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Modeling Impact of Execution Strategies on Resource Utilization

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Problem statement

The **load** on a resource is defined as a number of busy nodes at a certain time; it is determined by the number and parameters of jobs:

- the number of required nodes per job;
- required execution time called wall time per job;
- jobs generation rate.

The concept of an execution strategy is defined as the set of values of denoted parameters that uniquely define the group of jobs to be executed.

The goal

- find execution strategies that maximize the probability of utilizing a certain allocated resources;
- find the execution strategy that will optimize the utilization of a given number of core-hours on a resource.

Methods

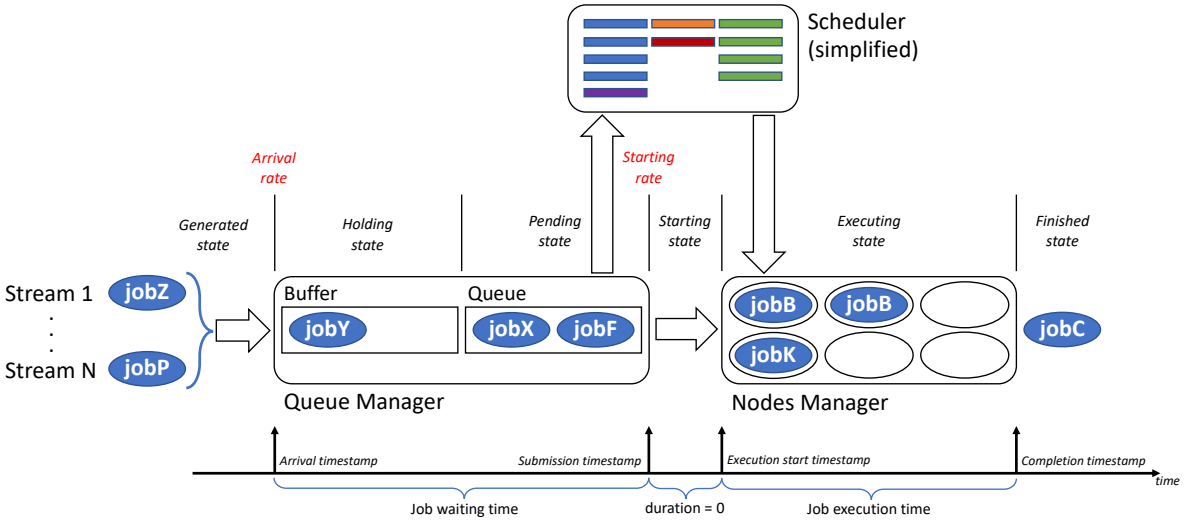
Simulator

Simulates the load on a supercomputer and produces job traces for a given workload

- used for the quantitative model validation and adjustment;
- based on queueing theory (M/M/total_num_nodes);
- supports job priorities and backfill mode;
- explicit job state model (state transitions).

Scheduler (backfill mode)

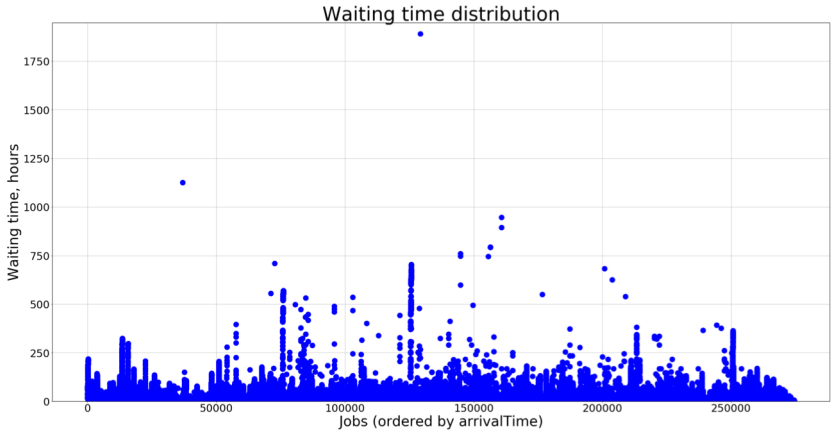
- **Input:** gets info about job sizes & duration and assigns corresponding nodes
- **Output:** a schedule when each job starts and executes



