifestyle, or other indications)

 No recommendation

Report all clinically significant postvaccination reactions to the Vaccine Adverse Event Reporting System (VAERS). Reporting forms and instructions on filing a VAERS report are available at www.vaers.hhs.gov or by telephone, 800-822-7967.

Information on how to file a Vaccine Injury Compensation Program claim is available at www.hrsa.gov/vaccinecompensation or by telephone, 800-338-2382. To file a claim for vaccine injury, contact the U.S. Court of Federal Claims, 717 Madison Place, N.W., Washington, D.C. 20005; telephone, 202-357-6400.

Additional information about the vaccines in this schedule, extent of available data, and contraindications for vaccination is also available at www.cdc.gov/vaccines or from the CDC-INFO Contact Center at 800-CDC-INFO (800-232-4636) in English and Spanish, 24 hours a day, 7 days a week.

Use of trade names and commercial sources is for identification only and does not imply endorsement by the U.S. Department of Health and Human Services.

Problem Description: The Recommended Adult Schedule (Cont.)

Figure 2. Vaccines that might be indicated for adults based on medical and other indications



VACCINE ▼	INDICATION ▶	Pregnancy	Immuno-compromising conditions (excluding human immunodeficiency virus (HIV)) ^{3-4,13}	HIV Infection ^{3-4,13,14}		Diabetes, heart disease, chronic lung disease, chronic alcoholism	Asplenia ¹⁵ (including elective splenectomy and persistent complement component deficiencies)	Chronic liver disease	Kidney failure, end-stage renal disease, receipt of hemodialysis	Health-care personnel	
				CD4+ T lymphocyte count <200 cells/μL	≥200 cells/μL						
Tetanus, diphtheria, pertussis (Td/Tdap) ^{1,16}		Td	Substitute 1-time dose of Tdap for Td booster; then boost with Td every 10 yrs								
Human papillomavirus (HPV) ^{2,17}			3 doses for females through age 26 yrs								
Varicella ^{3,8}		Contraindicated	2 doses								
Zoster ⁴		Contraindicated	1 dose								
Measles, mumps, rubella (MMR) ^{5,9}		Contraindicated	1 or 2 doses								
Influenza ^{6,10}			1 dose TIV annually								1 dose TIV or LAIV annually
Pneumococcal (polysaccharide) ^{7,11}			1 or 2 doses								
Hepatitis A ⁶			2 doses								
Hepatitis B ^{10,18}			3 doses								
Meningococcal ^{11,19}			1 or more doses								

*Covered by the Vaccine Injury Compensation Program.

 For all persons in this category who meet the age requirements and who lack evidence of immunity (e.g., lack documentation of vaccination or have no evidence of prior infection)
 Recommended if some other risk factor is present (e.g., on the basis of medical, occupational, lifestyle, or other indications)
 No recommendation

These schedules indicate the recommended age groups and medical indications for which administration of currently licensed vaccines is commonly indicated for adults ages 19 years and older, as of January 1, 2010. Licensed combination vaccines may be used whenever any components of the combination are indicated and when the vaccine's other components are not contraindicated. For detailed recommendations on all vaccines, including those used primarily for travelers or that are issued during the year, consult the manufacturers' package inserts and the complete statements from the Advisory Committee on Immunization Practices (www.cdc.gov/vaccines/pubs/acip-list.htm).

The recommendations in this schedule were approved by the Centers for Disease Control and Prevention's (CDC) Advisory Committee on Immunization Practices (ACIP), the American Academy of Family Physicians (AAFP), the American College of Obstetricians and Gynecologists (ACOG), and the American College of Physicians (ACP).


 DEPARTMENT OF HEALTH AND HUMAN SERVICES
 CENTERS FOR DISEASE CONTROL AND PREVENTION
 

Statistics reported following the 2007 NIS of Adults ⁷:

- Only **57.2%** of persons ages 18-64 and **44.1%** of persons ages 65+ had received the tetanus, diphtheria vaccine (Td) recently enough to be considered still valid.
- Only **65.6%** of persons 65+ had ever received the pneumococcal vaccine (a vaccine recommended for all persons in that age group)
- Only **1.9%** of persons 60+ received the zoster vaccine (recommended for all persons in that age group)

⁷ CDC. 2010. *The National Immunization Survey*. Department of Health and Human Services, National Center for Health Statistics, United States. URL: www.cdc.gov/nis.

Possible reasons for incorrect and untimely vaccination of adults ⁸:

- never vaccinated as children
- new vaccines which were unavailable during childhood
- fading immunity
- higher susceptibility to some diseases with age
- changes in medical condition, work environment, and lifestyle

⁸ CDC. 2010. *Adult Immunization Schedule*. National Centers for Immunization and Respiratory Diseases. URL: <http://www.cdc.gov/vaccines/recs/schedules/adult-schedule.htm>.

Importance of Immunization for All Ages

- Immunize to protect yourself
- Immunize to protect others
 - Pertussis (whooping cough) outbreak in California ⁹.
 - 10 deaths were reported in infants ≤ 2 months of age at disease onset
 - 363 hospitalized infants < 6 months of age
 - Sources of pertussis transmission to infants ^{10, 11}:
 - Parents (55%)
 - Siblings (16%-20%)
 - Aunts/uncles (10%)
 - Grandparents (6%-8%)
 - Caretakers (2%)

⁹ California Department of Public Health. Pertussis Report – November 2, 2010.

<http://www.cdph.ca.gov/programs/immunize/Documents/PertussisReport2010-11-02.pdf>

¹⁰ Wendelboe, A.M., et al. 2007. Transmission of *Bordetella pertussis* to Young Infants. *Pediatric Infectious Disease Journal*. **26** (4) 293-299.

¹¹ Bisgard, K.M., et al. 2004. Infant Pertussis: Who Was the Source? *Pediatric Infectious Disease Journal*. **23** (11) 985-989.

Aim

Provide a freely available and easy to use automated tool for constructing catch-up schedules aimed at providers and caretakers

Immediate benefits:

- Eliminate human error.
- Speedup the process.
- Improve public access to vital information.

Long-term benefits:

- Alleviate missed opportunities.
- Improve timely vaccination rates.
- Improve awareness and parental participation.

Paradigm

Given past vaccination history, each remaining dose that can be **feasibly** administered and not contraindicated must be scheduled.

Feasibility requirements:

- **Minimum** and **maximum** age requirement for each dose of each vaccine.
- **Gap** between (not necessarily successive) doses of the same vaccine must not violate the minimum allowed. This gap may vary by vaccine, dose, current age and/or age at which previous dose is administered.
- “Live-virus” vaccines may be administered during the **same visit or at least 28 days apart**.

