Replacing Vacuum Ejectors with PV Central Vacuum System

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Global Trend

Increase Productivity via automation has become an imperative option since it more reliable, faster and affordable nowadays. Using Vacuum as a mean for pick & place or hold-down remain a corner stone technology for such automated production.

Hence, many new automation machine / production line are being equipped with Vacuum Ejectors because of its ease of adaption and low initial ownership cost to generate vacuum.

Whilst this approach to vacuum generation is feasible when the needs are minimal, it generate a very high cost on energy.

The Difference?

A Vacuum Ejector uses Dry Compressed Air as the motive medium to generate vacuum. In other words, a constant flow of compressed air is required as long as suction (vacuum) is required.

This is entirely difference for a PV Central Vacuum Source. The system generally remain passive throughout the Production/Machine Cycle after the initial effort to produce the vacuum required.

In other words, in a Production Facility the demand for vacuum at each of the Point Of Use will happen haphazardly or intermittently giving rise to the opportunity of applying a diversity factor.

The combination effects of such an approach will be able to generate Average Reduction in Energy Cost of up to 80%.

To better illustrate this effects, we will use a Case;

Case Study Base Parameters;

1. Two Electronic Production Facility that has 759 Testers and 2333 Testers respectively.
2. Each Tester Production Cycle is 25 Minutes
3. Consumption of Vacuum is Process Driven. It happens for a total of 4 seconds per cycle. 2 seconds at the start and 2 seconds at the end of the cycle.
4. The Plants have an Average Total Production Cycle of 7301.83 Cycles Per Hour.

Design Assumptions / Basis

1. Since vacuum consumption happens at the start and end of the cycle, we would assume that for every 25 divided by 2 = 12.5 minutes, there is a demand for vacuum.
2. In other words, the worst case (busiest time), all the tester installed will requires vacuum once within 12.5 minutes duration.
3. Since there is a TIME Lapse between Process Respond and Mechanical Activation, we will use the industry practice of adopting a 10 seconds duration for any vacuum demand.
4. The allowable Threshold for Error in computation resulting in the necessity for a Tester to have to wait to conduct it process is 0.02%. In other words, there will be No LACK IN VACUUM UTILITIES WHEN IT REQUIRED BY ANY TESTER 99.98% OF THE TIME.

Computed Diversity Factor

1. Taking Reference from Appendix One & Two, the Minimum Numbers of Testers Demand to be designed will be 24 out of 759 & 54 out of 2333 respectively.

Energy Cost

Plant	Using Conventional Vacuum Ejectors	PV Central Vacuum System	Remarks
759 Testers	1 to 2 x 315 Kw Air Compressors	1 to 2 x 90 Kw PV Vacuum Package	Dry Compressed Air is Required for Vacuum Ejectors to generate vacuum.
2333 Testers	4 to 5 x 315 Kw Air Compressors	2 to 3 x 90 kw Vacuum Package	

Conclusion

It is clear in the above example which is based on actual field data, the saving in Energy Cost of PV approach is quite significant.

System Usage Queues

Assume that during the busiest time, an average of 759 users demand per 12.5 Minutes, and the average usage time (use per vacuum point) is 10 seconds.

Average Users' demand rate during the busiest time: $\lambda := \dfrac{759}{12.5\text{min}}$

Average time for Usage At Each Vacuum Point: $x := 10 \cdot \text{sec}$

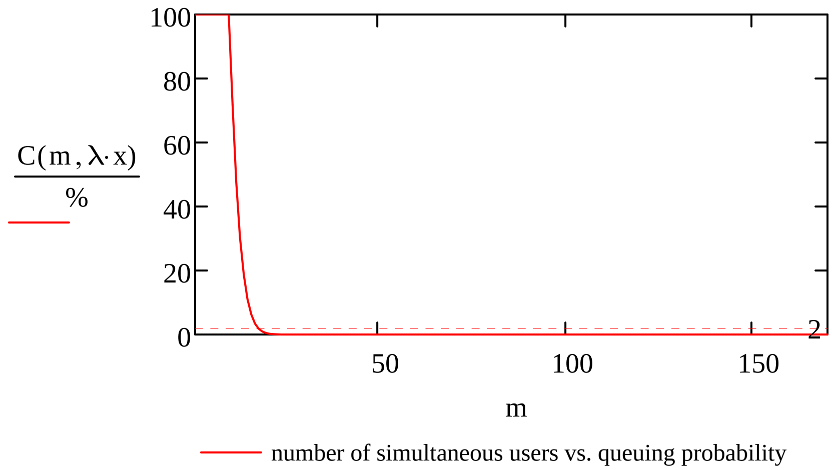
We will use queuing theory (the discipline which concerns itself with waiting-in-line systems) to calculate the probability of waiting for use of the system, given the numbers above. We know from queuing theory that, for this type of queuing system, the probability of waiting is given by the Erlang 's delay formula:

$$C(m,a) := \text{if}\left[\frac{a}{m} < 1, \frac{\dfrac{a^m}{m!}}{\left(1-\dfrac{a}{m}\right)\cdot\displaystyle\sum_{i=0}^{m-1}\frac{a^i}{i!}+\frac{a^m}{m!}}, 1\right]$$

Here, m is the number of Allow Simultaneous Users In The System, and a = λx. This formula reflects the fact that, for some ratios of Demand to number of Simultaneous Users, there will always be a wait; specifically, if λx / m >1, your changes of waiting for use are 100%.