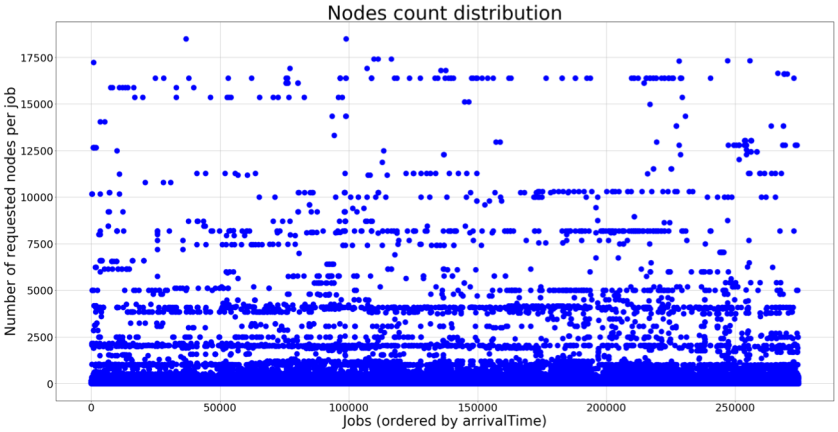
Job state transitions

Waiting time distributions

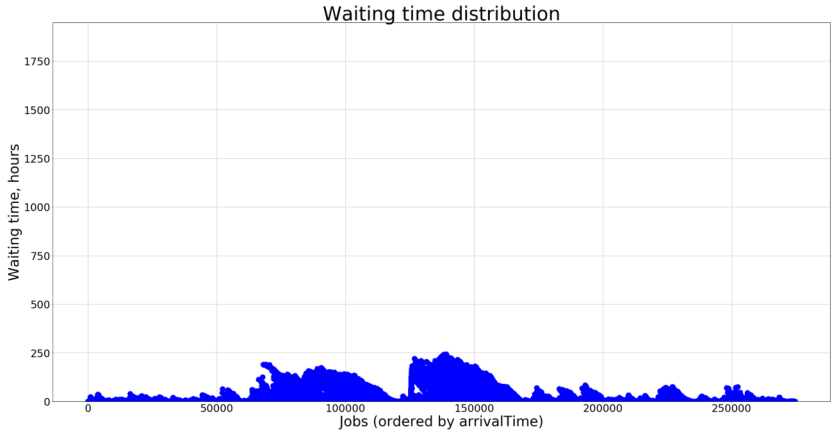
Titan log data *(from aug'17 to jan'18)*



