"Just-for-Peak" Buffer Inventory For Peak Electricity Demand Reduction of Manufacturing Systems

Lin Li

Assistant Professor

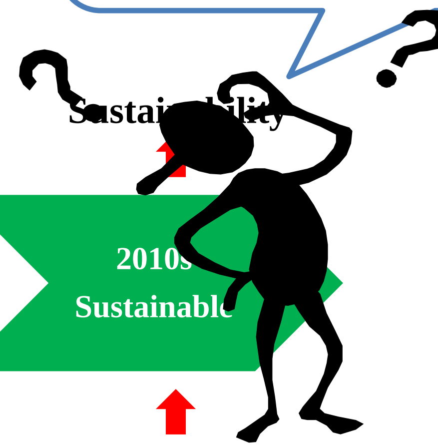
University of Illinois at Chicago

Manufacturing Paradigms

GAP: Resources such as energy and water are not considered. Only the direct materials involved in a manufacturing process are concentrated. Source: http://www.epa.gov/lean/environment/pdf/leanreport.pdf

"Sustainability means living on nature's income rather than its capital."
— **Murray Gell-Mann** 1969
Nobel Prize in physics

Objective	**Customization**	**Cost**	**Quality**	**Sustainability**
	19th Century Craftsmanship	**1913 Mass**	**1980s Lean**	**2010s Sustainable**
Enabler	Skilled Workforce General Purpose Tools	Flow Line Assembly Line	Operation Management	Joint Consideration



Profitability
Environment
Ecology
Society



Example of Potential Benefits by Sustainability: Electricity

- Summer Peak Demand Reduction

Potential for U.S. Summer Peak Demand Savings (GW)

Realistic Achievable Potential	2010	2020	2030
Energy Efficiency	1.6	34.8	78.5
Demand Response	16.6	44.4	78.4
Total	18.2	79.2	156.9
Maximum Achievable Potential	**2010**	**2020**	**2030**
Energy Efficiency	10.8	81.7	117.0
Demand Response	29.8	65.9	101.1
Total	40.6	147.6	218.1

Potential for Summer Peak Demand Savings from Energy Efficiency and Demand Response

Summer Peak Demand Savings	2010 (%)	2020 (%)	2030 (%)
Realistic Achievable Potential (RAP)	2.2	8.2	14.0
Maximum Achievable Potential (MAP)	4.9	15.3	19.5

Source: Assessment of Achievable Potential from Energy Efficiency and Demand Response Programs in the U.S. (2010–2030) by Electric Power Research Institute

State-of-Art and Research Objectives

- **State-of-Art**
  - Most existing literature focuses on power supply side management, e.g., policy & strategy (Vassileva et al., 2012; Greening, 2010), wholesale pricing (Faria et al., 2011; Doostizadeh and Ghasem, 2012; Faria and Vale, 2011; Yousefi et al., 2011), hardware infrastructure (Kiliccote et al., 2009; Piette et al., 2007; Koch and Piette, 2007), etc., and demand (customer) side applications of commercial & residential building sector (Corno and Razzak, 2012; Wang et al., 2012; Motegi et al., 2007)
- **Research Objectives**
  - To establish a systems view for customer-side electricity demand response and to develop cost-effective strategies of electricity demand response for environment-friendly sustainable manufacturing systems.

Sample of Electricity Bill

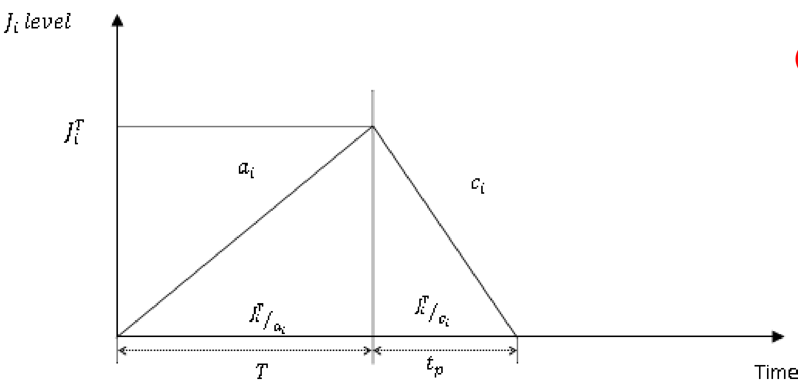
- Electricity Consumption Charge ($/kWh)
- Demand Charge ($/kW)
  - Based on the highest average power of any 15-minute periods throughout the whole billing cycle

Season	Type	Time of Day	Consumption Rate ($/kWh)	Demand Rate ($/kW)
Summer (Jun–Sep)	Off-Peak	7pm–1pm	0.08274	0
	On-Peak	1pm–7pm	0.16790	18.80
Winter (Oct–May)	Off-Peak	9pm–10am	0.08274	0
	On-Peak	10am–9pm	0.11224	8.12

