Weill Cornell Medicine

Cornell Institute for Disease & Disaster Preparedness (CIDDP)

Vaccine Distribution Warehouse Allocator

User Guide

For use with *Vaccine Distribution Warehouse Allocator - v1-1.xlsm*

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Introduction

Supply chains for distributing vaccines consist of three types of locations. The first is the *manufacturer's warehouse*, which receives the production of vaccines. The second set of locations we call *Distribution Warehouses*. These warehouses receive shipments directly from the manufacturer's warehouse. There may be one manufacturer's warehouse, but there are likely to be hundreds of Distribution Warehouses located throughout the United States, for example. Each of these Distribution Warehouses is responsible for supplying a collection of locations at which vaccines are administered, which we designate as *Dispensing Locations*. There are or will be many thousands of such locations. The number of both Distribution Warehouses and Dispensing Locations per Distribution Warehouse will vary by country.

The purpose of the following comments is to provide insight into the spreadsheet tools that can be employed to determine daily allocations of available supplies from the manufacturer's warehouse to Distribution Warehouses, and from Distribution Warehouses to Dispensing Locations. The model is designed to be executed every day as conditions change. These allocations are determined considering:

1. Uncertainty in demand each day at each Dispensing Location.
2. Lead times associated with the transfer of stocks from one location to another.
3. The manufacturer's vaccine box quantity (doses of vaccine per box).
4. The available stock at the manufacturer's warehouse and Distribution Warehouses.
5. The on-hand stock at each Dispensing Location.
6. The desired level of service at each location in the distribution system.

By including service level targets, we provide the user with the flexibility to prioritize allocations to the most vulnerable patient communities served by each Distribution Warehouse. As we will see, the spreadsheet user is asked to provide data pertaining to all these parameters. While it seems to be a substantial task to enter these data, we will also see that it is not a daunting one. Once entered, the best possible allocations are determined by running the model. Most of the mathematics used to determine the allocations can be found in our paper Application of Supply Chain Principles to Pandemic Planning.

In this document, we focus on a spreadsheet tool for making allocations from one manufacturer warehouse to a collection of Distribution Warehouses. We call this spreadsheet the "Vaccine Distribution Warehouse Allocator". In another document (titled "Vaccine Dispensing Locations Allocator User Guide"), we show how to employ a companion spreadsheet (titled "Vaccine Dispensing Locations Allocator") for making allocations from a Distribution Warehouse to a collection of Dispensing Locations.

Why Use the Vaccine Distribution Warehouse Allocator?

The Vaccine Distribution Warehouse Allocator is based on fundamental supply chain principles that have a long pedigree in the field of operations research. Together with its companion spreadsheet Vaccine Dispensing Locations Allocator, it applies a supply chain distribution method that maximizes "vaccinated person-days", a concept that refers to the number of days patients have protection from the virus that the vaccine targets. While it was developed as a response to Covid-19, the method is equally applicable to other pandemic supply chain responses that may arise.

By maximizing vaccinated person-days, we minimize the time from a manufacturer's production of vaccines to the time patients receive shots in their arms. In other words, it provides the most protection, for the most patients, in the least amount of time. By doing so, it both minimizes each patient's risk of becoming ill and reduces the chances of virus variants from occurring. It accomplishes the latter result by vaccinating more people, more quickly, than when using other allocation strategies.

In summary, when vaccine supplies can be allocated and distributed as suggested by the Vaccination Distribution Warehouse Allocator and its companion Vaccination Dispensing Locations Allocator, people get vaccinated sooner, supplies are used up faster, fewer people experience COVID symptoms, fewer people are hospitalized, and fewer people will succumb to the disease.

We illustrate the concept of vaccinated person-days using a simple example. Suppose a vaccination dispensing site receives 100 doses of vaccine on a Monday. If the site vaccinates 100 people on Monday, 100 x 5 days = 500 vaccinated person-days occur over a five-day time horizon. If the site is capable of only vaccinating 20 persons per day for 5 days, the corresponding number of vaccinated person-days over that five-day period would be 20 x 5 + 20 x 4 + 20 x 3 + 20 x 2 + 20 x 1 = 300 days. By administering the vaccine as soon as it arrives, 67% more days of coverage are provided for those 100 patients. The model's imbedded algorithms allocate vaccine supplies so that vaccinated person-days are maximized, with priority given to sites having higher service level targets.