waitingTime (hours) - mean=5.75, std=30.59



Simulator using Titan log data

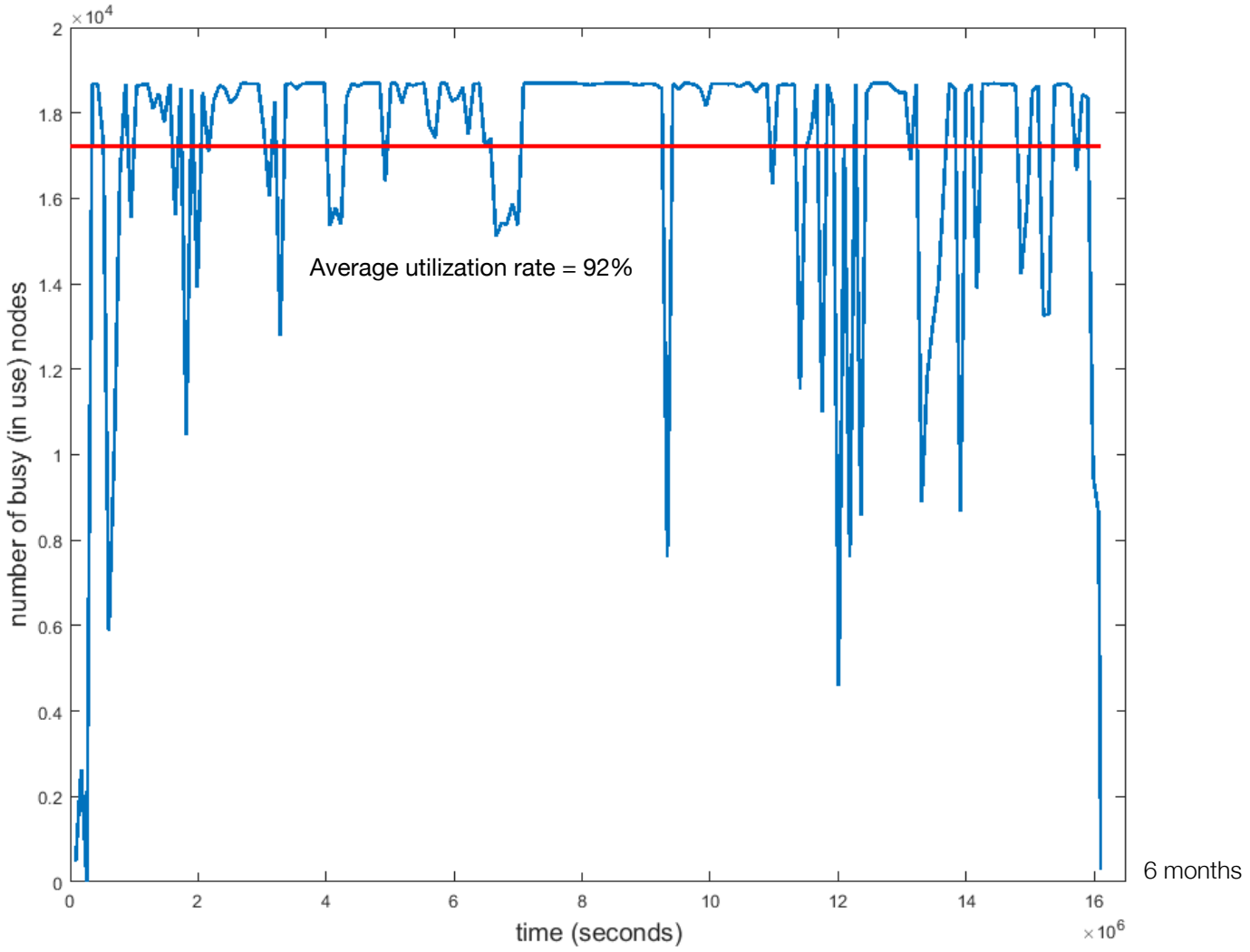


waitingTime (hours) - mean=14.50, std=37.54

Simulation parameters:

- Job characteristics from Titan log
  - arrival timestamp
  - number of nodes per job
  - real execution time
- Queue characteristics
  - priority discipline
  - initial priorities (for "big" jobs)
  - no limitation by stream
- Scheduling usage

Simulator load using Titan log data



6 months

Quantitative model

A quantitative model to estimate the probability of a given number of core-hours being utilized

- trained by the previous processes of utilization of the resource;
- represented by the equation which calculates the probability that utilization U during the time interval $\mathrm{T_0}$ will reach or exceed the predefined value $\mathrm{U_0}$.

$$P\,(U > U_0) = \sum_{n=100}^{\infty} \left[\int_{U_0}^{\infty} f\left(x, n\mu_U, n\sigma_U^2\right) dx \left(\int_{-\infty}^{T_0} f\,(x, n\mu, n\sigma^2)\, dx - \int_{-\infty}^{T_0} f\,(x, (n+1)\mu, (n+1)\sigma^2)\, dx \right) \right]$$

Probability that utilization will reach the defined utilization value during the defined time period (cumulative distribution function).

- $\mathrm{f(x, \mu, \sigma^2)}$ is a function of probability density of the normal distribution $\mathrm{N(\mu, \sigma^2)}$;
- μ and σ^2 are expected value and variance of a random variable describing duration of waiting time in the queue for jobs correspondingly;
- μ_U and σ_U^2 - the same as previous, but for a random variable describing utilization of one job.

