Table 2 – Workers One Lane

This table determines the number of workers required to operate a fully staffed delivery lane.

Moreover, it explains why a delivery lane represents the smallest unit of calculation.

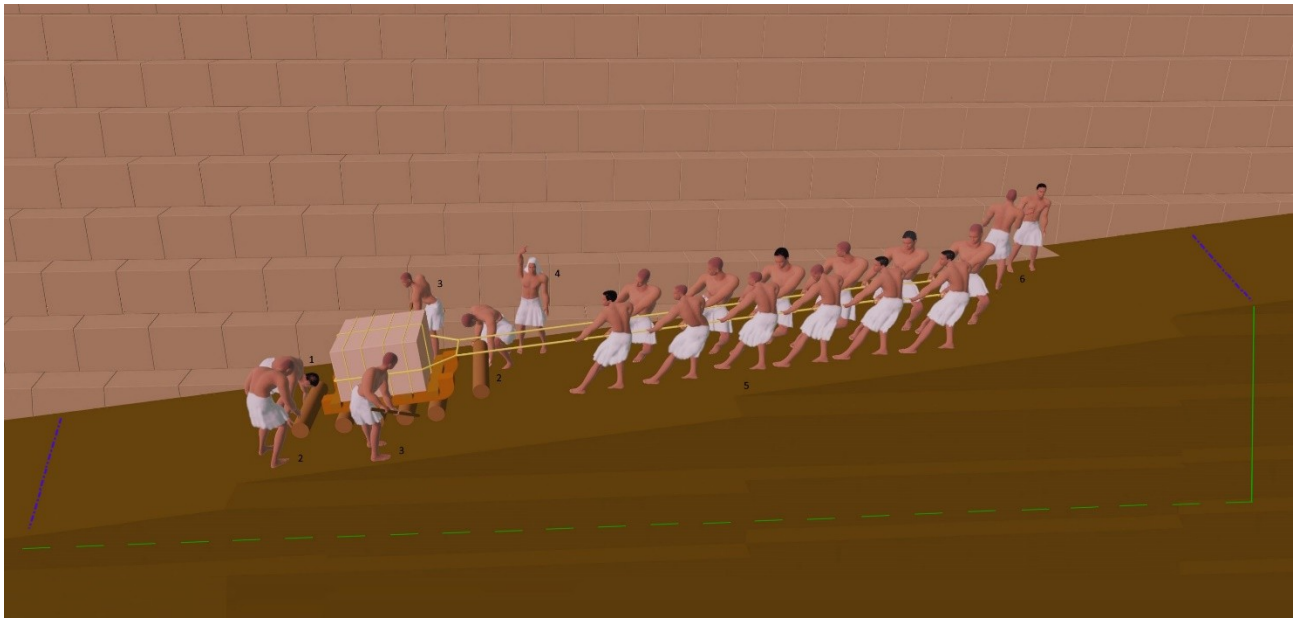
Since the paths become longer with increasing height, the number of workers increases with the height. From the very bottom to the very top there is an increase of just over 4 times.
A single transport lane requires about 1,800 workers at ground level and about 7,300 workers near the pyramidion.
There is an analysis and a diagram at the end of this document.

Let's consider only a single 3.3 m wide transportation lane on the pyramid. We also assume that this delivery lane is operating at full capacity, meaning a 2.3-ton block is delivered every 5 minutes. With two 6-hour shifts, this equates to 144 blocks per workday.

We can consider a delivery lane like an assembly line in a modern factory, which continually grows longer.

Based on the number of workers per lane, **Table 3** determines how many transport lanes on the pyramid can be operated simultaneously. This is a measure of the overall system's performance factor.

Level No.	The Level Number counts the levels from the bottom to the top (1 - 210).
Property	Special property of the level, i.e. medium.
Pyramid height m	Since each level has a height of 0.7 m, the height evaluates as follows: **Height = 0.7 * Level_No**
Corners	Number of corners of the path up to the corresponding level.



A towing team of 20 workers was required to transport a block with 2.3 tons.
The towing teams were spaced 18.75 m apart (blue lines), including a 6 m buffer.
The space needed for one team corresponded to an increase of 3.08 levels (green lines).
The teams moved at a speed of 3.75 m/min.
Thus, one block was delivered every 5 minutes with each transport lane.

