Data Driven Performance Metrics for Smart Manufacturing

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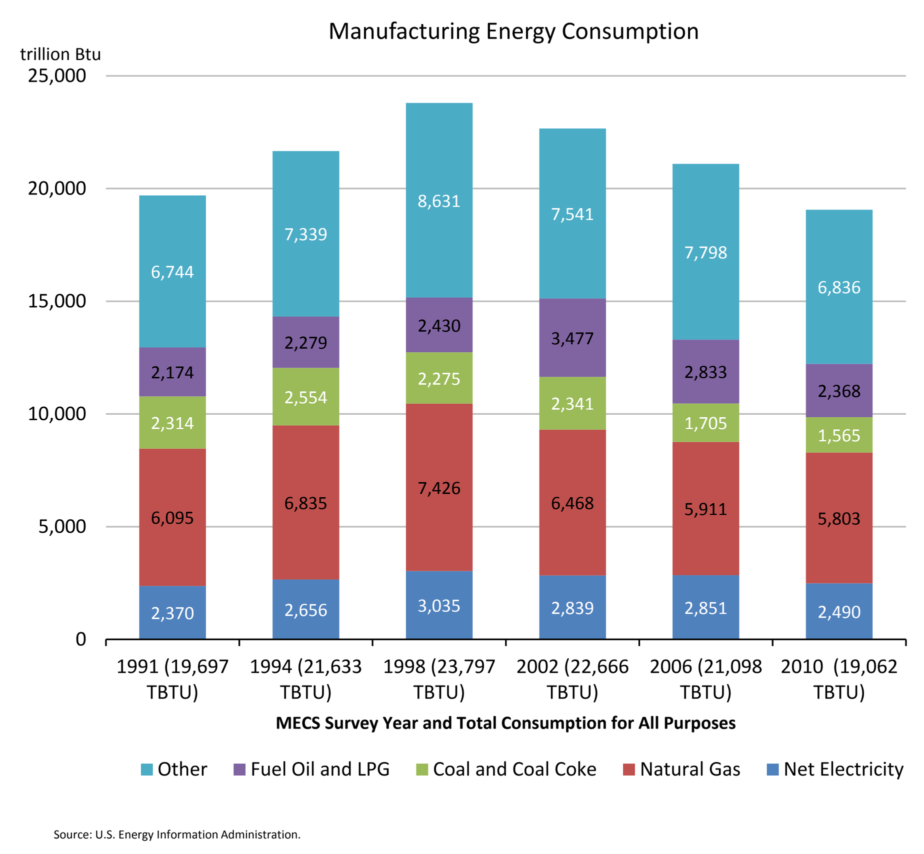
Introduction & Motivation

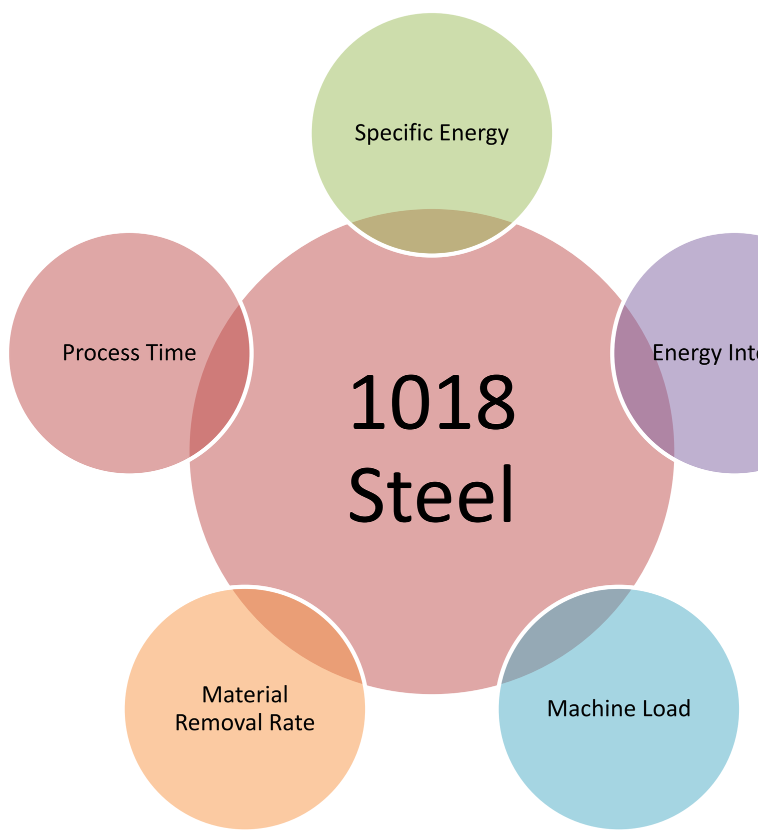
- Engineers play a vital role in sustainability. Incorporating correct performance metrics, big data, and smart manufacturing gives us the ability to improve the effectiveness and efficiency of manufacturing processes.