Quantitative model testing with synthetic data (I)

Common parameters for the quantitative model and for the simulator

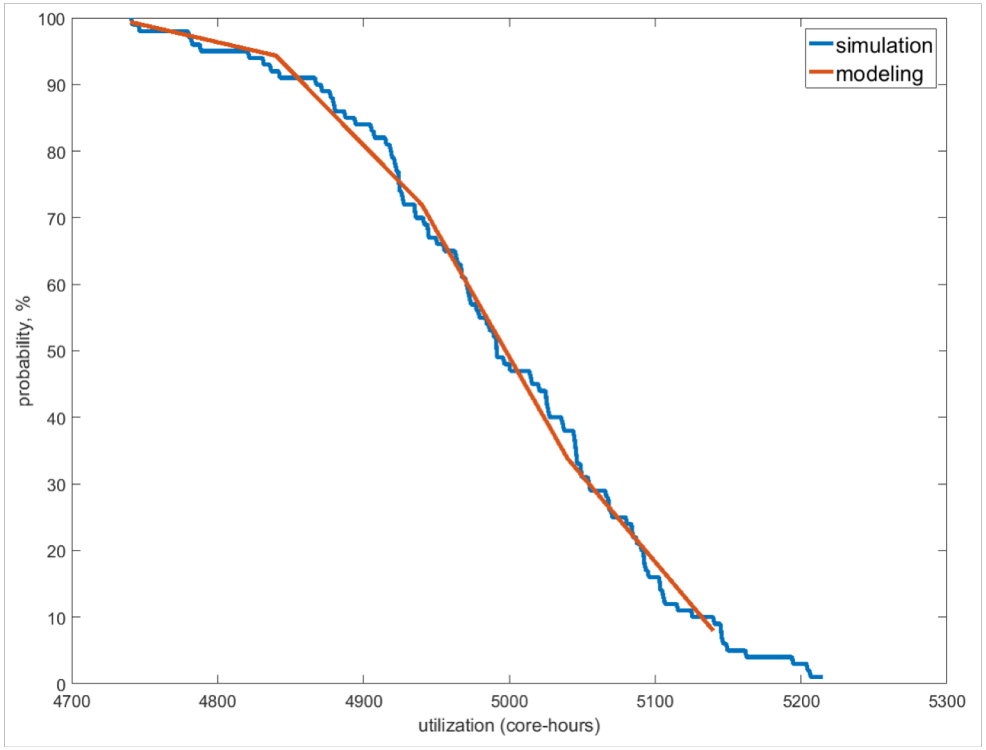
- number of nodes / cores per job = 1
- job waiting time and execution time characteristics (same values for both parameters) - expected value, variance = 1, 1
- the total processing time = 5000 (time units / hours)

Specific parameters for a simulation process

- job waiting time is defined according to the Poisson distribution
- job execution time is defined according to the Normal distribution
- job launching scheme: one stream and there is always one job in the queue
- the total number of simulation runs = 100

Quantitative model testing with synthetic data (II)