Paradigm

Given past vaccination history, each remaining dose that can be feasibly administered and not **contraindicated** must be scheduled.

Possible **contraindications**:

- The **previous dose** is administered at an age that no longer warrants further vaccination.
- The **current age** no longer warrants further vaccination.

Example (Contraindicating *PCV*)

The second dose of *PCV* is deemed final if the first dose is administered after age 12 months or the current age is 24-59 months. In either case, the third and fourth doses are unnecessary.

Paradigm

Given past vaccination history, each remaining dose that can be feasibly administered and not contraindicated must be scheduled.

Discretionary measures:

- The **aggressiveness** of catch-up regime, i.e.

Administer when recommended

vs

Administer as soon as feasibly possible

- The maximum number of **simultaneous** administrations.
- The number of doctor's **visits**.

The Catch-up Scheduling Problem & Machine Scheduling

Machine scheduling	Catch-up Scheduling
Similarities	
Jobs	Vaccine doses
Release and due dates	Window for each dose
Number of processors	Number of simultaneous administrations
Separation time between jobs	Spacing between doses
(Chain) Precedence	Doses must be given in sequence
Dissimilarities	
Processing time	Doses can be administered instantly
Typically single objective (i.e. makespan, tardiness etc.)	Multilevel objective: <ol style="list-style-type: none"> 1. Maximize completable vaccination series. 2. Maximize number of administered doses. 3. Minimize total delay in administering doses.
Typically constant separation times or setup time depends only on previous job	Spacing may vary by age and age any previous dose is given

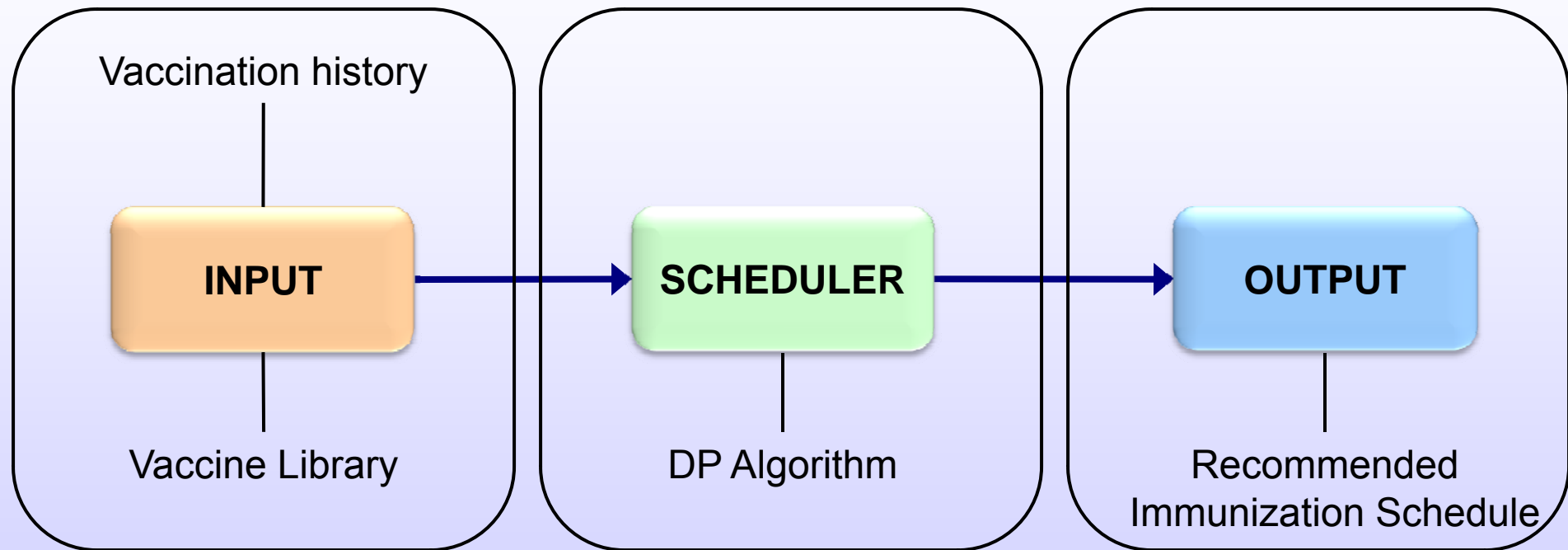
Proposition

The catch-up scheduling problem remains NP-hard:

1. without minimum gap between doses and live vaccines,
2. without any maximum age for a dose and without live vaccines, and
3. without a limit on the number of simultaneous administrations.

Four main criteria:

1. the tools must be **user-friendly** for providers to use on a regular basis,
2. the tools must be **easily modified** to accommodate changes to the recommended schedule,
3. the tools must return a user's recommended immunization schedule **quickly**, and
4. the tools must return a recommended immunization schedule that **meets all guidelines** and **optimizes an individual's coverage** against vaccine-preventable diseases



The Tool (User Input and Interface) – Catch-Up Immunization Scheduler

Catchup Immunization Scheduler [-] [x]



Catch-Up immunization scheduler
for children six years and younger

[Disclaimer](#)

Based on 2010 Childhood Immunization Schedule

Birth Date: July 4 2010

Name: Child's Name

Schedule Type: Accelerated Schedule
 Routine Schedule

Vaccine	Doses Administered	Dates Administered (in MM/DD/YYYY format only)
HepB	1	7/4/2010 
Rota	0	
DTaP	1	9/2/2010 
Hib	1	9/2/2010 
PCV	1	9/2/2010 
IPV	0	
MMR	0	
Var	0	
HepA	0	

Get Schedule

Reset

Save

Retrieve Doses



The Tool (User Input and Interface) – Adult Immunization Scheduler

Adult Immunization Scheduler _ □ ×

Adult Immunization Scheduler

Instructions
[Calendar Help](#)

[Based on the 2010 Recommended Adult Immunization Schedule](#)

Name: Birth Date: April 16 1975 Sex: Female

Vaccine	Doses Administered	Dates Administered in Chronological Order (in MM/DD/YYYY format only) Approximate Dates are Acceptable
Td	3 or	<input type="text" value="01/05/2010"/> <input type="checkbox"/> ? ← Enter date of most recent dose. If unknown, select the check box.
Tdap	0	
HPV2 / HPV4	0	
VAR	0	
ZOS	0	
MMR	1	<input type="text" value="01/11/2000"/> <input type="checkbox"/>
PPSV23	0	
HepA	0	
MCV4/MPSV4	0	
HepB	0	