During the Covid-19 pandemic, it has not been uncommon for some states in the US to be allocated more supply than they could quickly use, while other states had more patients seeking vaccinations than they had supply. The Vaccination Distribution Warehouse Allocator can avoid these misallocations by using updated estimates of patient vaccine demand levels and vaccine administration capacities. The model incorporates uncertainty of daily demand at each Distribution Warehouse. To incorporate uncertainty in the spreadsheet, the user provides the mean, standard deviation, and maximum doses needed at each Distribution Warehouse. For Distribution Warehouses that are already operational, these estimates should be easy to obtain from historical vaccination data.

As we have stated, when vaccine supplies are allocated efficiently and effectively, people get vaccinated sooner, supplies are used up faster, fewer people experience COVID symptoms, fewer people are hospitalized, and fewer people will succumb to the disease. The easy-to-use Vaccine Distribution Warehouse Allocator and its companion Vaccine Dispensing Locations Allocator ensures such allocations occur. Furthermore, the tool requires no specialized knowledge or skill to use. It is helpful however to have basic familiarity with Microsoft Excel and rudimentary knowledge of statistics.

Model Assumptions

The Vaccine Distribution Warehouse Allocator is based on the following assumptions:

1. The supply of vaccines to be distributed is a single vaccine type, e.g., Pfizer-BioNTech, or Moderna, or Johnson & Johnson, or another. If Distribution Warehouses provide vaccines from multiple manufacturers, separate "Vaccine Distribution Warehouse Allocator" spreadsheets must be used for each. Demand estimates must then be provided for each manufacturer's vaccine independently. The model will not "mix" vaccines from multiple suppliers.

2. Distribution Warehouses are served from a single source of a manufacturer's supply. One manufacturer provides all supply of a particular vaccine type to each Distribution Warehouse.

3. Vaccines are distributed in whole boxes only. The model does not accommodate dividing single boxes of vaccines among multiple Distribution Warehouses.

4. Vaccine supplies cannot be shared between locations. The model does not accommodate re-allocation of excess supply at one Distribution Warehouse to another. In practice, if excess from one location does get shipped to another, subtract the transshipped amount from the sending location's inventory and add it to the receiving location's inventory in *Column D* when preparing the inputs.

5. Demand quantities are not known with certainty. For this reason, the model requires estimates of the daily mean, standard deviation and maximum quantities to be needed at each Distribution Warehouse. Standard deviations can be easily derived from history if available, otherwise a multiplier can be applied to the mean daily demand. For example, a multiplier of .01 would imply a coefficient of variation of 0.01.

Spreadsheet Overview

Application of Supply Chain Principles to Pandemic Planning User guide available here See paper available at ssrn.com/abstract=3794252

Vaccine Distribution Warehouse Allocator v1-1 Demo video available here

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Enter data in green cells. Other cells contain model outputs. See explanations in notes fields. Click "Allocate Vaccine to Distribution Warehouses" button to run the model.

Manufacturer's Supply	3,000,000	doses
Box Size	100	doses
Boxes to Allocate	30,000	