Teams one lane

Number of towing teams needed for a single transportation lane.

This is a sum of the following components:

$T_1 = 2$

At the bottom of the pyramid, 2 towing teams were waiting to be deployed.

T_2 = Level_No / 3.08

This is the most important component, representing the number of teams that moved up the inclined ramps.

That means that there was a team on roughly 3 levels.

The slope of the ramps was 6.6 degrees.
The angle was chosen to be close to 7 degrees and in the rhythm of the pyramid, which corresponds to relation
$\tan(6.6°) = 1/5.5$

The towing teams were spaced by 18.75 m.
The height of one level is 0.7 m. Therefore, one team corresponds to 3.08 levels according to the relationship
$\sin(6.6°) = (3.08 * 0.7) / 18.75$

$T_3 = 1 + 0.5 * (210 - \text{Level\_No}) / 30$

This term represents the number of teams located on the surface of the pyramid.
There was 1 team waiting to remove the stone block.
The term $0.5 * (210 - \text{Level\_No})$ describes half the length of the pyramid surface measured in blocks.
Since there was no incline on the surface of the pyramid, a team could move within 5 minutes the length of 30 blocks, what corresponds to 33 m.

T_4 = Corners

This represents the number of corners up to the corresponding level.
There was a team at each corner for the turning maneuver.

$\text{Teams} = 1.2 * (T_1 + T_2 + T_3 + T_4)$

$= 1.2 * (3 + \text{Corners} + \text{Level\_No} / 3.08 + (210 - \text{Level\_No}) / 60))$

The factor 1.2 expresses that an additional 20 % of teams were on the way back.

This previous formula is very precise and somewhat complicated, but the following formula provides a good estimate:

$\text{Teams} \approx 1.2 * (7 + \text{Level\_No} / 3)$

From this it is easy to see that the number of towing teams increases linearly with the height of the pyramid.
A diagram at the end of this document provides an overview.

Workers towing

Number of workers in one day who towed the blocks on a single lane up to the corresponding level.

This is calculated as follows:

$$W_1 = 2 * 20 * Teams\_one\_lane$$

Each tow team consisted of 20 workers.
The factor 2 stands for the two shifts in one day.

According to the approximate formula, the following formula results:

$$W_1 \approx 336 + 16 * Level\_No$$

Workers quarries

Workers who worked in the quarries to supply one lane.
They had to produce, smooth, store and install blocks. Also, they had to transport the blocks next to but not onto the pyramid.

$$W_2 = 6 * 144 = 864$$

Each block required 6 days of work.
One block can be delivered per lane every 5 minutes.
This corresponds to 12 blocks per hour.
There were 2 shifts per day lasting 6 hours. This meant 12 working hours per day, allowing 144 blocks to be installed per day and per lane.

Workers productive

The productive workers were those who worked in the quarries or towed blocks.

$$W_3 = W_1 + W_2$$

Workers others

Workers which neither towed blocks nor worked in the quarries.

$$W_4 = W_3 * 34/66$$
$$= (W_1 + W_2)\ 34/66$$

The percentage of the productive workers were 66 %.
The percentage of the other workers were 34 %.

Workers total one lane

Total number of workers who supplied one lane.

$$W_5 = W_3 + W_4 = W_1 + W_2 + W_4$$
$$= (W_1 + W_2)\ 100/66$$

The derivation of this formula shows that all terms are related.
Therefore, a single delivery lane must be considered the smallest unit of calculation.

The following approximate formula results:

$$W_5 \approx 1{,}800 + 24 * Level\_No$$

Level No.	Property	Pyramid height m	Corners	Teams one lane	Workers towing	Workers quarries	Workers productive	Workers others	Workers total one lane
1	Bottom, 1st round	0.7	0	8.2	327	864	1,191	613	1,804
2		1.4	0	8.5	342	864	1,206	621	1,827
3		2.1	0	8.9	356	864	1,220	629	1,849
4		2.8	0	9.3	371	864	1,235	636	1,871
5		3.5	0	9.6	386	864	1,250	644	1,894
6		4.2	0	10.0	401	864	1,265	652	1,916
7		4.9	0	10.4	416	864	1,280	659	1,939
8		5.6	0	10.8	430	864	1,294	667	1,961
9		6.3	0	11.1	445	864	1,309	674	1,984
10		7.0	0	11.5	460	864	1,324	682	2,006