Questions

Do you smoke? Yes No

Do you work in health-care? Yes No

Were you born in the United States? Yes No

Are you an Alaska Native or American Indian younger than 65? Yes No

Are you a resident of a nursing home or long-term care facility? Yes No

Have you had the chicken pox? Yes No

Have you had a lab test confirming immunity to varicella? Yes No

Have you had herpes zoster (shingles)? Yes No

Do you have an immunocompromising condition? Yes No

Have you had a lab test confirming immunity to measles or had a physician's diagnosis for measles? Yes No

Additional Questions

Do you have any of the medical conditions for which vaccination against pneumococcus is recommended? Yes No

Do you fall under any of the categories for which vaccination against HepA is recommended? Yes No

Do you fall under any of the categories for which vaccination against HepB is recommended? Yes No

Do you fall under any of the categories for which vaccination against meningococcus is recommended? Yes No

Are you a male between the ages of 9 and 26 who would like to be vaccinated against HPV? Yes No

Get Schedule

Reset Save Retrieve Doses

The Tool (User Input and Interface) – Adolescent Immunization Scheduler

Adolescent Immunization Scheduler

[Calendar Help](#)

Adolescent Immunization Scheduler

for Persons Aged 7 Through 18 Years

Based on the 2010 Recommended Adolescent Immunization Schedule

Name:
Birth Date: June 15 1997
Sex: Female

Vaccine	Doses Administered	Dates Administered in Chronological Order (in MM/DD/YYYY format only)
DTaP / Tdap / Td	5	08/15/1997 10/15/1997 12/15/1997 06/17/1998 06/15/2001 Was one of these doses Tdap? No
HPV2 / HPV4	0	
MCV4/MPSV4	0	
PPSV23	0	
HepA	2	06/17/1998 12/15/1998
HepB	3	06/15/1997 08/15/1997 12/15/1997
IPV	4	08/15/1997 10/15/1997 12/15/1997 06/15/2001
MMR	2	06/17/1998 06/15/2001
Var	2	06/17/1998 06/15/2001

Questions


Do you have a medical condition for which early vaccination against Meningococcal disease is recommended? Yes No

Do you have a medical condition for which vaccination against Pneumococcal disease is recommended? Yes No

Are you in one of the groups for which vaccination against Hepatitis A is recommended? Yes No

The Tool (User Input and Interface) – Canadian Immunization Scheduler

Canadian Immunization Scheduler



Canadian Paediatric Society

Working for kids since 1922



Instructions

Canadian Immunization Scheduler

Based on the Canadian Nursing Coalition on Immunization, 2004

Name:

Birth Date: 25 June 2007

Province/Territory of Residence: Alberta

Vaccine	Doses Administered	Dates Administered in Chronological Order (in DD/MM/YYYY format only) <i>(estimated dates are fine)</i>	Check below if dates unknown
DTaP-IPV-Hib	4	25/08/2007 23/10/2007 30/12/2007 30/12/2008	<input type="checkbox"/>
Tdap	0		<input type="checkbox"/>
HB	0		<input type="checkbox"/>
MMR	1	30/06/2008	<input type="checkbox"/>
Var	1	30/06/2008	<input type="checkbox"/>
Men-C	3	25/08/2007 23/10/2007 30/06/2008	<input type="checkbox"/>
MCV-4	0		<input type="checkbox"/>
Pneu-C-7	4	25/08/2007 23/10/2007 30/12/2007 30/12/2008	<input type="checkbox"/>
HPV	0		<input type="checkbox"/>

[Calendar Help](#)

Save **Retrieve Doses** **Reset** **Get Schedule**

Example (Vaccine Library File for PCV)

ID	Name	Live?	Num. Doses	Num. Dose Constraints
5	PCV	No	4	6

Dose	Min Age	Max Age	Max Age Prev. Dose	Rec. Age		Rec. Gap to Next Dose	
				Min	Max	Min	Max
1	6w	5y	-	2m	2m	4w	4w
2	10w	5y	2y	4m	4m	8w	8w
3	14w	5y	2y	6m	6m	6m	6m
4	12m	5y	2y	12m	15m	-	-

Next Dose	Prev Dose	Current Age		Age of Prev Dose		Min Gap Between Dose	Final Dose?
		Min	Max	Min	Max		
2	1	0	<24m	0	<12m	4w	No
2	1	0	-	12m	-	8w	Yes
2	1	24m	59m	0	-	8w	Yes
3	2	0	<12m	0	-	4w	No
3	2	12m	-	0	-	8w	Yes
4	3	0	-	0	-	8w	Yes

Parameters:

τ = time horizon

V = set of vaccines

$n(v)$ = number of doses of vaccine $v \in V$

$\tau(v, k) = \{t \in \tau : \minAge(v, k) \leq t \leq \maxAge(v, k)\}$

$R(v)$ = the number of rows from the second part of the VML input
Rows $r = 1, \dots, R(v)$

Decision variables:

$x_t = 1$ if a doctor's visit is scheduled on day t ; 0 otherwise.

$y_{(v,k,t)} = 1$ if the k^{th} dose of vaccine v is administered on day t ; 0 otherwise.

Optimization Models (Integer Programming)

C1. Administer each dose at-most once:

$$\sum_{t \in \tau(v,k)} y_{v,k,t} \leq \begin{cases} 1, & \text{if } k = 1 \text{ and} \\ \sum_{t \in \tau(v,k-1)} y_{v,k-1,t}, & \text{otherwise.} \end{cases}$$

C2. Regulating gap between doses:

$$\sum_{t \in \tau(v,k_2(v,r))} t \cdot y_{v,k_2(v,r),t} - \sum_{t \in \tau(v,k_1(v,r))} t \cdot y_{v,k_1(v,r),t} \geq \minGap(v,r).$$

C3. Scheduling doctor visits:

$$|V| \cdot x_t - \sum_{v \in V} \sum_{k=1}^{n(v)} y_{v,k,t} \geq 0$$

C4. Limiting number of simultaneous administrations:

$$\sum_{v \in V} \sum_{k=1}^{n(v)} y_{v,k,t} \leq \maxSim.$$

Optimization Models (Integer Programming)

Objective Function: Minimize “penalty” – “reward”