Allocate Vaccine to Distribution Warehouses

	Distribution Warehouses	Manufacturer to Distribution Warehouse Lead Time	Target probability of not running out of stock	Distribution Location Net Inventory	Estimated Vaccine Demand Parameters in doses: Daily Mean	Daily Standard Deviation	Maximum Demand	Lead Time Mean	Lead Time Standard Deviaion	Lead Time Maximum Demand	Allocation in doses	Allocation in boxes	Doses Available for Dispensing	Expected Shortages in doses	Expected Excess Supply in doses	Expected Vaccination (Fill) Rate	Optimal Stock Level S_j^*	Safety Stock
	Totals			5,775,567	2,994,903	15,597	3,041,697	8,735,968	26,599	8,872,497	2,998,700	29,987	8,774,267	938	38,299	0.9999	8,771,654	35,686
1	Alabama	3	0.91	91,471	45,350	250	46,100	136,050	433	138,300	45,200	452	136,671	15	621	0.9999	136,631	581
2	Alaska	5	0.91	27,546	6,871	36	6,978	34,355	80	34,890	7,000	70	34,546	0	191	1.0000	34,463	108
3	Arizona	3	0.91	135,120	67,339	357	68,409	202,017	618	205,227	67,800	678	202,920	20	903	0.9999	202,847	830
4	Arkansas	3	0.91	55,269	27,485	143	27,913	82,455	248	83,739	27,600	276	82,869	5	414	0.9999	82,788	333
5	California	3	0.91	724,702	361,429	1,891	367,101	1,084,287	3,275	1,101,303	364,000	3,640	1,088,702	135	4,415	0.9999	1,088,679	4,392
6	Colorado	3	0.91	104,741	52,222	285	53,078	156,666	494	159,234	52,600	526	157,341	19	675	0.9999	157,328	662
7	Connecticut	2	0.91	33,275	32,982	178	33,517	65,964	252	67,034	33,100	331	66,375	5	411	0.9999	66,302	338
8	Delaware	3	0.91	16,597	8,246	36	8,353	24,738	62	25,059	8,300	83	24,897	0	159	1.0000	24,822	84
9	Florida	3	0.91	394,761	196,519	1,034	199,622	589,557	1,791	598,866	197,200	1,972	591,961	74	2,404	0.9999	591,959	2,402
10	Georgia	3	0.91	196,549	97,572	499	99,070	292,716	864	297,210	97,400	974	293,949	30	1,233	0.9999	293,875	1,159
11	Hawaii	4	0.91	37,325	12,368	71	12,582	49,472	142	50,328	12,400	124	49,725	2	253	1.0000	49,663	191
12	Idaho	3	0.91	33,226	16,491	71	16,705	49,473	123	50,115	16,500	165	49,726	1	253	1.0000	49,638	165
13	Illinois	3	0.91	233,054	115,437	606	117,257	346,311	1,050	351,771	114,700	1,147	347,754	41	1,443	0.9999	347,719	1,408
14	Indiana	3	0.91	124,586	61,842	321	62,805	185,526	556	188,415	61,700	617	186,286	22	760	0.9999	186,272	746
15	Iowa	3	0.91	58,073	28,859	143	29,287	86,577	248	87,861	28,900	289	86,973	6	396	0.9999	86,910	333
16	Kansas	3	0.91	52,720	26,111	143	26,539	78,333	248	79,617	26,000	260	78,720	6	387	0.9999	78,666	333
17	Kentucky	3	0.91	83,044	41,228	214	41,870	123,684	371	125,610	41,200	412	124,244	11	560	0.9999	124,181	497
18	Louisiana	3	0.91	85,738	42,602	214	43,244	127,806	371	129,732	42,600	426	128,338	13	532	0.9999	128,303	497
19	Maine	3	0.91	24,907	12,368	71	12,582	37,104	123	37,746	12,400	124	37,307	3	203	0.9999	37,269	165
20	Maryland	3	0.91	110,300	54,970	285	55,826	164,910	494	167,478	55,300	553	165,600	18	690	0.9999	165,572	662
21	Massachusetts	2	0.91	63,720	63,216	321	64,179	126,432	454	128,358	63,400	634	127,120	13	688	0.9999	127,041	609
22	Michigan	3	0.91	185,476	92,075	464	93,466	276,225	804	280,398	91,900	919	277,376	27	1,151	0.9999	277,303	1,078
23	Minnesota	3	0.91	104,921	52,222	285	53,078	156,666	494	159,234	52,500	525	157,421	14	755	0.9999	157,328	662
24	Mississippi	3	0.91	55,421	27,485	143	27,913	82,455	248	83,739	27,400	274	82,821	8	366	0.9999	82,788	333
25	Missouri	3	0.91	113,663	56,344	285	57,201	169,032	494	171,603	56,100	561	169,763	15	731	0.9999	169,694	662
26	Montana	3	0.91	19,337	9,620	36	9,727	28,860	62	29,181	9,700	97	29,037	0	177	1.0000	28,944	84
27	Nebraska	3	0.91	35,953	17,865	107	18,186	53,595	185	54,558	17,900	179	53,853	7	258	0.9999	53,844	249

Allocation to DistribWarehouses

The above sample spreadsheet contains all required input data needed to make allocations to Distribution Warehouses. The cells shaded in **green** are those in which input data are required. The cells colored gold and gray have computed values in them. All other cells contain data that result from executing the allocation algorithm. We will next discuss the content of each of the **green** cells.

Column B "**Distribution Warehouse**" contains the names of the warehouses; enter your Distribution Warehouse names in this column. In this example, there are 52 warehouses: one for each state in the US.

	Distribution Warehouses
1	Alabama
2	Alaska
3	Arizona
4	Arkansas
5	California
6	Colorado
7	Connecticut
8	Delaware
9	Florida
10	Georgia
11	Hawaii

Etc.