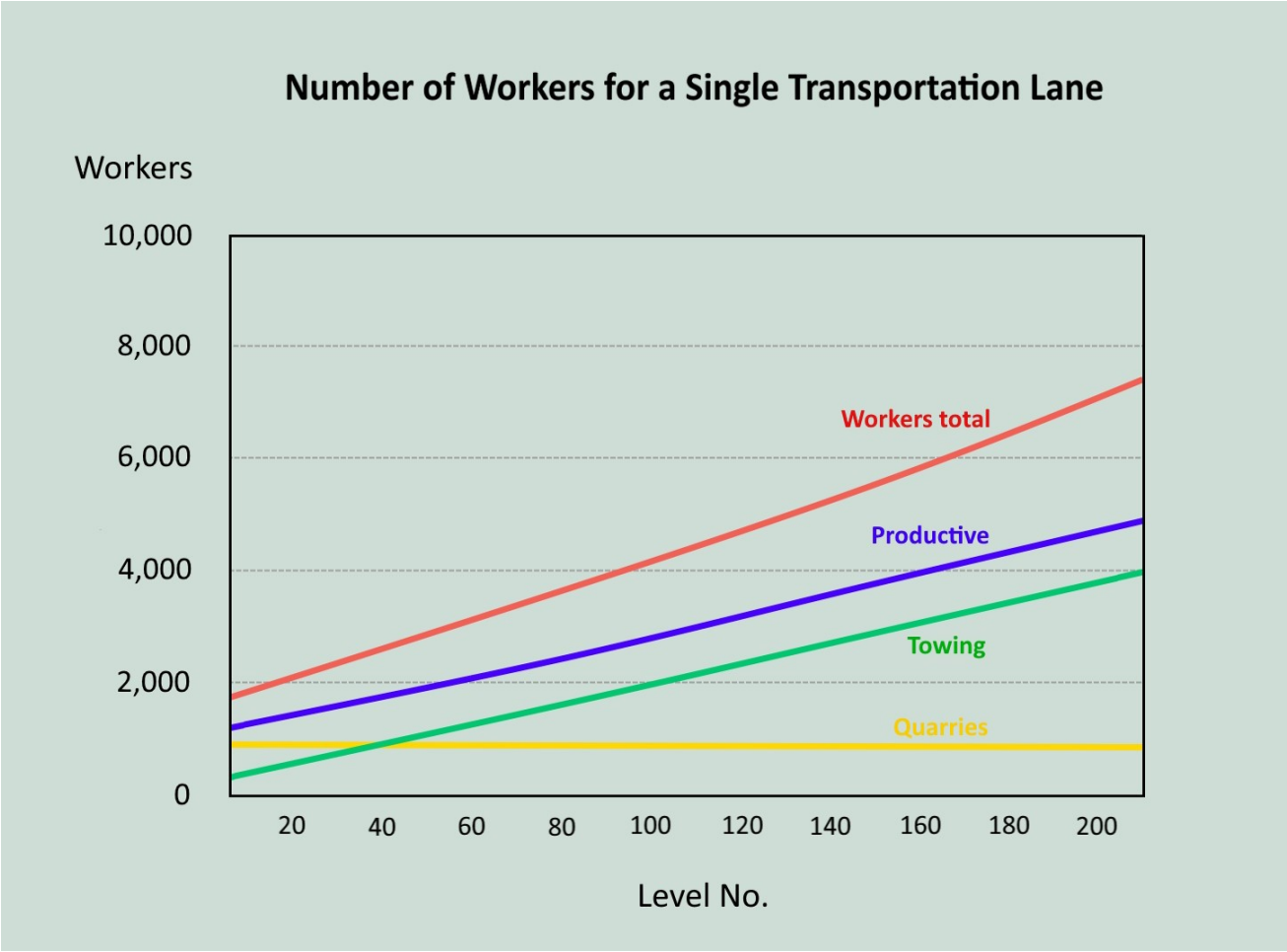
Level No.	Property	Pyramid height m	Corners	Teams one lane	Workers towing	Workers quarries	Workers productive	Workers others	Workers total one lane
11		7.7	0	11.9	475	864	1,339	690	2,028
12		8.4	0	12.2	489	864	1,353	697	2,051
13		9.1	0	12.6	504	864	1,368	705	2,073
14		9.8	0	13.0	519	864	1,383	712	2,096
15		10.5	0	13.3	534	864	1,398	720	2,118
16		11.2	0	13.7	549	864	1,413	728	2,140
17		11.9	0	14.1	563	864	1,427	735	2,163
18		12.6	0	14.5	578	864	1,442	743	2,185
19		13.3	0	14.8	593	864	1,457	751	2,208
20		14.0	0	15.2	608	864	1,472	758	2,230
21		14.7	0	15.6	623	864	1,487	766	2,252
22		15.4	0	15.9	637	864	1,501	773	2,275
23		16.1	0	16.3	652	864	1,516	781	2,297
24	North entrance	16.8	0	16.7	667	864	1,531	789	2,320
25		17.4	0	17.0	682	864	1,546	796	2,342
26		18.1	0	17.4	697	864	1,561	804	2,365
27		18.8	0	17.8	711	864	1,575	812	2,387
28		19.5	0	18.2	726	864	1,590	819	2,409
29		20.2	0	18.5	741	864	1,605	827	2,432
30		20.9	0	18.9	756	864	1,620	834	2,454
31		21.6	0	19.3	771	864	1,635	842	2,477
32		22.3	1	20.8	833	864	1,697	874	2,572
33	1st corner	23.0	1	21.2	848	864	1,712	882	2,594
34		23.7	1	21.6	863	864	1,727	890	2,617
35		24.4	1	21.9	878	864	1,742	897	2,639
36		25.1	1	22.3	892	864	1,756	905	2,661
37		25.8	1	22.7	907	864	1,771	912	2,684
38		26.5	1	23.1	922	864	1,786	920	2,706
39		27.2	1	23.4	937	864	1,801	928	2,729
40		27.9	1	23.8	952	864	1,816	935	2,751
41		28.6	1	24.2	966	864	1,830	943	2,773
42		29.3	1	24.5	981	864	1,845	951	2,796
43	Vol. 50%	30.0	1	24.9	996	864	1,860	958	2,818
44		30.7	1	25.3	1,011	864	1,875	966	2,841
45		31.4	1	25.6	1,026	864	1,890	973	2,863
46		32.1	1	26.0	1,040	864	1,904	981	2,885
47		32.8	1	26.4	1,055	864	1,919	989	2,908
48		33.5	1	26.7	1,070	864	1,934	996	2,930
49		34.2	1	27.1	1,085	864	1,949	1,004	2,953
50		34.9	1	27.5	1,100	864	1,964	1,012	2,975
51		35.6	1	27.9	1,114	864	1,978	1,019	2,998
52		36.3	1	28.2	1,129	864	1,993	1,027	3,020
53		37.0	1	28.6	1,144	864	2,008	1,034	3,042
54		37.7	1	29.0	1,159	864	2,023	1,042	3,065
55		38.4	1	29.3	1,174	864	2,038	1,050	3,087
56		39.1	1	29.7	1,188	864	2,052	1,057	3,110
57		39.8	1	30.1	1,203	864	2,067	1,065	3,132
58		40.5	1	30.4	1,218	864	2,082	1,073	3,154
59		41.2	1	30.8	1,233	864	2,097	1,080	3,177
60	2nd corner	41.9	2	32.4	1,295	864	2,159	1,112	3,272