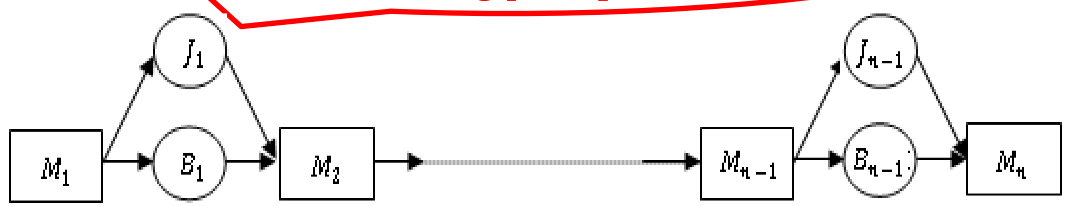
Source: https://www.oru.com/documents/tariffsandregulatorydocuments/ny/electrictariff/electricsc20.pdf

Peak Demand Reduction through “Just-for-Peak” Buffer Inventory Management

- To reduce electricity demand without compromising system throughput during peak periods by buffer inventory management.



“Just-for-Peak” buffer inventory is accumulated during off peak periods and used during peak periods



J_i^T: the target unit of “Just-for-Peak” inventory accumulated in J_i that can ensure the production of the corresponding downstream machine not to be influenced when the upstream machine is turned off for peak demand reduction

a_i : the assumed linear accumulation rate for “Just-for-Peak” inventory built up in J_i during the off-peak period

c_i : the consumption rate of “Just-for-Peak” inventory in J_i during the peak period when demand reduction is implemented

T: the scheduled off-peak period

t_p: the follow-up scheduled peak period

Objective Function: to identify the optimal energy control actions by minimizing the holding cost of the buffer inventory and the electricity bill cost.

$$minTC(k_i) = \min\left(\sum_{i=1}^{n-1} h_i \left[\frac{(J_i^T)^2(1-k_i)k_{i+1}(a_i+c_i)}{2a_i c_i (T+t_p)}\right] + \sum_{i=1}^{n} E_i\right)$$

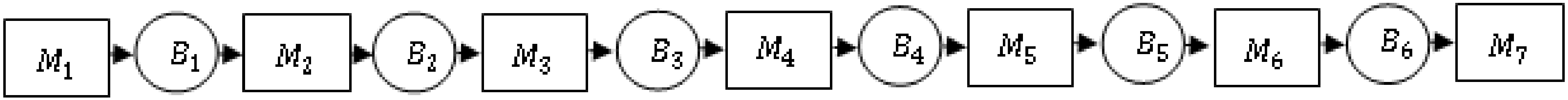
Holding cost per unit time of "Just-for-Peak" buffer inventory accumulated in J_i

where $$E_i = \frac{\varphi_i(T)(r_i)C_R + \varphi_i k_i(t_p)C_P + \varphi_i k_i C_D}{T + t_p}$$

Electricity bill cost per unit time of machine *i*

h_i: holding cost per unit held per unit time for the "Just-for-Peak" buffer inventory stored in J_i
k_i: it takes 1 if the machine i is not turned off during peak period, and zero otherwise
φ_i the rated power of machine i
C_P : on-peak energy consumption charge rate ($/kWh)
C_R : off-peak energy consumption charge rate ($/kWh)
C_D : on-peak demand charge rate ($/kW);
r_i : the availability of machine i

Case Study



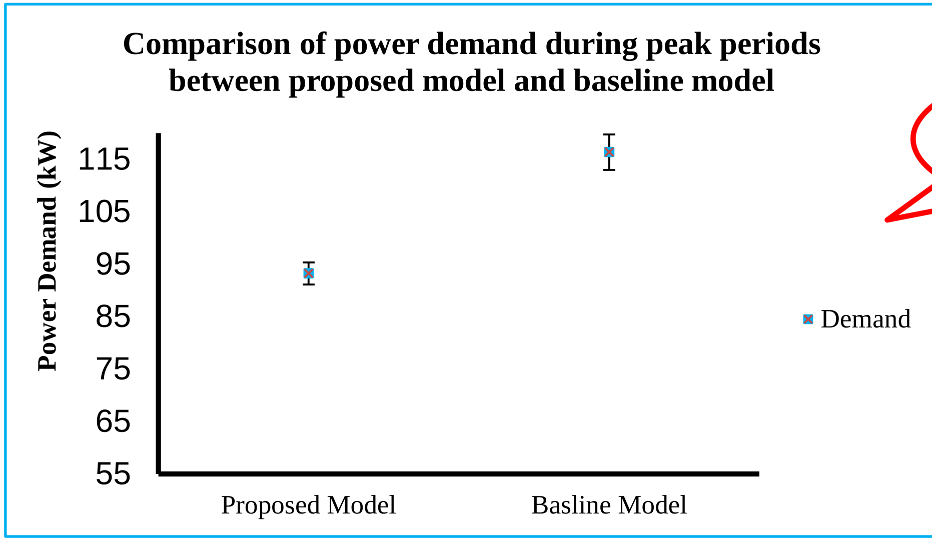
Machine	Cycle Time (min)	MTBF (min)	MTTR (min)	Power (kW)
1	0.455	100.0	4.95	14
2	0.492	45.6	11.7	24
3	0.473	98.8	16.0	14
4	0.489	217.5	27.3	15
5	0.483	109.4	18.4	25
6	0.469	107.7	15.6	25
7	0.482	127.5	19.98	13

