Deriving an Equation for Number of Printers in a Print Farm for the 6th International Symposium on Academic Makerspaces

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Introduction

This abstract demonstrates the method used by the Terrapin Works 3D Printer Farm (TWPF) to determine the number of 3D printers to purchase in a makerspace overhaul.

The TWPF, a 3D printing lab at the University of Maryland, College Park, provides 3D printing services to students, faculty and staff. In 2019, the TWPF served more than 700 customers and printed for more than 25,000 hours across its 35 Fused Filament Fabrication (FFF) 3D printers.

In the fall of 2021, the TWPF began planning the replacement of its 3D printers, due to their age and the manufacturers retirement of its print tracking software, the Innovation Center Platform (ICP). The central goal of the overhaul was to match the maximum output of the old print farm. The TWPF used the process described in this abstract to reduce its quantity of printers from forty to only fifteen.

Data

Some terms of the calculation detailed in this abstract were gathered from an ICP data set from April 2019 to February 2020, which contains start dates, print times, and outcomes. However, some data entries from this set are missing a print time value. This is corrected for in the calculation, and the correction is detailed in the derivation section.

Derivation

The goal is to transform the constraint that the old maximum output and the new maximum output must match into an equation for calculating the number of printers. To do so, a numerical metric for output is defined as the successful print time per day of the farm. With this metric, the constraint can be restated as (1), where O_{new} is the peak output the new farm is capable of, and O_{old} is the peak output of the old farm.

$$O_{new} = O_{old} \tag{1}$$

Since O_{new} is the peak output of the entire farm it is equal to the number of printers multiplied by the peak output of each printer. This relationship is shown in (2), where N is

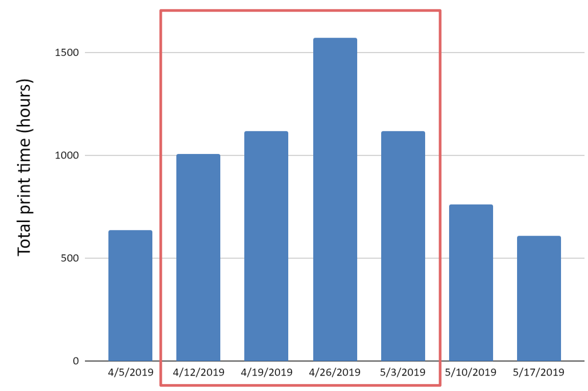

Fig 1. Histogram of print time by week from 4/5/2019 to 5/23/2019. Highlighted 4/12/19 to 5/9/2019.

the number printers, and o_{new} is the average output a new printer is capable of.

$$O_{new} = N * o_{new} \tag{2}$$

Combining (1) and (2) gives (3), an equation for calculating the number of printers in terms of the peak output of the old farm and the average peak output of the new printers. So now the goal becomes finding a value for O_{old} and o_{new}.

$$N = \frac{O_{old}}{o_{new}} \tag{3}$$

o_{new} can be broken down into the product of t_{new}, the average print time per day including success and failures, and r_{new}, the success rate of the printer, as shown in (4).

$$o_{new} = t_{new} * r_{new} \tag{4}$$

r_{new} is estimated to be 85% across the lifetime of the printer. This is estimated from anecdotal evidence based off of the old farm in its prime. t_{new} is constrained by when technicians are able to start and harvest jobs. For example, if a print finishes at 3 AM, there will be at least 6 hours of downtime until a technician arrives at 9 AM and starts a new print. The TWPF examined its schedule to better estimate t_{new}.

Technicians harvest old prints and start new ones between 9 and 10 AM and between 3 and 4 PM. Prints less than 5 hours, can print between 10 AM and 3 PM, and longer prints can print between 4 PM and 9 AM the next day. With this in mind, it is estimated that the TWPF can print for an average of 3 hours between 10 AM and 3 PM, and for 10-14 hours between 4 PM and 9 AM. Summing these values, gives an upper limit of 13 hours and a lower limit of 17 hours on t_{new}. Plugging into (4) gives an upper limit on o_{new} of 14.5 hours and a lower limit of 11 hours. With these limits, all that is needed to calculate a range for N is O_{old}.