Level No.	Property	Pyramid height m	Corners	Teams one lane	Workers towing	Workers quarries	Workers productive	Workers others	Workers total one lane
61		42.6	2	32.8	1,310	864	2,174	1,120	3,294
62		43.3	2	33.1	1,325	864	2,189	1,128	3,317
63		44.0	2	33.5	1,340	864	2,204	1,135	3,339
64		44.7	2	33.9	1,355	864	2,219	1,143	3,362
65		45.4	2	34.2	1,369	864	2,233	1,151	3,384
66		46.1	2	34.6	1,384	864	2,248	1,158	3,406
67		46.8	2	35.0	1,399	864	2,263	1,166	3,429
68		47.5	2	35.3	1,414	864	2,278	1,173	3,451
69		48.2	2	35.7	1,429	864	2,293	1,181	3,474
70	Height 1/3	48.9	2	36.1	1,443	864	2,307	1,189	3,496
71		49.6	2	36.5	1,458	864	2,322	1,196	3,518
72		50.3	2	36.8	1,473	864	2,337	1,204	3,541
73		51.0	2	37.2	1,488	864	2,352	1,212	3,563
74		51.6	2	37.6	1,503	864	2,367	1,219	3,586
75		52.3	2	37.9	1,517	864	2,381	1,227	3,608
76		53.0	2	38.3	1,532	864	2,396	1,234	3,631
77		53.7	2	38.7	1,547	864	2,411	1,242	3,653
78		54.4	2	39.0	1,562	864	2,426	1,250	3,675
79		55.1	2	39.4	1,577	864	2,441	1,257	3,698
80		55.8	2	39.8	1,591	864	2,455	1,265	3,720
81		56.5	2	40.2	1,606	864	2,470	1,272	3,743
82	3rd corner	57.2	3	41.7	1,669	864	2,533	1,305	3,838
83		57.9	3	42.1	1,684	864	2,548	1,312	3,860
84		58.6	3	42.5	1,698	864	2,562	1,320	3,883
85		59.3	3	42.8	1,713	864	2,577	1,328	3,905
86		60.0	3	43.2	1,728	864	2,592	1,335	3,927
87		60.7	3	43.6	1,743	864	2,607	1,343	3,950
88		61.4	3	43.9	1,758	864	2,622	1,351	3,972
89		62.1	3	44.3	1,772	864	2,636	1,358	3,995
90		62.8	3	44.7	1,787	864	2,651	1,366	4,017
91		63.5	3	45.1	1,802	864	2,666	1,373	4,039
92		64.2	3	45.4	1,817	864	2,681	1,381	4,062
93		64.9	3	45.8	1,832	864	2,696	1,389	4,084
94		65.6	3	46.2	1,846	864	2,710	1,396	4,107
95		66.3	3	46.5	1,861	864	2,725	1,404	4,129
96		67.0	3	46.9	1,876	864	2,740	1,412	4,152
97		67.7	3	47.3	1,891	864	2,755	1,419	4,174
98		68.4	3	47.6	1,906	864	2,770	1,427	4,196
99		69.1	3	48.0	1,920	864	2,784	1,434	4,219
100		69.8	3	48.4	1,935	864	2,799	1,442	4,241
101		70.5	4	49.9	1,998	864	2,862	1,474	4,336
102	2nd round	71.2	4	50.3	2,013	864	2,877	1,482	4,359
103		71.9	4	50.7	2,028	864	2,892	1,490	4,381
104		72.6	4	51.1	2,042	864	2,906	1,497	4,404
105	Median	73.3	4	51.4	2,057	864	2,921	1,505	4,426
106		74.0	4	51.8	2,072	864	2,936	1,512	4,448
107		74.7	4	52.2	2,087	864	2,951	1,520	4,471
108		75.4	4	52.5	2,101	864	2,965	1,528	4,493
109		76.1	4	52.9	2,116	864	2,980	1,535	4,516
110		76.8	4	53.3	2,131	864	2,995	1,543	4,538