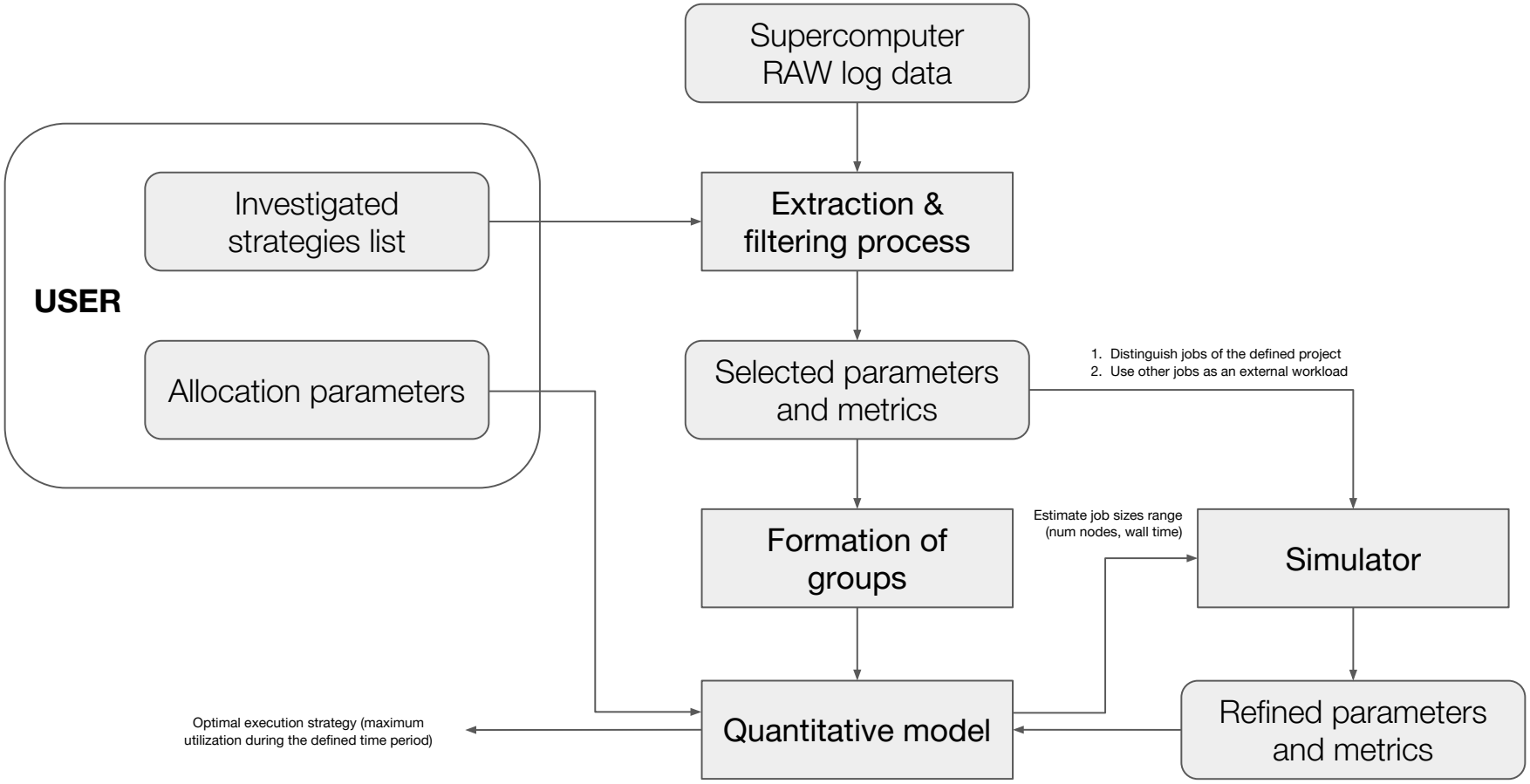
Plot with two lines that represent the probability that a given utilization will be achieved in a given time interval. The blue line corresponds to the results obtained on the simulator, while the red line corresponds to calculations with the quantitative model.



Probability (axis Y) that utilization will reach the corresponding utilization value (axis X) during the time of 5000 hours.

Experiments

Analysis workflow



Log data analysis overview

Log data characteristics

- contains information about job processing
  - job arrival timestamp (to the queue)
  - execution start timestamp
  - completion timestamp
  - the number of required nodes (1 node = 16 cores at Titan)
  - requested walltime