- Conservation efforts have been working, but improvements are still needed. Engineers have a responsibility to design, manufacture, and process materials and products in an ever more effective and efficient manner in order better use our limited resources and reduce negative impacts.

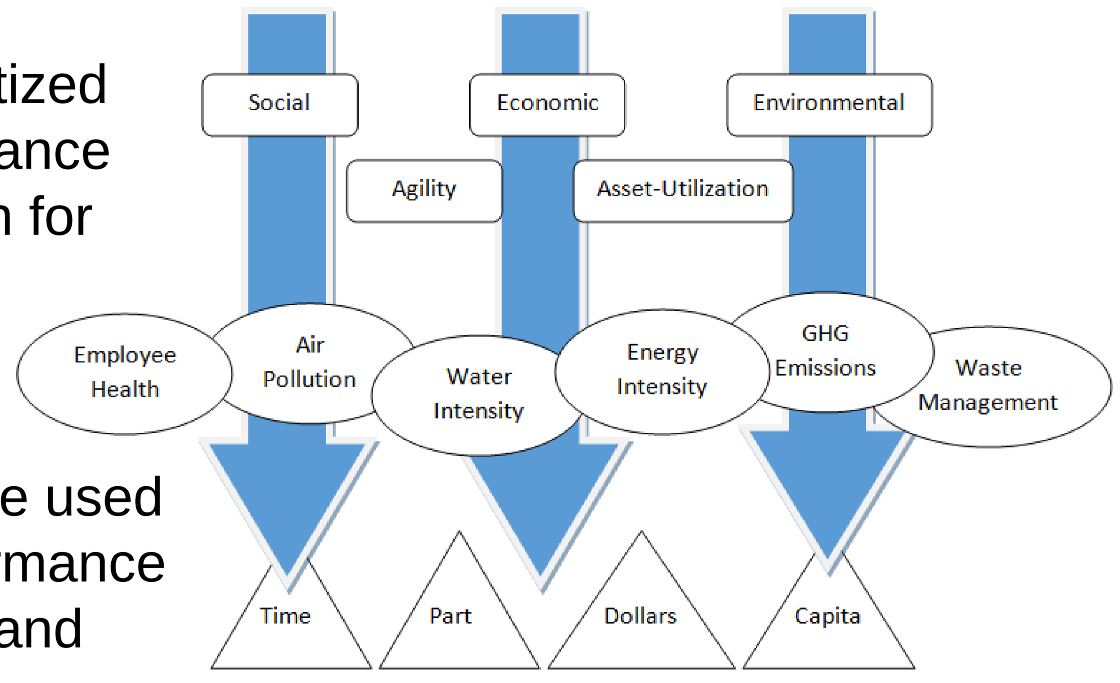
Objective

- Understand how effective current standard manufacturing performance metrics are in analyzing smart manufacturing processes.
  - Smart performance metrics require continuous improvement while maintaining the integrity of the process.
  - Reacting and adapting to external and internal process changes such as an increase in production rate.
  - Analyze energy performance metrics for a subtractive manufacturing process.