O_{old} is equal to the average output over the busiest period from the ICP data set. It is calculated by dividing $t_{successful}$, the total successful print time, by T, the number of workdays.

$$O_{old} = \frac{t_{successful}}{T} \quad (5)$$

To find the busiest period in the data set, the TWPF examined the print time per week of the ICP data set. The busiest period in the data set was from April 12th to May 9th, as shown in Fig. 1. This period contains four of the seven weeks in the data set with over 1000 hours of print time, and correlated with expectations that the largest surges occur shortly before the end of the spring and fall semesters.

From April 12th to May 9th, the total recorded print time, $t_{recorded}$, was 5450 hours, and the success rate was 63%. Similarly to (4), (6) breaks $t_{successful}$ into the product of the total print time and the success rate. However, as mentioned earlier, there are 208 entries during the four weeks that are missing print times. To account for this, t_{total} is calculated as the sum of the recorded print time and an estimation of the lost print time, which is calculated in (7).

r_{old} is the success rate over the four weeks, 63%. n_{loss} is the number of missing print times, 208. t_{avg} is the average print time of the entire data set, 5.38 hours. Combining (5), (6), and (7) and plugging in all of the values gives a value for O_{old} of 207 hours per day.

$$t_{successful} = t_{total} * r_{old} \quad (6)$$

$$t_{total} = t_{recorded} + n_{loss} * t_{avg} \quad (7)$$

Results and Conclusions

With a value for O_{old} and bounds for o_{new}, (3) can be used to find upper and lower bounds for N.

$$\frac{207}{14.5} < N < \frac{207}{11} \quad (8)$$

$$14 < N < 19 \quad (9)$$

The TWPF opted on the lower side of (9), 15 printers, because the decline in demand caused by the pandemic is ongoing. By purchasing on the lower side, the TWPF saves on expenses in the short term, and leaves the option to expand as demand increases.

At its peak, the TWPF operated with 40 printers. This process showed that the lab could reduce that amount to only 15. This is a reduction in quantity of 63%. Combined with a further 60% reduction in unit price, the new farm costs 85% less than the old. Less printers require less technicians, training, and support. The reduction in quantity will also lower maintenance and labor costs over the lifetime of the new farm.

Lessons and Future Plans

Over the next year the TWPF aims to reestablish data collection to a similar or greater degree as the ICP. The TWPF wants to reexamine how it gathered t_{new} and r_{new} in the calculation to see if it can improve its methods. An examination of the distribution of print durations and how they fit into the TWPFs schedule could improve the calculation of t_{new}. r_{new} can be tracked in the same manner as r_{old} once data collection is reestablished in the new farm. r_{new} is likely to be above 85% while the printers are brand new, and tracking how the success rate declines with age could help in determining when to initiate a new overhaul.

If a makerspace has the same question as the TWPF, "how many printers to purchase in an overhaul?", this process could be directly translatable. If not, then hopefully this abstract demonstrates the benefits of gathering quantitative data about makerspaces, translating qualitative goals into mathematical constraints, and utilizing those tools in answering difficult questions.

Table 1 Symbols, terms, definitions and values

Output	Successful print time per day	
O_{new}	Peak output the new farm is capable of.	
O_{old}	Peak output of the old farm.	207 hours
N	Number of printers to purchase	14-19
o_{new}	Average output a new printer is capable of.	11-14.5 hours
t_{new}	Average print time per day the new printers are capable of	13-17 hours
r_{new}	Success rate of new printers	85%
$t_{successful}$	The estimated successful print time from April 12th to May 9th	4138 hours
T	The number of workdays from April 12 to May 9th	20
t_{total}	The estimated total print time from April 12th to May 9th	6569 hours
r_{old}	The success rate across the ICP data set	63%
$t_{recorded}$	The recorded print time from April 12th to May 9th	5450 hours
n_{loss}	The number of data entries missing a print time value from April 12th to May 9th	208
t_{avg}	The average print time across the ICP data set	5.38 hours