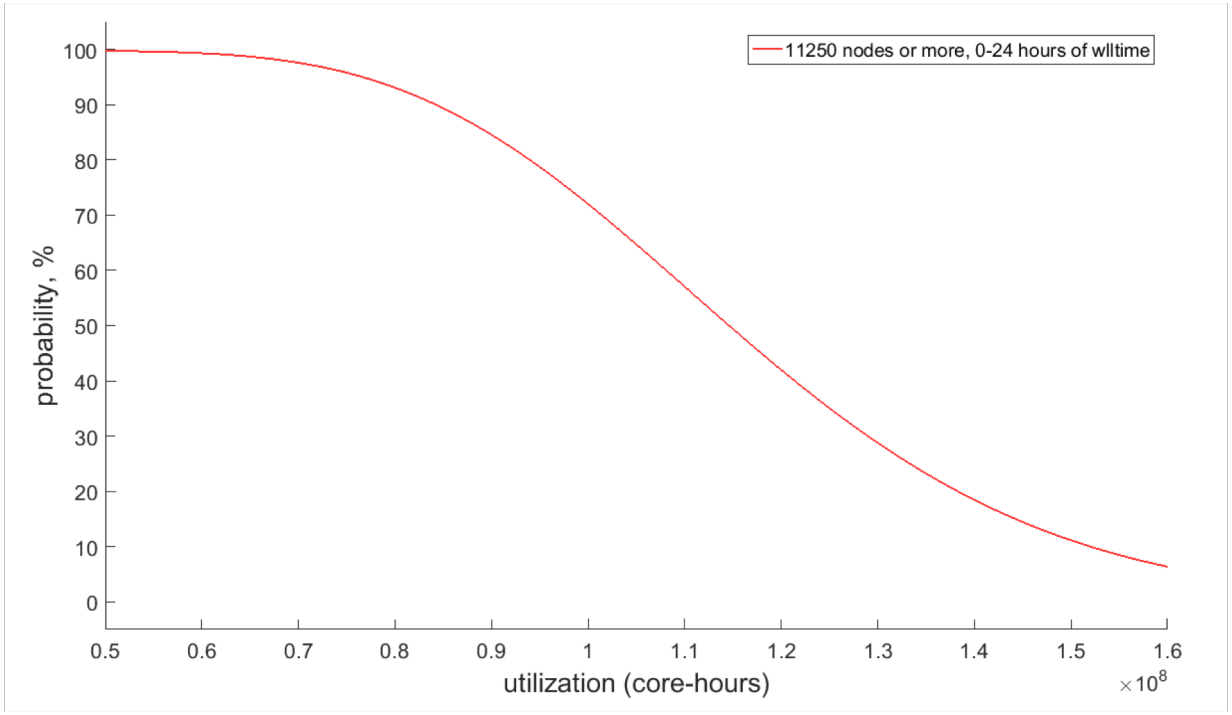
Analysis actions

- all jobs are divided into categories according to the number of required nodes and the amount of wall time requested (every category corresponds to a particular Titan's bin, where bin is a group of jobs that are treated equally)
- for each category the following values are calculated: the expected value and variance of waiting time in the queue and the utilization achieved
- obtained values were used as input data in equation for the quantitative model to calculate the probability that jobs of a given category will be able to utilize provided allocation in 3 months
- job launching scheme: one stream and there is always one job in the queue

Titan log data analysis

Probability distribution of utilization of the resource during 3 months

Bin #1

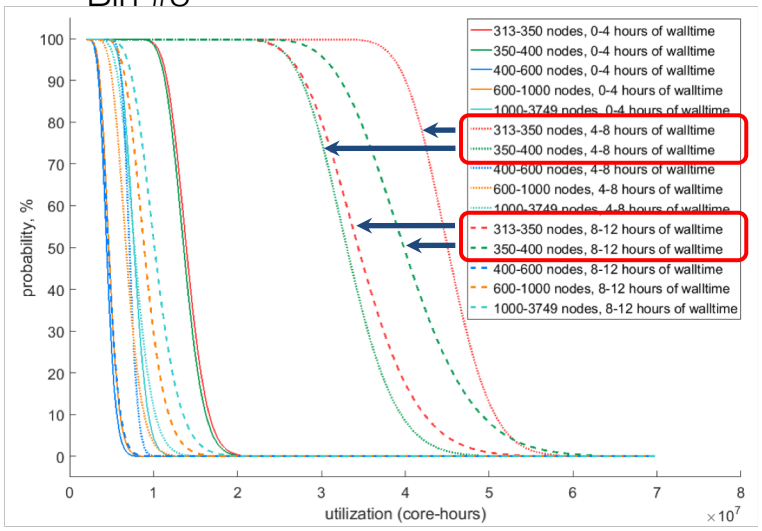


data collected for 6 months (from aug'17 to jan'18)