Let's plot the queuing probability for 1 to 759 Simultaneous Users. Since we want this probability to be less than 0.02%, this threshold is shown on the graph.

number of simultaneous users $\boxed{m := 1..759}$



It looks like the 0.02% line crosses the probability curve at around **24**, given this rate of demands. The exact percentage probability of waiting with **24** simultaneous users system is calculated at right.

$$\boxed{C(24, \lambda \cdot x) = 0.015\%}$$

The graph also shows how the probability of having to wait decreases as we add simultaneous users. The trend of the curve is predictable: the more simultaneous users added, the less likely that users will have to wait. Notice also that the relationship is not linear. If only **23** simultaneous users are available instead of **24**, the probability of waiting jumps from 0.015% to over 0.037%.

$\boxed{\frac{24 - 23}{24} = 4.167\%}$ percent decrease in number of simultaneous users

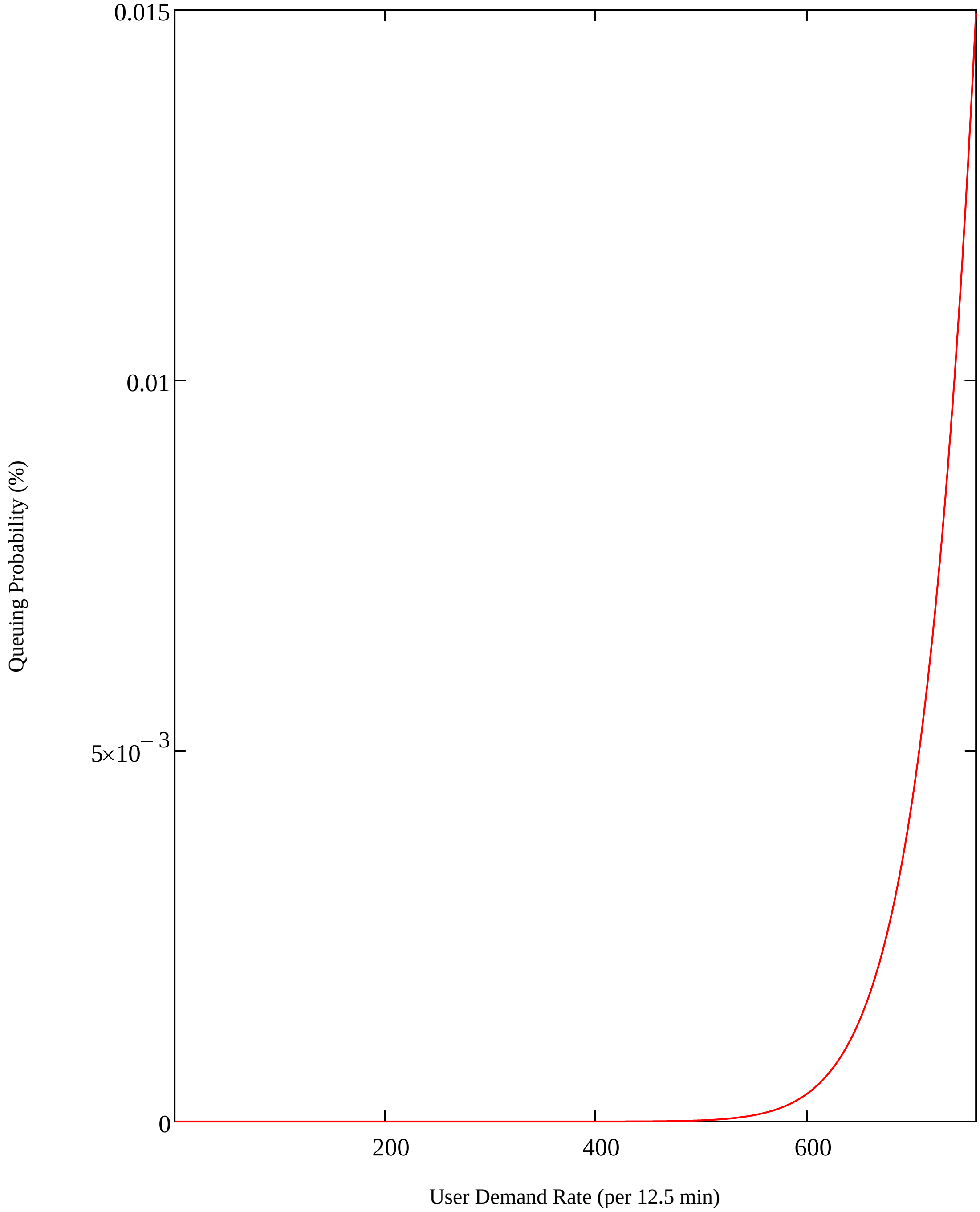
$\boxed{C(23, \lambda \cdot x) = 0.037\%}$ new probability of having to wait