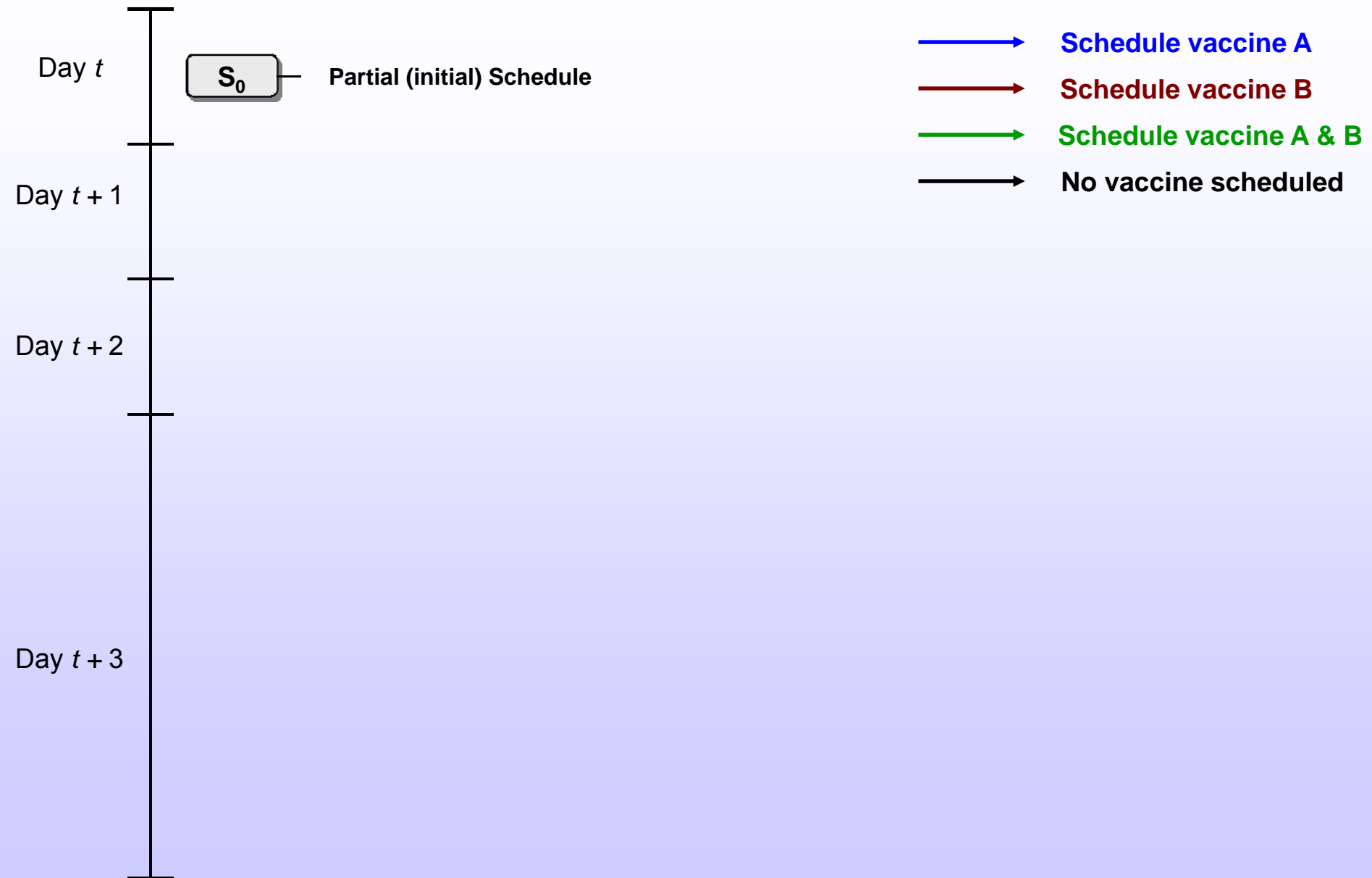
Large reward for administering dose

Penalize delay in administering dose

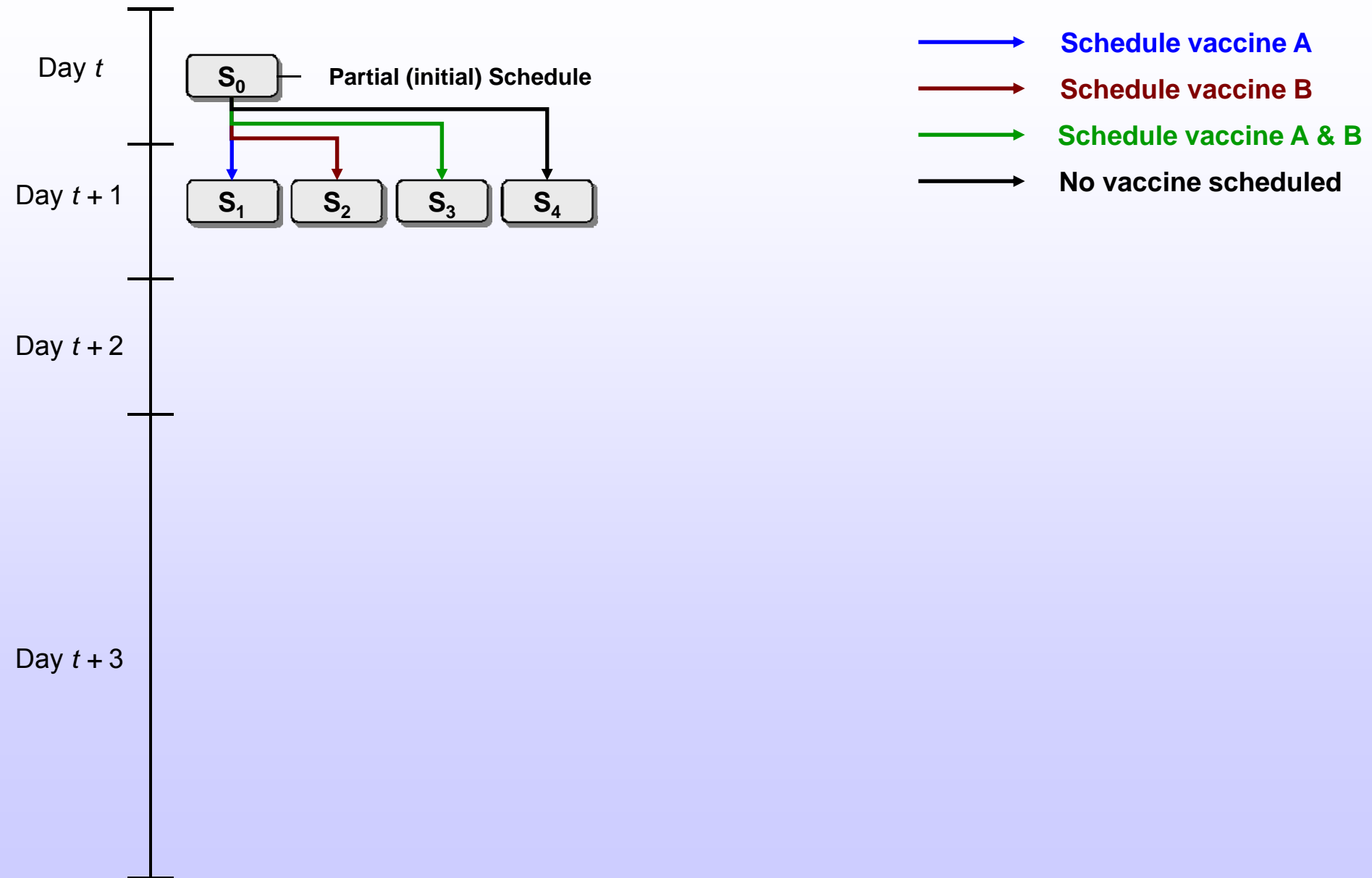
$$\sum_{t \in \tau} x_t - \sum_{v \in V} \sum_{k=1}^{n(v)} \sum_{t \in \tau(v,k)} M \cdot J_{v,k,t} + \sum_{v \in V} \sum_{k=1}^{n(v)} d_{v,k} + \sum_{v \in V} \sum_{k=1}^{n(v)-1} g_{v,k}$$