Level No.	Property	Pyramid height m	Corners	Teams one lane	Workers towing	Workers quarries	Workers productive	Workers others	Workers total one lane
111		77.5	4	53.6	2,146	864	3,010	1,551	4,560
112	Vol. 90%	78.2	4	54.0	2,160	864	3,024	1,558	4,582
113		78.9	4	54.4	2,175	864	3,039	1,566	4,605
114		79.6	4	54.8	2,190	864	3,054	1,573	4,628
115		80.3	4	55.1	2,205	864	3,069	1,581	4,650
116		81.0	4	55.5	2,220	864	3,084	1,589	4,672
117		81.7	5	57.1	2,283	864	3,147	1,621	4,768
118		82.4	5	57.4	2,297	864	3,161	1,629	4,790
119		83.1	5	57.8	2,312	864	3,176	1,636	4,812
120		83.8	5	58.2	2,327	864	3,191	1,644	4,835
121		84.5	5	58.5	2,342	864	3,206	1,651	4,857
122		85.2	5	58.9	2,357	864	3,221	1,659	4,880
123		85.8	5	59.3	2,371	864	3,235	1,667	4,902
124		86.5	5	59.7	2,386	864	3,250	1,674	4,924
125		87.2	5	60.0	2,401	864	3,265	1,682	4,947
126		87.9	5	60.4	2,416	864	3,280	1,690	4,969
127		88.6	5	60.8	2,431	864	3,295	1,697	4,992
128		89.3	5	61.1	2,445	864	3,309	1,705	5,014
129		90.0	5	61.5	2,460	864	3,324	1,712	5,037
130		90.7	6	63.1	2,523	864	3,387	1,745	5,132
131		91.4	6	63.4	2,538	864	3,402	1,752	5,154
132		92.1	6	63.8	2,552	864	3,416	1,760	5,176
133		92.8	6	64.2	2,567	864	3,431	1,768	5,199
134		93.5	6	64.6	2,582	864	3,446	1,775	5,221
135		94.2	6	64.9	2,597	864	3,461	1,783	5,244
136		94.9	6	65.3	2,612	864	3,476	1,790	5,266
137		95.6	6	65.7	2,626	864	3,490	1,798	5,289
138		96.3	6	66.0	2,641	864	3,505	1,806	5,311
139		97.0	6	66.4	2,656	864	3,520	1,813	5,333
140	Height 2/3	97.7	7	68.0	2,719	864	3,583	1,846	5,429
141		98.4	7	68.3	2,734	864	3,598	1,853	5,451
142		99.1	7	68.7	2,748	864	3,612	1,861	5,473
143		99.8	7	69.1	2,763	864	3,627	1,869	5,496
144		100.5	7	69.4	2,778	864	3,642	1,876	5,518
145		101.2	7	69.8	2,793	864	3,657	1,884	5,541
146		101.9	7	70.2	2,808	864	3,672	1,891	5,563
147		102.6	7	70.6	2,822	864	3,686	1,899	5,585
148		103.3	7	70.9	2,837	864	3,701	1,907	5,608
149		104.0	8	72.5	2,900	864	3,764	1,939	5,703
150	3rd round	104.7	8	72.9	2,915	864	3,779	1,947	5,725
151		105.4	8	73.2	2,930	864	3,794	1,954	5,748
152		106.1	8	73.6	2,944	864	3,808	1,962	5,770
153		106.8	8	74.0	2,959	864	3,823	1,969	5,793
154		107.5	8	74.3	2,974	864	3,838	1,977	5,815
155		108.2	8	74.7	2,989	864	3,853	1,985	5,837
156		108.9	8	75.1	3,003	864	3,867	1,992	5,860
157		109.6	9	76.7	3,066	864	3,930	2,025	5,955
158		110.3	9	77.0	3,081	864	3,945	2,032	5,977
159		111.0	9	77.4	3,096	864	3,960	2,040	6,000
160		111.7	9	77.8	3,111	864	3,975	2,048	6,022