Cell C8 “Manufacturer to Distribution Warehouse Lead Time” indicates the number of days to ship, receive and prepare vaccines for allocation at each Distribution Warehouse. The worksheet determines the total supply needed to be in process plus on order to meet the demands at each Distribution Warehouse this number of days into the future.

Manufacturer to Distribution Warehouse Lead Time
3
5
3
3
3
3
2
3
3
3
4

Cell C8 “Manufacturer’s Supply” indicates that a supply of 3,000,000 doses of vaccine is available to allocate from the manufacturer, and the “Box Size” in *Cell C9* is 100 doses. *Cell C10* indicates the number of whole boxes available for allocation.

Manufacturer's Supply	3,000,000	doses
Box Size	100	doses
Boxes to Allocate	30,000	

The data in rows 15 through 64 in *column D* "Target probability of not running out of stock" indicate the target probability of not running out of stock at the end of the lead time at the corresponding Distribution Warehouse. This number must be a number between 0 and 1, but less than 1. By setting this value, you set priorities for allocating the available supply. In our example, we set this value to .91 for each Distribution Warehouse.

Target probability of not running out of stock
0.9100
0.9100
0.9100
0.9100
0.9100
0.9100
0.9100
0.9100
0.9100

Etc.

Caution: when supplies are constrained, care should be taken in setting the target probability of running out of stock too close to 1. That can result in high levels of expected excess being "trapped" at some locations and unavailable for use at other locations where there might be shortages. Users are advised to run the model with various combinations of targets until a desired balance between expected shortages and expected excess quantities are achieved at all Distribution Warehouses.

The total number of doses in transit to and on hand at Distribution Warehouses plus total supplies at the Dispensing Locations supplied by the corresponding Distribution Warehouse prior to allocation of additional vaccine to them is displayed in column E "Distribution Location Net Inventory ".

Distribution Location Net Inventory
91,471
27,546
135,120
55,269
724,702
104,741
33,275
16,597
394,761
196,549
37,325

Etc.

In the same rows in *columns F through H*, enter the daily mean, standard deviation and maximum patient demands you expect to have per day at the corresponding Distribution Warehouse.

Daily Mean	Daily Standard Deviation	Maximum Demand
45,350	250	46,100
6,871	36	6,978
67,339	357	68,409
27,485	143	27,913
361,429	1,891	367,101
52,222	285	53,078
32,982	178	33,517
8,246	36	8,353
196,519	1,034	199,622
97,572	499	99,070
12,368	71	12,582

Etc.

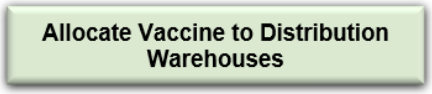
Columns I-K present the expected demands during one lead time at the Dispensing Locations supplied by each corresponding Distribution Warehouse. These are simply the values in *columns F-H* multiplied by the lead time entered in *column C*.

Lead Time Mean	Lead Time Standard Deviaion	Lead Time Maximum Demand
136,050	433	138,300
34,355	80	34,890
202,017	618	205,227
82,455	248	83,739
1,084,287	3,275	1,101,303
156,666	494	159,234
65,964	252	67,034
24,738	62	25,059
589,557	1,791	598,866
292,716	864	297,210
49,472	142	50,328

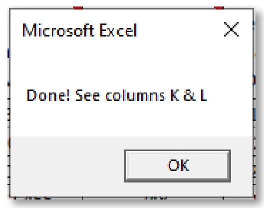
Etc.

The spreadsheet can accommodate up to 200 Distribution Warehouses served by one Manufacturer. There are no restrictions on naming conventions. However, you are not permitted to enter a Distribution Warehouse with zero or blank demand estimates between locations with positive demand estimates.

After you have entered these data, click the large "**Allocate Vaccine to Distribution Warehouse**" button:



For most scenarios, the model runs very quickly, and results are displayed almost immediately. In some scenarios, for example when box sizes are large and supplies are constrained, there may be some delay in displaying results while the calculations are performed. When the model completes calculating and posting its results, a done message will appear:



Upon completion, click the "OK" button to view results.