Penalize deviation from recommended gap

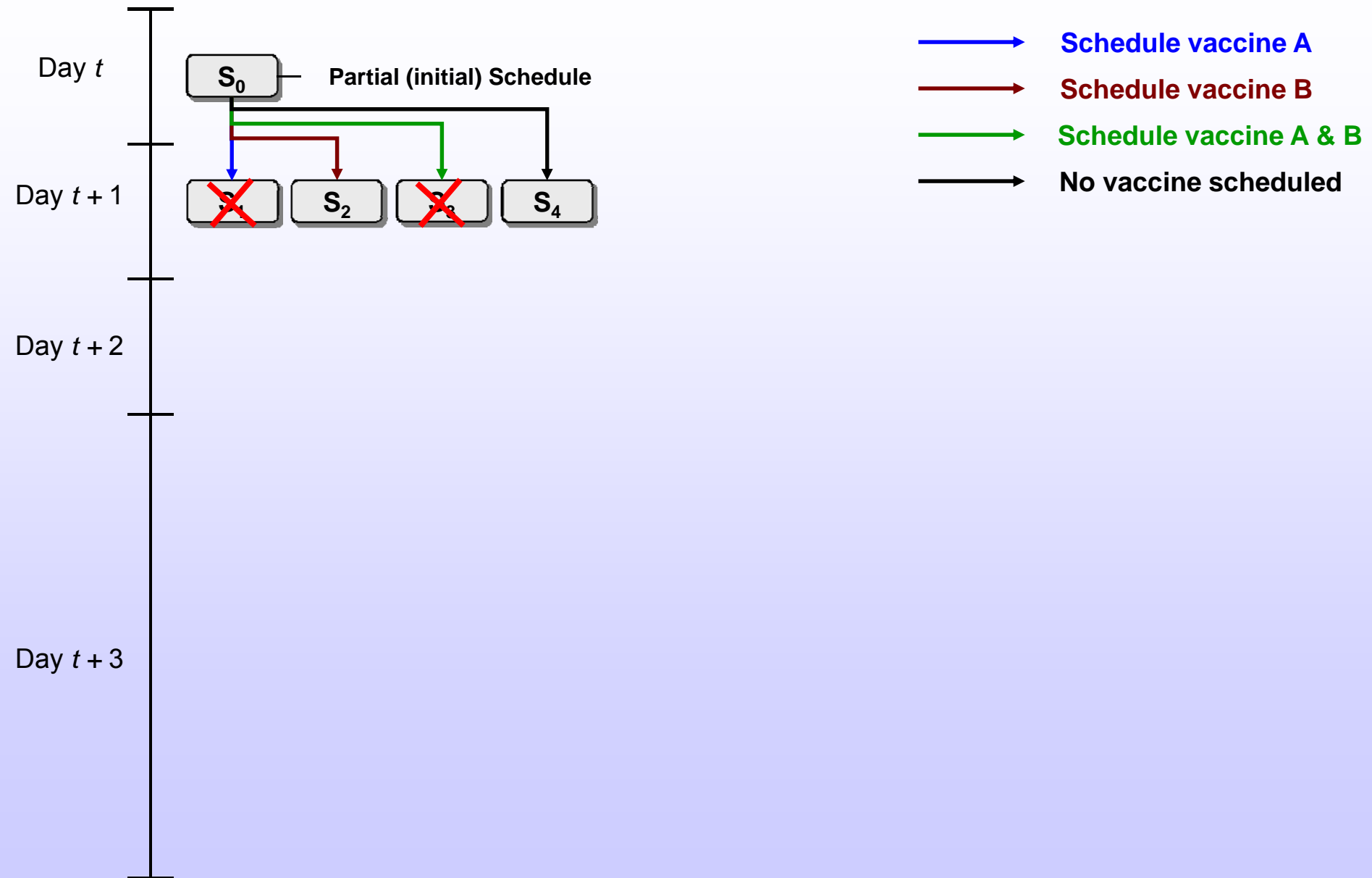
A Dynamic Programming Algorithm



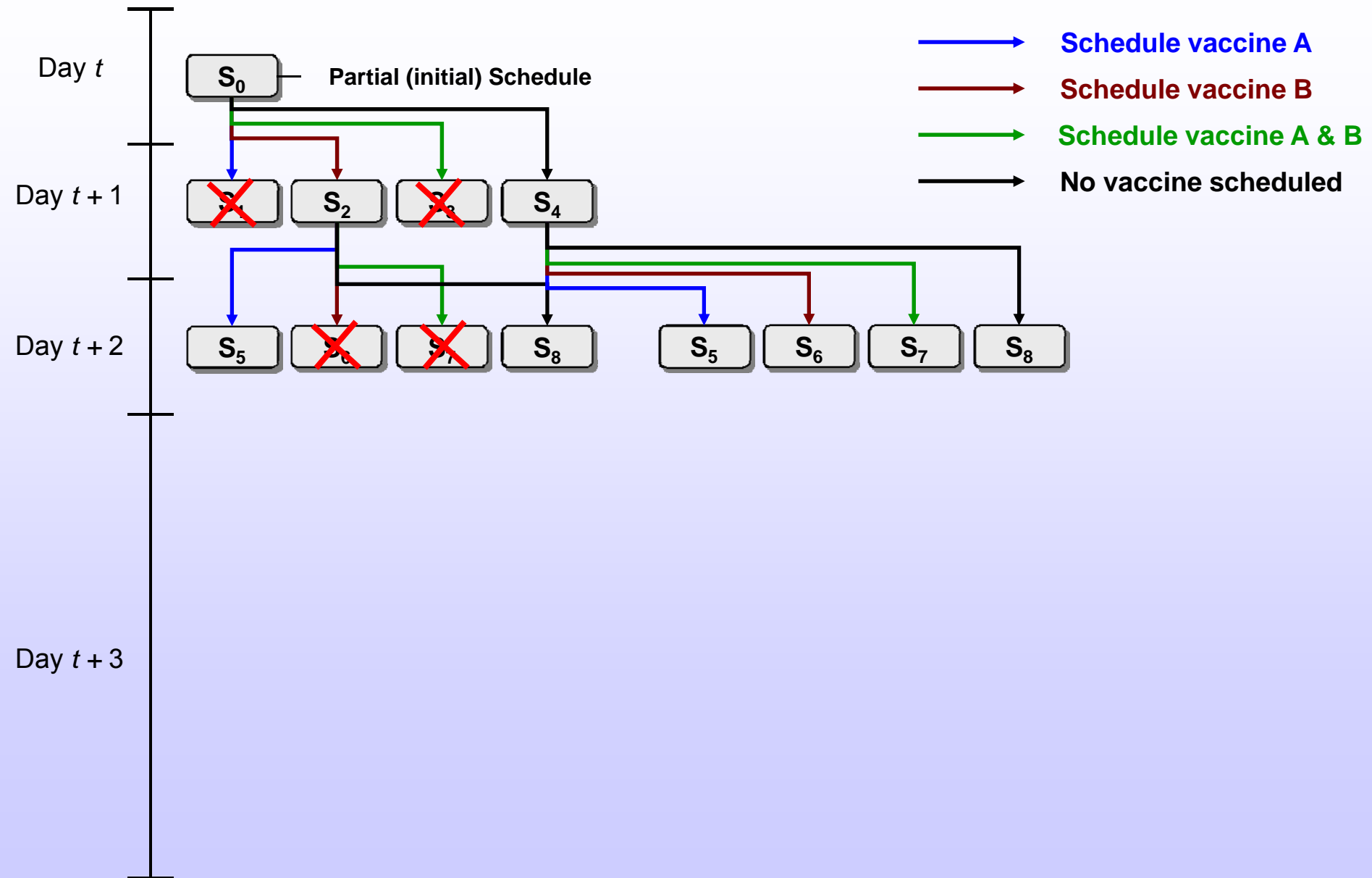
A Dynamic Programming Algorithm



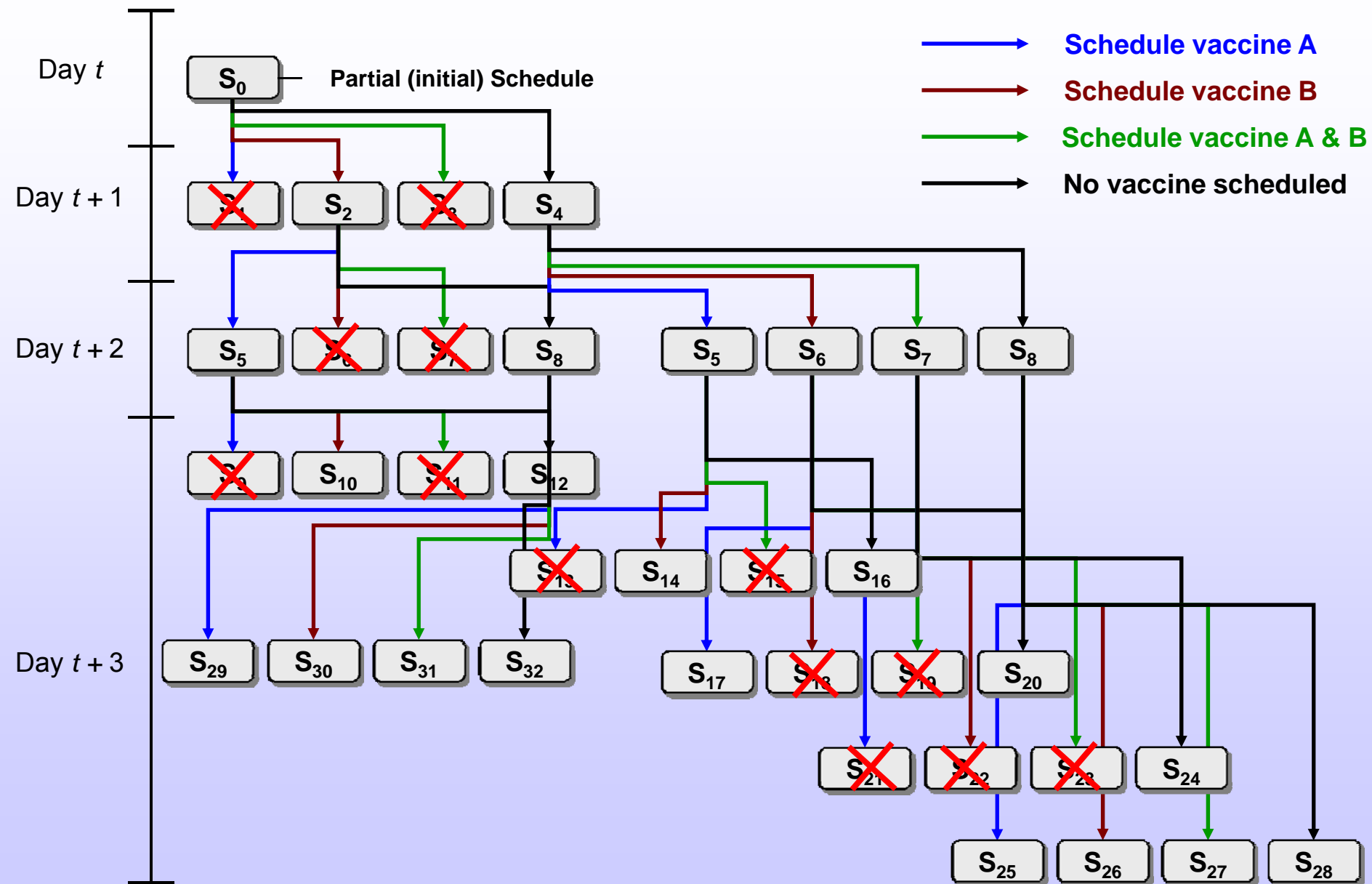
A Dynamic Programming Algorithm



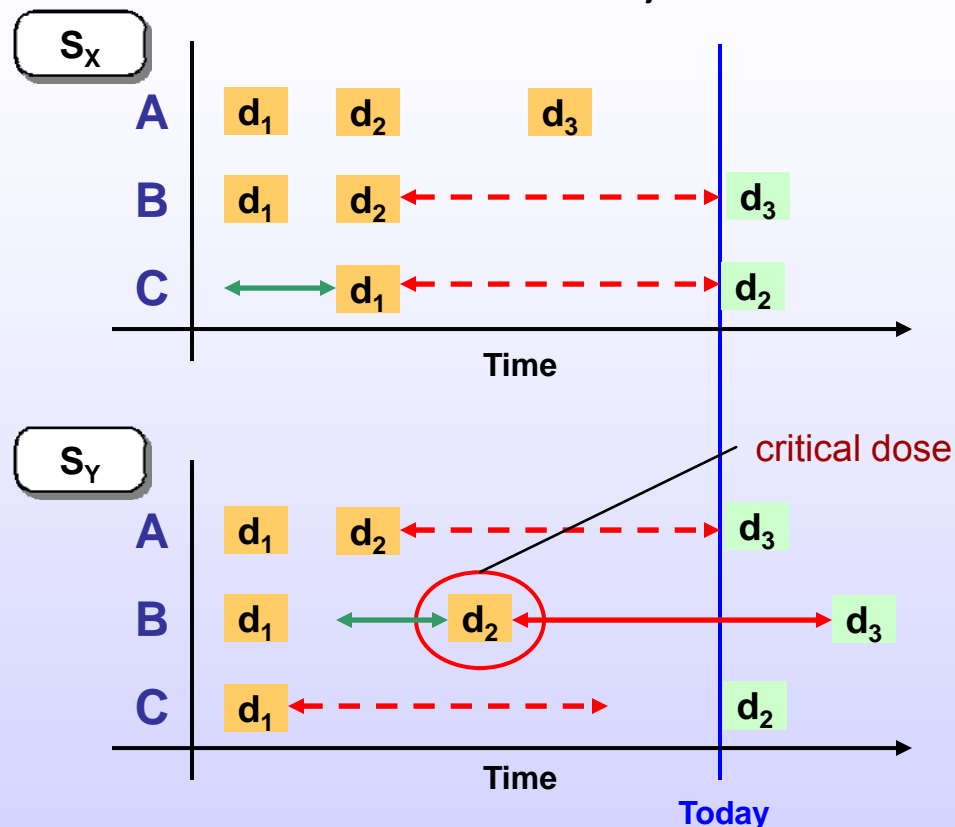
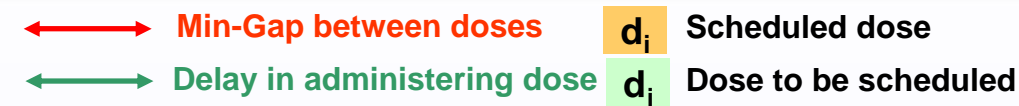
A Dynamic Programming Algorithm



A Dynamic Programming Algorithm



A Dynamic Programming Algorithm



Dominance criteria

Schedule **S_x** dominates **S_y** if:

1. The **number** of doses administered in **S_x** is no less than **S_y** for each vaccine,
2. The **timing** of each **critical** dose administered in **S_y** is no earlier than in **S_x**, and
3. The total **delay** in administering doses in common is less in **S_x**.

Proposition

If **S_x** dominates **S_y** then any completion of **S_y** cannot be better than the best completion of **S_x** and thus, **S_y** is unwarranted.