Level No.	Property	Pyramid height m	Corners	Teams one lane	Workers towing	Workers quarries	Workers productive	Workers others	Workers total one lane
161		112.4	9	78.1	3,125	864	3,989	2,055	6,045
162		113.1	9	78.5	3,140	864	4,004	2,063	6,067
163		113.8	9	78.9	3,155	864	4,019	2,070	6,089
164	Vol. 99%	114.5	10	80.4	3,218	864	4,082	2,103	6,185
165		115.2	10	80.8	3,233	864	4,097	2,110	6,207
166		115.9	10	81.2	3,247	864	4,111	2,118	6,229
167		116.6	10	81.6	3,262	864	4,126	2,126	6,252
168		117.3	10	81.9	3,277	864	4,141	2,133	6,274
169		118.0	11	83.5	3,340	864	4,204	2,166	6,369
170		118.7	11	83.9	3,355	864	4,219	2,173	6,392
171		119.3	11	84.2	3,369	864	4,233	2,181	6,414
172		120.0	11	84.6	3,384	864	4,248	2,188	6,437
173		120.7	11	85.0	3,399	864	4,263	2,196	6,459
174		121.4	12	86.5	3,462	864	4,326	2,228	6,554
175	4th round	122.1	12	86.9	3,477	864	4,341	2,236	6,577
176		122.8	12	87.3	3,491	864	4,355	2,244	6,599
177		123.5	12	87.7	3,506	864	4,370	2,251	6,621
178		124.2	13	89.2	3,569	864	4,433	2,284	6,717
179		124.9	13	89.6	3,584	864	4,448	2,291	6,739
180		125.6	13	90.0	3,598	864	4,462	2,299	6,761
181		126.3	13	90.3	3,613	864	4,477	2,306	6,784
182		127.0	14	91.9	3,676	864	4,540	2,339	6,879
183		127.7	14	92.3	3,691	864	4,555	2,346	6,901
184		128.4	14	92.6	3,706	864	4,570	2,354	6,924
185		129.1	14	93.0	3,720	864	4,584	2,362	6,946
186		129.8	14	93.4	3,735	864	4,599	2,369	6,969
187		130.5	14	93.8	3,750	864	4,614	2,377	6,991
188	Vol. 99.9%	131.2	14	94.1	3,765	864	4,629	2,385	7,013
189	5th round	131.9	14	94.5	3,780	864	4,644	2,392	7,036
190		132.6	14	94.9	3,794	864	4,658	2,400	7,058
191		133.3	14	95.2	3,809	864	4,673	2,407	7,081
192		134.0	14	95.6	3,824	864	4,688	2,415	7,103
193		134.7	14	96.0	3,839	864	4,703	2,423	7,125
194		135.4	14	96.3	3,854	864	4,718	2,430	7,148
195		136.1	14	96.7	3,868	864	4,732	2,438	7,170
196		136.8	14	97.1	3,883	864	4,747	2,446	7,193
197		137.5	14	97.4	3,898	864	4,762	2,453	7,215
198		138.2	14	97.8	3,913	864	4,777	2,461	7,237
199	6th round	138.9	14	98.2	3,928	864	4,792	2,468	7,260
200	Vol. 99,99%	139.6	14	98.6	3,942	864	4,806	2,476	7,282
201		140.3	14	98.9	3,957	864	4,821	2,484	7,305
202		141.0	14	99.3	3,972	864	4,836	2,491	7,327
203	7th round	141.7	14	99.7	3,987	864	4,851	2,499	7,350
204		142.4	14	100.0	4,001	864	4,865	2,506	7,372
205		143.1	14	100.4	4,016	864	4,880	2,514	7,394
206		143.8	14	100.8	4,031	864	4,895	2,522	7,417
207	8th round	144.5	14	101.1	4,046	864	4,910	2,529	7,439
208		145.2	14	101,5	4.061	864	4.925	2.537	7.462
209	9th round	145.9							
210	Pyramidion	146.5							