$\boxed{\frac{C(23, \lambda \cdot x)}{C(24, \lambda \cdot x)} = 2.449}$ increase in probability

Now, consider what happens if the number of simultaneous users remains the same, but the average demand rate increases. As traffic increases, it’s reasonable to expect that the probability of waiting does so as well.

number of simultaneous users $\boxed{m := 24}$

average users’ demand rate during the busiest time $\boxed{\lambda := \frac{1}{12.5\mathrm{min}}, \frac{2}{12.5\mathrm{min}} .. \frac{759}{12.5\mathrm{min}}}$



Engineering Computation Sheet

Project Name: Appendix Two

Project No: NA Date: X-XX-XXXX

Subject: Probability Of Waiting To Use System

CENTRAL VACUUM SYSTEM

System Usage Queues

Assume that during the busiest time, an average of 2333 users demand per 12.5 Minutes, and the average usage time (use per vacuum point) is 10 seconds.

Average Users' demand rate during the busiest time: $\lambda := \frac{2333}{12.5\text{min}}$

Average time for Usage At Each Vacuum Point: $x := 10 \cdot \text{sec}$

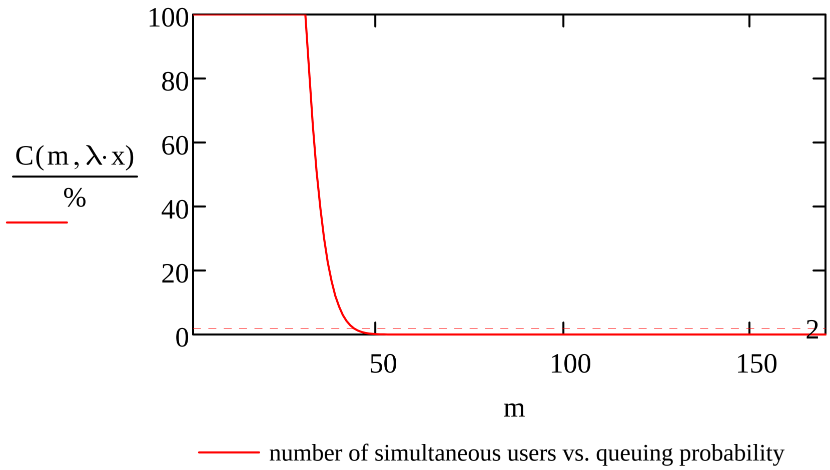
We will use queuing theory (the discipline which concerns itself with waiting-in-line systems) to calculate the probability of waiting for use of the system, given the numbers above. We know from queuing theory that, for this type of queuing system, the probability of waiting is given by the Erlang 's delay formula:

$$C(m,a) := \text{if}\left[\frac{a}{m} < 1, \frac{\frac{a^m}{m!}}{\left(1 - \frac{a}{m}\right)\cdot\sum_{i=0}^{m-1}\frac{a^i}{i!} + \frac{a^m}{m!}}, 1\right]$$

Here, m is the number of Allow Simultaneous Users In The System, and a = λx. This formula reflects the fact that, for some ratios of Demand to number of Simultaneous Users, there will always be a wait; specifically, if $\lambda x / m > 1$, your changes of waiting for use are 100%.

Let's plot the queuing probability for 1 to 2333 Simultaneous Users. Since we want this probability to be less than 0.02%, this threshold is shown on the graph.

number of simultaneous users $m := 1..2333$



It looks like the 0.02% line crosses the probability curve at around **54**, given this rate of demands. The exact percentage probability of waiting with **54** simultaneous users system is calculated at right.

$C(54, \lambda \cdot x) = 0.013\%$

The graph also shows how the probability of having to wait decreases as we add simultaneous users. The trend of the curve is predictable: the more simultaneous users added, the less likely that users will have to wait. Notice also that the relationship is not linear. If only **53** simultaneous users are available instead of **54**, the probability of waiting jumps from 0.013% to over 0.023%.

$\frac{54 - 53}{54} = 1.852\%$ percent decrease in number of simultaneous users

$C(53, \lambda \cdot x) = 0.023\%$ new probability of having to wait

$\frac{C(53, \lambda \cdot x)}{C(54, \lambda \cdot x)} = 1.782$ increase in probability

Now, consider what happens if the number of simultaneous users remains the same, but the average demand rate increases. As traffic increases, it’s reasonable to expect that the probability of waiting does so as well.

number of simultaneous users $\boxed{m := 54}$

average users’ demand rate during the busiest time $\boxed{\lambda := \frac{1}{12.5\text{min}}, \frac{2}{12.5\text{min}} .. \frac{2333}{12.5\text{min}}}$