Scenario 1

A 4 month old child who has received 1 dose of *HepB* at birth and one each of *DTaP*, *Hib* and *PCV* at 2 months of age.

Schedule* generated for: on Nov 05, 2010 (11/05/2010)

Birth Date: Jul 04, 2010 (07/04/2010). Current Age: 0 year/s, 4 month/s and 0 week/s

Timeline	0-4 weeks	1-2 months	3-5 months	6-11 months	12-14 months	15-17 months	18-23 months	4-6 years				
Rec. Date ** (mm/dd/yy)	07/04/10	09/02/10	Today 11/05/10	12/03/10	01/04/11	07/04/11	10/04/11	01/04/12	06/04/12	07/04/14	07/04/16	Tally
HepB ¹	AD		CD		OD							3/3
Rota ²												0/3
DTaP		AD	OD		OD		OD			OD		5/5
Hib ⁴		AD	OD		OD	OD						4/4
PCV ⁵		AD	OD		OD	OD						4/4
IPV			CD	CD	OD					OD		4/5
MMR ⁷					OD					OD		2/2
Var ⁸					OD					OD		2/2
HepA ⁹					OD		OD					2/2

AD - Administered Dose **CD** - Catch-up Dose **OD** - On-time Dose **PD** - Preemptive Dose

Scenario 1... cont.