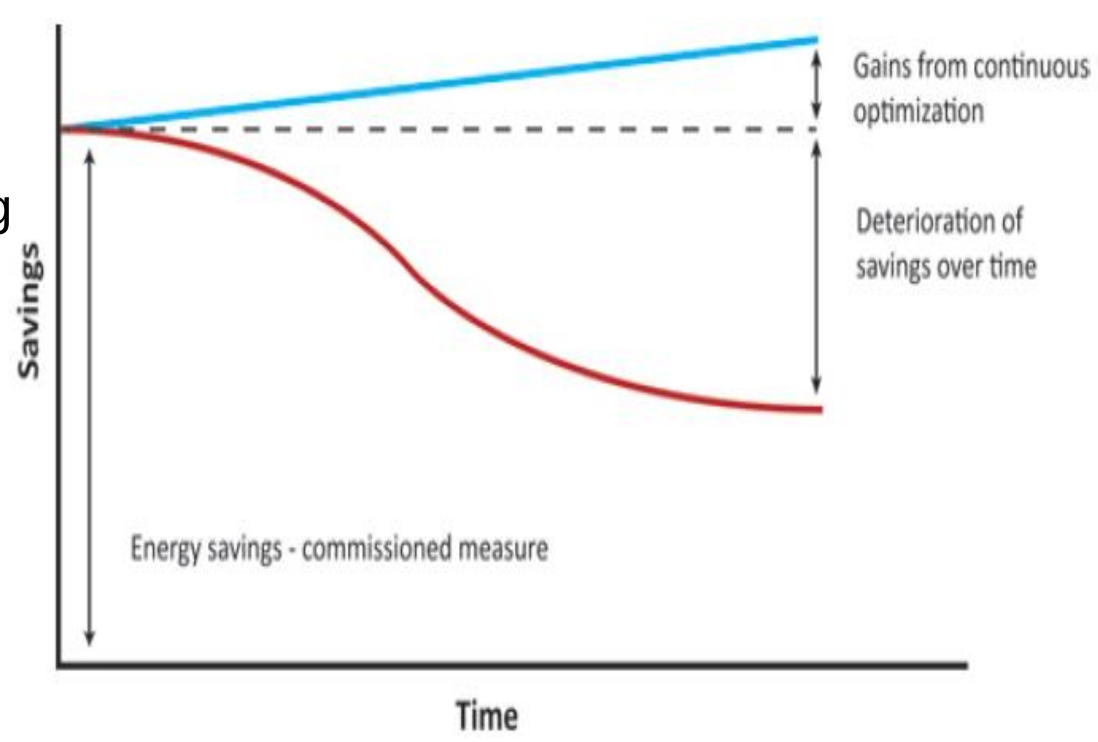
Performance Metrics

- All three sustainability pillars should be reviewed, and their subsets, to understand what aspects need to be considered during analysis.
- According to prioritized concerns, performance metrics are chosen for evaluation and improvement.
- Functional units are used to frame the performance metrics in relative and comparable terms.



Smart Manufacturing

- Smart Manufacturing (SM) refers to intelligent, automated manufacturing systems that leverage information technology to enable cost-effective and efficient fabrication.
  - Enabled by improvements in, and a reduction in cost of, monitoring equipment and computing power.
  - Real-time data capture to react and adapt to internal and external changes to the system.



Methodology

- How to evaluate the *smartness* of performance metrics.
  - Define the system for evaluation.
  - What quality and quantity of relevant variables are required.
  - Evaluate performance metrics.
  - Subject performance metrics to an internal or external change.
  - Can the performance metrics guide the system to a decision which improves the performance metrics while maintaining the integrity of the process.

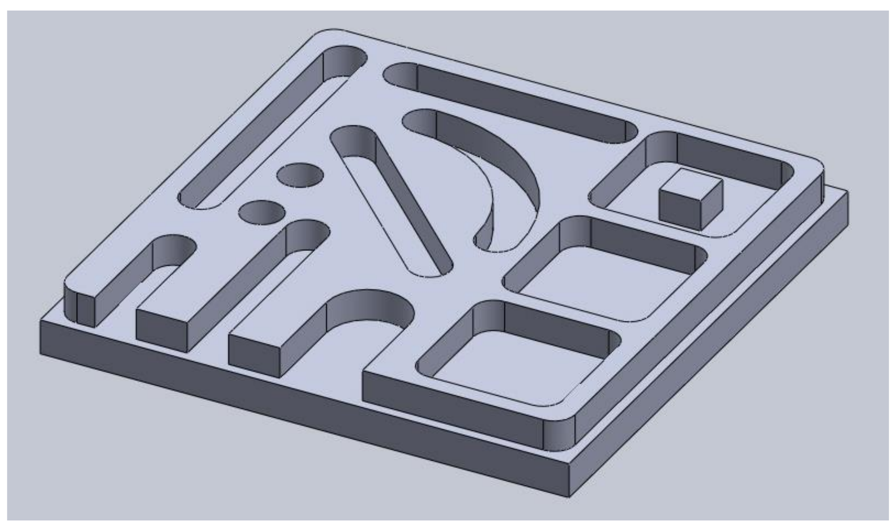
Chosen Energy Performance Metrics

$$Specific\ Energy = \frac{Process\ Energy}{MRR * Total\ Process\ Time}\quad,\quad \text{units of J/mm}^3$$

$$Energy\ Intensity = \frac{Process\ Energy}{\#\ Produced\ Part}\quad,\quad \text{units of}\ \frac{\text{Wh}}{\#\ \text{of Parts}}$$