Analysis



144 blocks are quarried, transported, and installed each working day.
Therefore, the number of workers in the quarries (yellow) remains constant at 864, regardless of the height of pyramid.

As the paths become longer with the height of the pyramid, more teams are on the paths and more workers are needed to tow (green).

Table 3 shows for each level, how many transport lanes can be operated based on the worker capacity.
The calculated number of transport lanes must also physically exist.
This is determined in **Table 1**.

In the literature, a single tow team is usually used as the starting point for the calculation. However, this is problematic because the quantity delivered depends heavily on the height of the pyramid. Furthermore, the number of workers required for towing, production, and overhead are linked. Therefore, a single delivery lane must be considered as the **smallest functional unit**, comparable to an assembly line in a modern factory.

As the pyramid grows taller, the paths become longer and more towing teams are required. Therefore, the total workforce per lane increases.
The number of delivery lanes is a measure of the overall system's performance factor.

Final Remark:

This table is based on the geometric properties of a transport lane as defined in **Table 1**.

Table 3 determines the number of transport lanes per level.
The following results are required for this:

Table 1 (physically existing lanes),

Table 2 (workers one lane).

The results presented in each table are solely a consequence of the results in the preceding tables.
There are no hidden assumptions, no implicit conclusions.

All tables, images, and further information www.cheops-pyramid.net/en

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