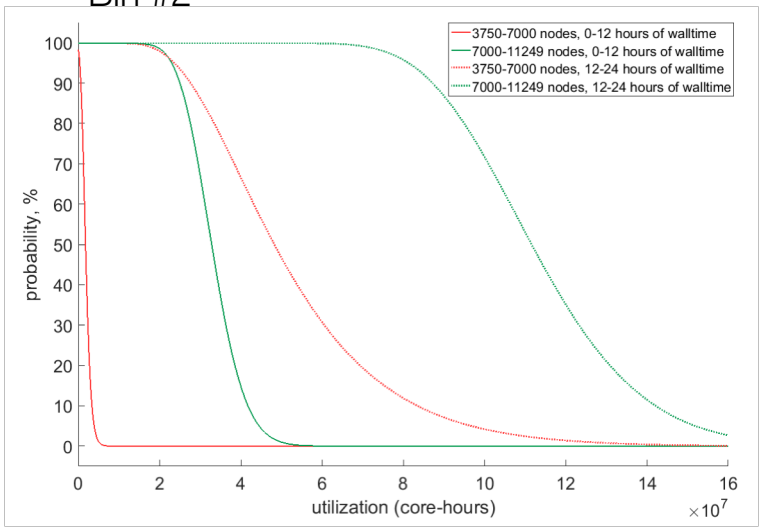
Titan log data analysis

Probability distribution of utilization of the resource during 3 months

Bin #3



Bin #2

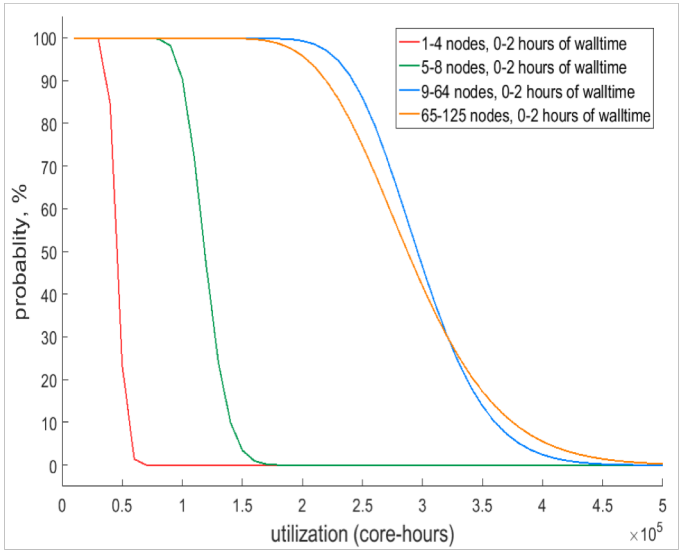


data collected for 6 months (from aug'17 to jan'18)