Case Study

- Machine: Mori Seiki NVD 1500 DCG.
- Tool: 5/16" solid carbide center cutting end mill.
- Internal/External change: Increase in production from 10 to 12 and 17 parts per day.
- Priority: maintain daily processing schedule
- Trial 3 is the business as usual case (BAU)

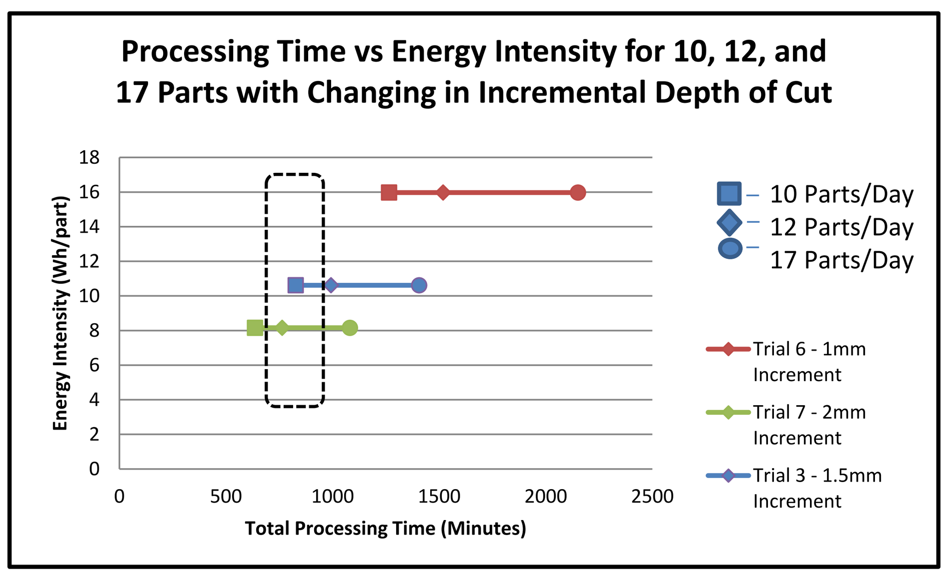


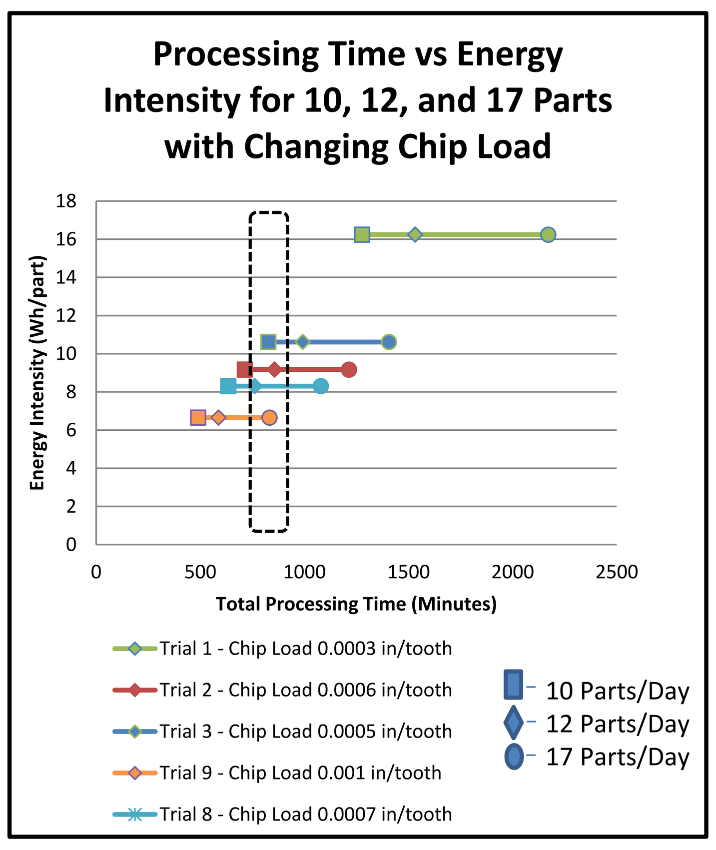
Steel Trial (#)	Chip Load (inch/tooth)	Cutting Speed (rpm)	Feed Rate (mm/min)	Incremental Depth of Cut (mm)
1	0.0003	1750	53.34	1.5
2	0.0006	1750	106.68	1.5
3	0.0005	1750	88.9	1.5
4	0.0005	1500	76.2	1.5
5	0.0005	2000	101.6	1.5
6	0.0005	1750	88.9	1
7	0.0005	1750	88.9	2
8	0.0007	1750	124.46	1.5
9	0.001	1750	177.8	1.5