A 4 month old child who has received 1 dose of *HepB* at birth and one each of *DTaP*, *Hib* and *PCV* at 2 months of age.

Schedule* generated for: on Nov 05, 2010 (11/05/2010)

Birth Date: Jul 04, 2010 (07/04/2010). Current Age: 0 year/s, 4 month/s and 0 week/s

Timeline	0-4 weeks	1-2 months	3-5 months		12-14 months		15-17 months	18-23 months		4-6 years			
Rec. Date <small>(mm/dd/yy)</small>	07/04/10	09/02/10	Today 11/05/10	12/03/10	12/31/10	07/04/11	08/05/11	10/04/11	01/04/12	06/04/12	07/04/14	07/04/16	Tally
HepB ¹	AD		CD		OD								3/3
Rota ²													0/3
DTaP		AD	OD	PD		PD					OD		5/5
Hib ⁴		AD	OD	PD		OD							4/4
PCV ⁵		AD	OD	PD		OD							4/4
IPV			CD	CD	OD						OD		4/5
MMR ⁷						OD	PD						2/2
Var ⁸						OD	PD						2/2
HepA ⁹						OD			OD				2/2

AD - Administered Dose **CD** - Catch-up Dose **OD** - On-time Dose **PD** - Preemptive Dose

Scenario 2

A 35-year-old female who has received 1 dose of MMR, 3 doses of Td, and remembers the date of her last dose of Td.