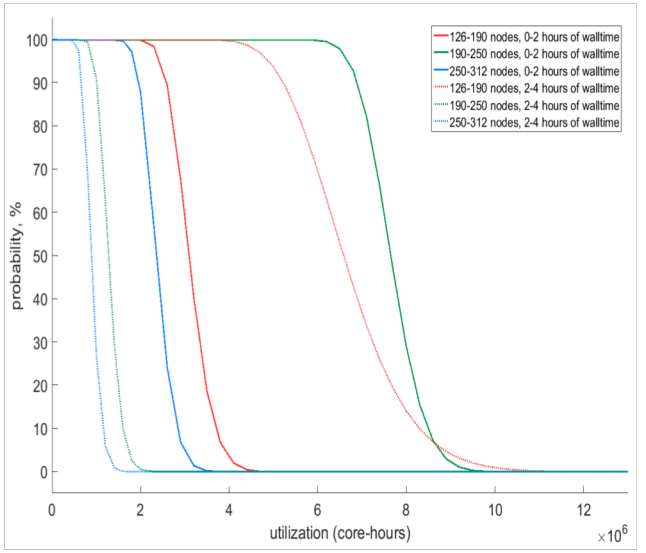
Titan log data analysis

Probability distribution of utilization of the resource during 3 months

Bin #5



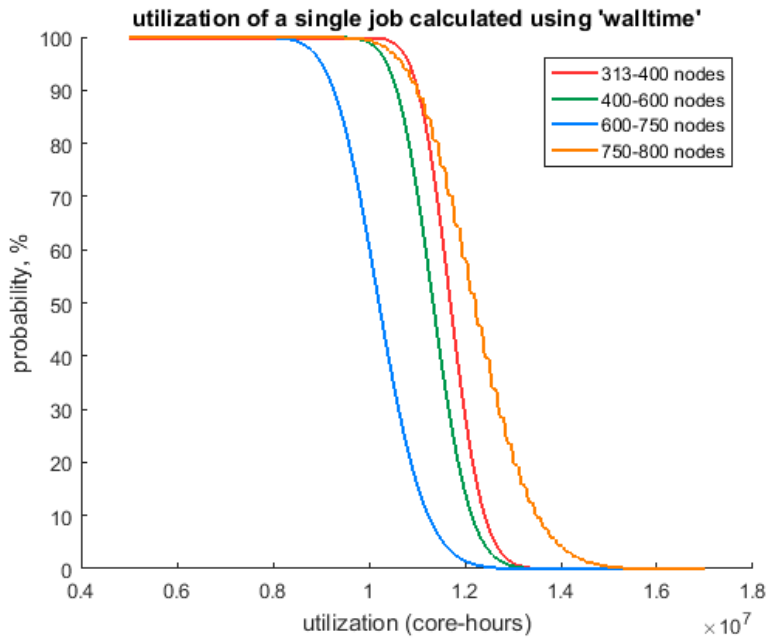
Bin #4

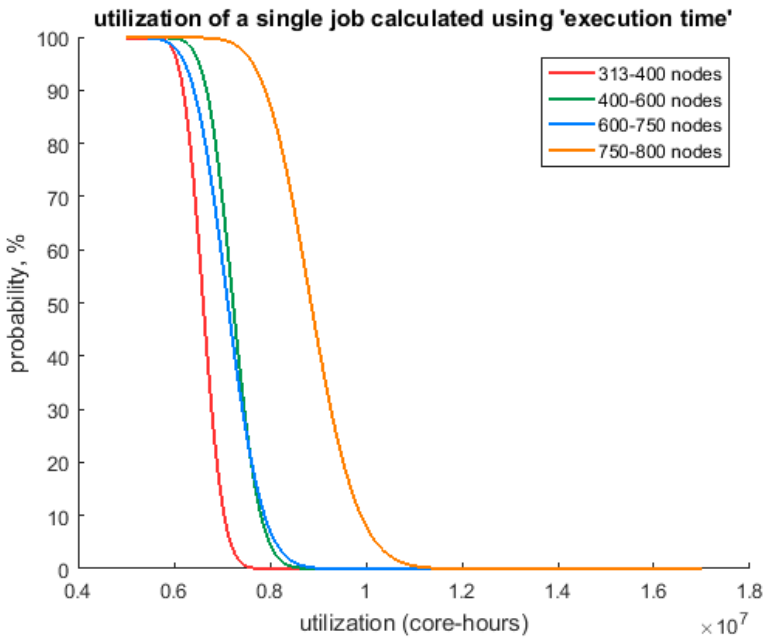


data collected for 6 months (from aug'17 to jan'18)

HEP110 (ALCC*) log data analysis

Probability distribution of utilization of the resource during 3 months





***** *ASCR (Advanced Scientific Computing Research) Leadership Computing Challenge*
https://science.energy.gov/ascr/facilities/accessing-ascr-facilities/alcc/

Conclusion

Summary

Developed tools provide possibility to adjust jobs parameters to regulate and improve the probability of utilizing a given allocation for a given project

Plans

- Extend considered conditions and decrease applied assumptions for developed model and simulator
  - The model and simulator are preliminary and require further tuning, to understand the accuracy and sensitivity (to initial conditions, training duration, workload types)
- Apply approach (in a test mode) for projects that are under the ALCC program
  - This early work will be extended to consider different kinds of workflows as well as different types of workloads of heterogeneous resources