Aluminum Trial (#)	Chip Load (inch/tooth)	Cutting Speed (rpm)	Feed Rate (mm/min)	Incremental Depth of Cut (mm)
1	0.0003	1750	53.34	1.5
2	0.0006	1750	106.68	1.5
3	0.0005	1750	88.9	1.5
4	0.0005	1500	76.2	1.5
5	0.0005	2000	101.6	1.5

Case Study Results

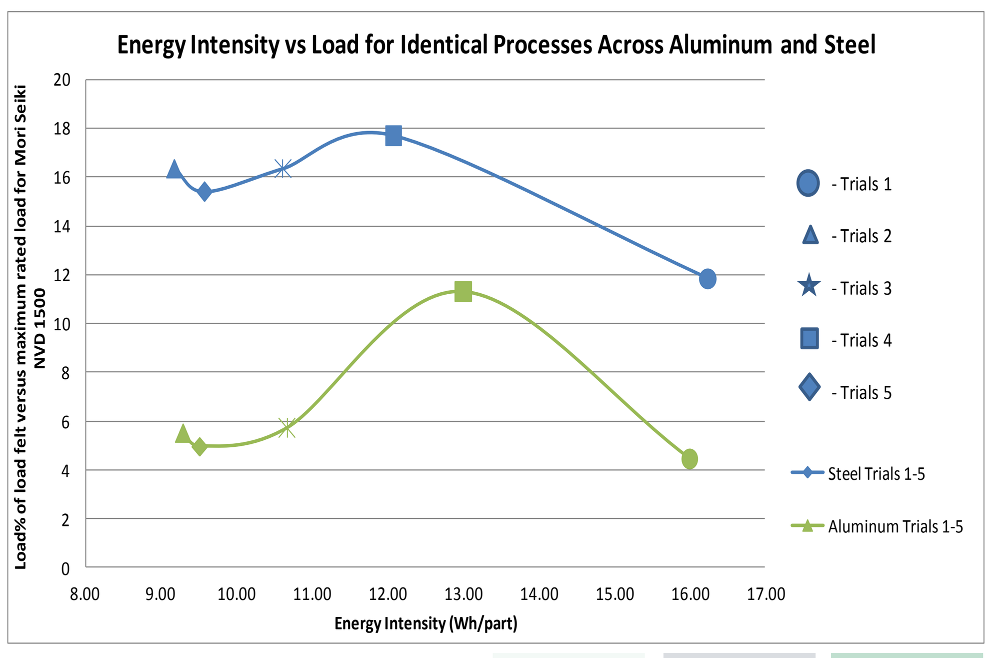
- 12 parts/day: Trial 7 results in lower energy intensity while maintaining similar daily processing time compared with BAU.
- 17 parts/day: Trial 9 results in lower energy intensity while maintaining similar daily processing time compared with BAU.
  - Tool damage occurs at Trial 9.
  - A limiting factor is required to balance the continuous improvements that the smart manufacturing system wants to make.
    - Machine load is chosen





Implementation and Conclusion

- The machine load, in conjunction with the specific energy and energy intensity performance metrics, gives the smart manufacturing system the ability to improve the energy performance while maintaining the integrity of the process.
  - Energy intensity trends lower with an increase in load.
    - Highly volatile which is where smart manufacturing excels.



- To evaluate and improve the energy performance of the process only a small amount of very detailed data is required: Energy use, material removed, process time, and the machine load.
- A limiting factor is required for effective use of performance metrics in a smart manufacturing system.

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