Schedule* generated for: on Oct 25, 2010 (10/25/2010)

Birth Date: Apr 16, 1975 (04/16/1975). Current Age: 35 year/s, 6 month/s and 1 week/s

Rec. Date** (mm/dd/yy)	01/05/10	Today 10/25/10	01/07/20	01/07/30	04/16/35	01/07/40	04/16/40	Tally
<u>Td</u>	AD			OD		OD		3/3
<u>Tdap</u> ²			CD					1/1
<u>ZOS</u>					OD			1/1
<u>PPSV23</u> ⁴							OD	1/1
<u>Influenza</u>		One Dose Recommended Annually						1/1

AD - Administered Dose
 CD - Catch-up Dose
 OD - On-time Dose
 PD - Preemptive Dose

Scenario 2... cont.

A 35-year-old female who has received 1 dose of MMR, 3 doses of Td, does not remember her last dose of Td, and works in healthcare.

Schedule* generated for: on Oct 25, 2010 (10/25/2010)

Birth Date: Apr 16, 1975 (04/16/1975). Current Age: 35 year/s, 6 month/s and 1 week/s

<u>Rec. Date</u> <small>(mm/dd/yy)</small>	Today 10/25/10	11/26/10	03/04/11	10/29/20	11/05/30	04/16/40	11/05/40	<u>Tally</u>
<u>Td</u>				OD	OD		OD	3/3
<u>Tdap</u> ²	CD							1/1
<u>VAR</u> ³	CD	CD						2/2
<u>MMR</u>	CD							1/1
<u>PPSV23</u> ⁵						OD		1/1
<u>Influenza</u>	One Dose Recommended Annually							1/1
<u>HepB</u>	OD	OD	OD					3/3

AD - Administered Dose
 CD - Catch-up Dose
 OD - On-time Dose
 PD - Preemptive Dose

Scenario 3

A 3-year-old child who is up-to-date on the recommended immunizations in Alberta, Canada

Schedule* generated for: for Alberta on 25 Oct, 2010 (25/10/2010)
 Birth Date: 25 Jun, 2007 (25/06/2007). Current Age: 3 year/s, 4 month/s and 0 week/s

Timeline	2 months	3 months	6 months	12 months	18 months	3 years	4 years	7 years	10 years	12 years	14 years	15 years	16 years						
Rec. Date <small>(dd/mm/yy)</small>	25/08/07	23/10/07	30/12/07	30/06/08	30/12/08	Today 25/10/10	25/06/11	25/05/12	25/06/14	25/06/17	25/08/17	25/12/17	25/06/19	25/06/21	25/09/22	25/06/23	25/07/23	25/05/24	Tally
DTaP-IPV-Hib	AD	AD	AD		AD														4/4
DTaP-IPV							OD												1/1
Tdap													OD						1/1
HB									OD	OD									2/2
MMR				AD			OD												2/2
Var				AD															1/1
Men-C	AD	AD		AD															3/3
MCV-4																			0/0
Pneu-C-7	AD	AD	AD		AD														4/4
Inf ¹⁰						One Dose Recommended Annually											1/1		
HPV ¹¹									OD	OD	OD								3/3

AD - Administered Dose CD - Catch-up Dose OD - On-time Dose PD - Preemptive Dose

Scenario 3... cont.

A 3-year-old child who is up-to-date on the recommended immunizations in Alberta, Canada ... moves to British Columbia

Schedule* generated for: for British Columbia on 25 Oct, 2010 (25/10/2010)
 Birth Date: 25 Jun, 2007 (25/06/2007). Current Age: 3 year/s, 4 month/s and 0 week/s

Timeline	2 months	3 months	6 months	12 months	18 months	3 years		4 years	7 years	11 years			13 years	14 years	16 years		17 years		
Rec. Date <small>(dd/mm/yy)</small>	25/08/07	23/10/07	30/12/07	30/06/08	30/12/08	Today 25/10/10	20/12/10	25/02/11	25/06/11	25/06/14	25/06/18	25/08/18	25/12/18	25/06/20	25/06/21	25/06/23	25/10/23	25/06/25	Tally
DTaP-IPV-Hib	AD	AD	AD		AD														4/4
DTaP-IPV									OD										1/1
Tdap														OD					1/1
HB							CD	CD	CD										3/3
MMR				AD			CD												2/2
Var				AD															1/1
Men-C	AD	AD		AD															3/2
MCV-4																			0/0
Pneu-C-7	AD	AD	AD		AD														4/3
Inf ¹⁰																			0/1
HPV ¹¹										OD	OD	OD							3/3

AD - Administered Dose **CD** - Catch-up Dose **OD** - On-time Dose **PD** - Preemptive Dose

Usage and Dissemination

- **Catch-up Immunization Scheduler:**
<http://www.cdc.gov/vaccines/recs/Scheduler/catchup.htm>
 - 64,949 downloads since June 2008
- **Adult Immunization Scheduler:**
<http://www.cdc.gov/vaccines/recs/Scheduler/AdultScheduler.htm>
 - 11,168 downloads since January 2010
- **Adolescent Immunization Scheduler:**
<http://www.cdc.gov/vaccines/recs/Scheduler/AdolescentScheduler.htm>
 - To be released December 2010

The Washington Post
For Parents, an Easier Way to Track Vaccines
Tuesday, July 15, 2008
Quick: Which shots have your kids received -- and which do they still need? The Centers for Disease Control and Prevention has a free online tool that can help.
The Catch-Up Immunization Scheduler (go to <http://www.cdc.gov/vaccines>, click on "Immunization schedules," then "Interactive Catchup Schedule") lets you plug in your child's birth date and vaccines given and see what's missing.



A New Tool to Manage Your Child's Vaccine Schedule

THE OFFICIAL NEWSMAGAZINE OF THE AMERICAN ACADEMY OF PEDIATRICS



AAP News

DEDICATED TO THE HEALTH OF ALL CHILDREN

Online scheduler keeps track of missed immunizations

Entrepreneur
Catch-up immunization software.



Tool Creates Personalized Catch-up Immunization Schedules For Missed Childhood Vaccinations

Summary and ongoing work steps

- Automated tools quickly solve catch-up scheduling problem faced on a daily basis by health-care professionals
- Tools each meet defined criteria:
 - User-friendly
 - Easily modified
 - Fast
 - Schedules meet guidelines and optimize coverage
- Optimization technology is easily adapted to various groups and countries

Ongoing Work

- Spanish language versions of U.S. tools
- Schedules for immunosuppressed children (e.g. children with diabetes, HIV, undergoing therapy)
- Extend to other countries 
 - Canadian Immunization Scheduler available before the end of 2010.

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