Duration of off-peak period T (hour)	Duration of peak period t_p (hour)	Demand reduction requirement P_{saving} (kW)
7.5	0.5	16

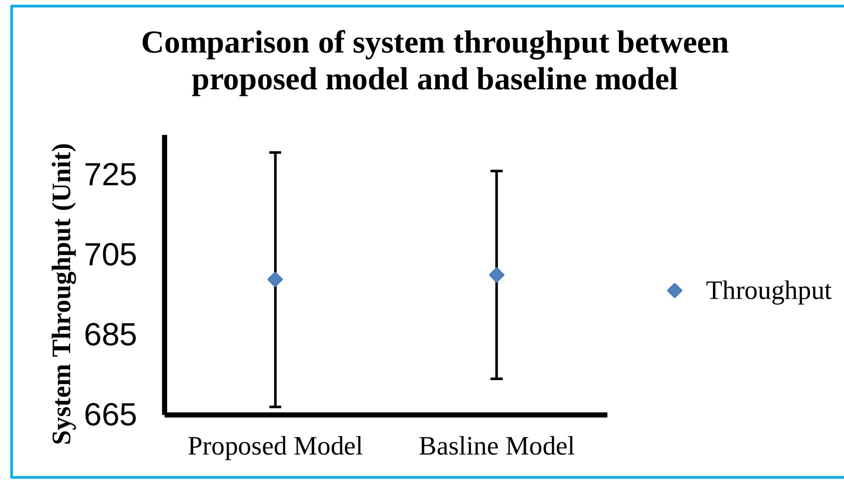
On peak demand charge rate C_D ($/kW)	On peak electricity consumption charge rate C_P ($/kWh)	Off peak electricity consumption charge rate C_R ($/kWh)
9.58	0.029	0.016

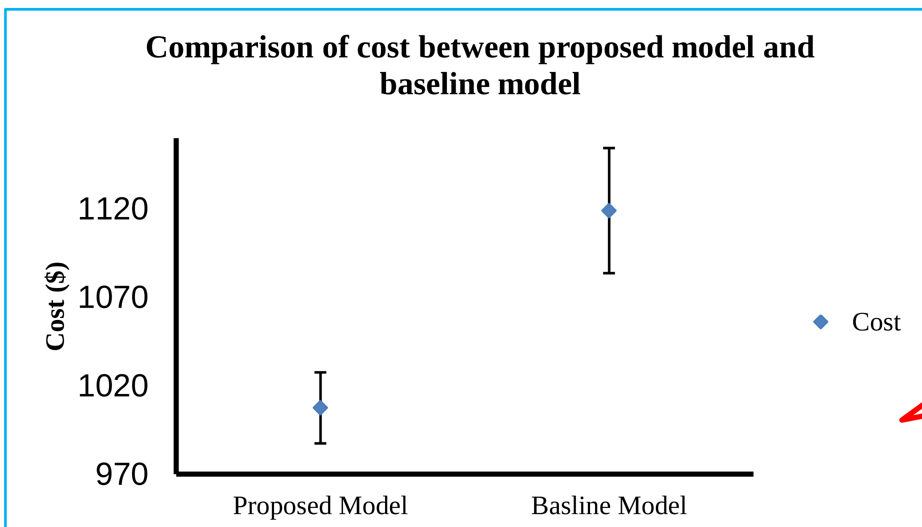
Buffer	Buffer Capacity B_i (unit)	Initial contents of B_i (unit)	Buffer Capacity J_i (unit)	Accumulation rate a_i (unit/hour)	Consumption rate c_i (unit/hour)	Holding cost H_i ($/unit /hour)
1	70	32	70	34.3	122	0.05
2	80	30	80	12.1	127	0.05
3	50	40	50	5.9	123	0.05
4	42	30	42	0.2	125	0.05
5	45	42	45	0.1	128	0.05
6	90	30	90	0.1	125	0.05

Results Analysis



20% Reduction





19% Reduction

Thank you very much!

Comments and questions?

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