The results of the allocation decision will be displayed in *columns L through S*:

L	M	N	O	P	Q	R	S
2,998,700	29,987	8,774,267	938	38,299	0.9999	8,771,654	35,686
Allocation in doses	**Allocation in boxes**	Doses Available for Dispensing	Expected Shortages in doses	Expected Excess Supply in doses	Expected Vaccination (Fill) Rate	Optimal Stock Level S_j^*	Safety Stock
45,200	**452**	136,671	15	621	0.9999	136,631	581
7,000	**70**	34,546	0	191	1.0000	34,463	108
67,800	**678**	202,920	20	903	0.9999	202,847	830
27,600	**276**	82,869	5	414	0.9999	82,788	333
364,000	**3,640**	1,088,702	135	4,415	0.9999	1,088,679	4,392
52,600	**526**	157,341	19	675	0.9999	157,328	662
33,100	**331**	66,375	5	411	0.9999	66,302	338
8,300	**83**	24,897	0	159	1.0000	24,822	84
197,200	**1,972**	591,961	74	2,404	0.9999	591,959	2,402
97,400	**974**	293,949	30	1,233	0.9999	293,875	1,159
12,400	**124**	49,725	2	253	1.0000	49,663	191

Based on the available stock to allocate from the Manufacturer, the target probabilities of not running out of stock and the mean, standard deviation and maximum demand parameter values for each Distribution Warehouse (rows 15-64 in the sample spreadsheet), there corresponds the doses available for dispensing (*column N*), an expected number of potential patients that would not be accommodated (*column O*), the expected number of doses remaining unused at the end of the following day (*column P*), the expected vaccination or fill rate (*column Q*), the target stock level (*column R*) and target safety stock level (*column S*).

The vaccination rate is defined to be 1 – expected number of potential patients that would not be accommodated / total expected demand for all Distribution Warehouses. Note that while 3,000,000 doses were available for allocation, only 2,998,700 were shipped to Distribution Warehouses. This occurred because the target probability of not running out of stock, .91, at each Distribution

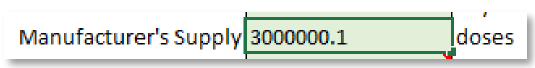
Warehouse was achieved without allocating all the stock. Note also that although the target probability of not running out of stock was .91 at all Distribution Warehouses, the expectation was that nearly all persons desiring vaccinations would receive them (vaccination rate = .9999 or close to 1).

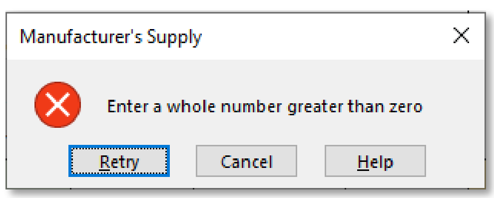
A Few Notes About Using the Worksheet

Most of the instructions contained in this user guide are also contained in the worksheet itself, as summarized by the statement in row 5:

Enter data in green cells. Other cells contain model outputs. See explanations in notes fields. Click "Allocate Vaccine to Distribution Warehouse" button to run the model.

The worksheet is protected. All but the green cells are locked, preventing any accidental input into cells intended for model outputs. To further aid the user, if an invalid number is entered in any of the green cells, error messages pop up. Informative messages guide the user to what values are valid. For example, if anything but a whole number greater than zero is entered in the "Manufacturer's Supply" field in cell C9, the following error message will appear:



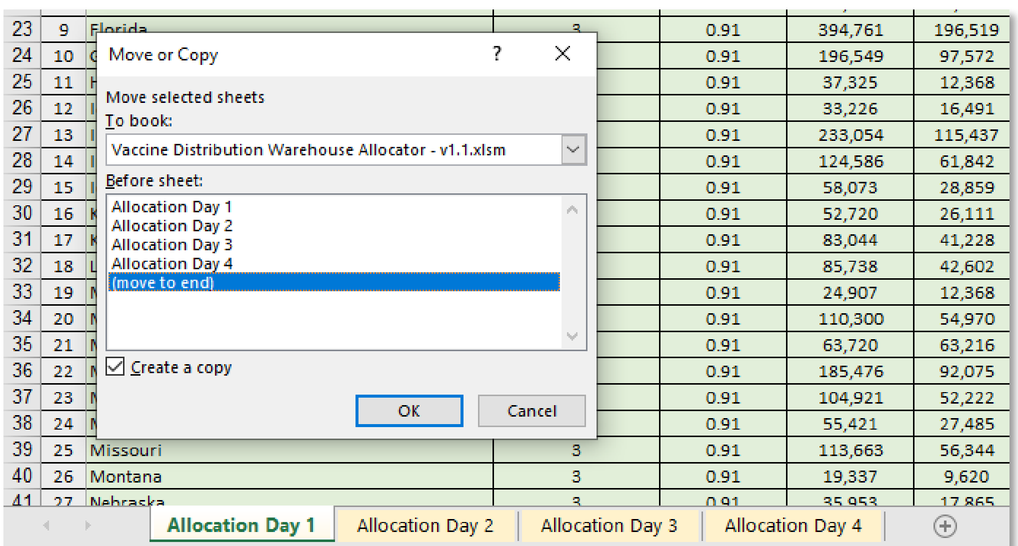


The spreadsheet contains information about both data input and data output fields at the top of the columns of data. The notes appear by hovering over any cell with a red triangle "◥" in the upper right portion. For example, when hovering over the "Manufacturer's Supply" field in cell C9, the following explanatory note appears:

> Enter the expected supply for the planning period.
>
> ***Discussion:***
>
> After all inputs are entered in the green cells and the model is run by hitting the "Allocate Vaccine to Dispensing Locations" button, recommended allocations of the expected supply to allocate will be displayed in columns K and L.
>
> When the expected supply to allocate is ***sufficient*** to supply all locations, the model will allocate each location enough supply to achieve its optimal supply based on its target probability of not running out of stock.
>
> If the expected supply is ***restricted*** but sufficient to bring all locations above their minimum estimated vaccine demand, then the model will allocate so as to maximize vaccinated person days as described in our academic paper.
>
> If the expected supply is ***severely restricted***, then the recommended allocation will be a "fair share" based on each location's expected demand without regard to its target probability of not running out of stock.
>
> More details on ***how and why*** this approach maximises vaccine protection are described in the academic paper at ssrn.com/abstract=3794252.

Each note follows a similar convention: a short description of the field is provided at the top of the note, a more detailed discussion follows. In the example above, we provide a short description of "Enter the expected supply for the planning period". In the discussion section, we explain how to run the model and how the model allocates the supply.

As stated previously, one worksheet represents the distribution of a single manufacturer's vaccine type from a single source of supply, for a single day. To prepare allocations for multiple days or multiple sources of supply, the worksheets can be copied and renamed within a single workbook and/or multiple workbooks can be copied and saved by right-clicking on the worksheet name:



In the example portion shown below, we have modelled a 50-state allocation of nearly 3 million vaccinations per day. The demand rates have been scaled to the populations of each state. The Distribution Location net inventories for each state are roughly equal to two days of supply, plus sufficient safety stock to achieve the target probabilities of not running out of stock during the lead time assumed in *column C*. Notice that the Doses Available for Dispensing in *column N* are all slightly higher than the Optimal Stock Levels listed in *column R*. This is due to the allocations of whole boxes containing 100 doses per box.

I	J	K	L	M	N	O	P	Q	R	S
8,735,968	26,599	8,872,497	2,998,700	29,987	8,774,267	938	38,299	0.9999	8,771,654	35,686
Estimated Vaccine Demand Parameters in doses										
Lead Time Mean	Lead Time Standard Deviaion	Lead Time Maximum Demand	**Allocation in doses**	**Allocation in boxes**	Doses Available for Dispensing	Expected Shortages in doses	Expected Excess Supply in doses	Expected Vaccination (Fill) Rate	Optimal Stock Level S^*_j	Safety Stock
136,050	433	138,300	**45,200**	**452**	136,671	15	621	0.9999	136,631	581
34,355	80	34,890	**7,000**	**70**	34,546	0	191	1.0000	34,463	108
202,017	618	205,227	**67,800**	**678**	202,920	20	903	0.9999	202,847	830
82,455	248	83,739	**27,600**	**276**	82,869	5	414	0.9999	82,788	333
1,084,287	3,275	1,101,303	**364,000**	**3,640**	1,088,702	135	4,415	0.9999	1,088,679	4,392
156,666	494	159,234	**52,600**	**526**	157,341	19	675	0.9999	157,328	662
65,964	252	67,034	**33,100**	**331**	66,375	5	411	0.9999	66,302	338
24,738	62	25,059	**8,300**	**83**	24,897	0	159	1.0000	24,822	84
589,557	1,791	598,866	**197,200**	**1,972**	591,961	74	2,404	0.9999	591,959	2,402
292,716	864	297,210	**97,400**	**974**	293,949	30	1,233	0.9999	293,875	1,159
49,472	142	50,328	**12,400**	**124**	49,725	2	253	1.0000	49,663	191

How to Report Problems or Suggestions

Comments and questions may be sent to ciddp@med.cornell.edu. We will strive to answer your questions in a timely manner, but our resources are limited and responses are not guaranteed.