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Mujtaba Agha, Raphaële Théry Hétreux, Gilles Hétreux, Alain Haït, Jean-Marc Le Lann. Integrated production and utility system approach for optimizing industrial unit operations. 2nd International Congress on Green Process Engineering, 2nd European Process Intensification Conference, Jun 2009, Venice, Italy. pp.0. hal-04104979

HAL Id: hal-04104979

<https://hal.science/hal-04104979>

Submitted on 24 May 2023

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To cite this version : Hait, Alain and Hetreux , Gilles and Le Lann, Jean Marc and Mujtaba, H. Agha and They, Raphaële (2009) *[Integrated production and utility system approach for optimizing industrial unit operations.](#)* In: 2nd International Congress on Green Process Engineering, 2nd European Process Intensification Conference, 14-17 June 2009, Venise, Italie.

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INTEGRATED PRODUCTION AND UTILITY SYSTEM APPROACH FOR OPTIMIZING INDUSTRIAL UNIT OPERATIONS

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Abstract. Energy intensive industrial units use onsite utility system to meet their utility requirements. However emphasis in these industrial units is placed on manufacturing (production) schedule while the aspect of operational planning of utility system is largely ignored. In this article an integrated approach is presented that simultaneously undertakes short-term scheduling of a multipurpose batch plant and operational planning of utility system. This approach is formulated using multi-period mixed-integer linear programming (MILP). Results indicate that integrated approach leads to significant reduction in energy costs and at the same time reduces emission of harmful gases.

Key-words. Short-term scheduling, CHP plant, Utility management, Energy cost, MILP.

The issue of energy has emerged as one of the greatest challenges facing the mankind. Ever since replacing less efficient sources, like water-driven mills and burning of timber, fossil fuels (oil, coal and gas) have been the primary source of energy. However, the extensive use of fossil fuels has not only resulted in depletion of the fossil fuel reserves but there also has been huge negative consequence on the ecological system of the planet. Intergovernmental Panel on Climate Channel¹ has identified the emissions of harmful gases (released during burning of fossil fuels) as the chief cause for the phenomenon of global warming.

In this context, there is increased emphasis on finding the alternative sources of energy, especially renewable sources like wind, solar, hydrogen, etc. There is no doubt that the alternative energy sources are the answer to the energy issue but it is also a reality that no such alternatives are available in immediate future. In fact projections of Environmental Information Agency² show that even in the year 2030 fossil fuels will remain as the primary source of energy. Hence, optimizing the utilization of energy generated by fossil fuels is perhaps just as important as finding the alternative sources of energy.

Energy optimization is particularly important for energy intensive industrial units as they consume large quantities of energy in shape of utilities. A utility can be defined as any quantity having high energy and which can be useful to industrial unit in manufacturing the finished product. In industrial unit the utility can be in shape of electricity, steam (at various pressure levels), hot/cold water and hot air. There are two possible ways of energy optimization in industrial units – firstly, by technological advances in machinery which enhance efficiency of individual industrial equipments and secondly use of methodologies like process integration³ that improve the operational efficiency of the industrial unit as a whole.

In this study the operational efficiency of an industrial unit is enhanced using mathematical modeling. A multi-period mixed-integer linear programming (MILP) model is used to develop a utility management for the industrial unit. The scope of this study is limited to only altering operating conditions and no structural changes are made to the industrial unit.

PROBLEM STATEMENT

Energy intensive industrial units normally fulfill their utility demands including that of electricity by employing an onsite utility system. Thus, these industrial units comprises of two distinct units - a utility system that generates utilities and a manufacturing unit that consumes utilities to produce the final product. Generally the emphasis is placed on the manufacturing unit while the utility system is regarded as a support function whose objective is to meet the energy demands of manufacturing unit. Due to this biased outlook the short-term scheduling of the industrial unit is carried out by sequential resolution of three sub-problems: scheduling of the manufacturing unit by minimizing inventory, estimating the utility needs of manufacturing unit and finally operation planning of the utility system.

The sequential approach creates a master-slave relationship between manufacturing unit and utility system. The first step of manufacturing unit scheduling is carried out without taking into the operational constraints utility system. Consequently the utility system functions below its potential and sub-optimal energy solutions are attained for industrial unit operations. In this study an integrated approach is adopted which concurrently carries out manufacturing unit scheduling and operational planning of utility system. This integrated approach results in better utility management and leads to higher energy efficiency of industrial unit.

MATHEMATICAL MODELING

The problem is formulated using discrete-time based MILP model. The planning horizon is divided into T periods with each period having duration of one hour. The model constraints are provided by applying - mass and energy balances, production and capacity constraints, simplified assumptions to linearize non-linear equations and use of binary variables to resolve conflicts on whether or not particular equipment is operational during time period t .

Sequential Approach

Step 1 - Task scheduling of manufacturing unit: The manufacturing unit, following production recipe, ascertains a schedule that allocates limited resources to manufacture one or more products. The schedule determines the number of tasks k ($k \in K$) and batch size of each task that is carried out by processing equipment j ($j \in J$) in manufacturing unit. The scheduling model in this study uses same capacity limitation constraints and material balance constraints that were first developed by Kondili et al⁴. However, for allocation constraints "big M" equations are replaced by following equation which was used by Méndez et al⁵:

$$\sum_{k \in K_j} \sum_{t'=t-p_k+1} W_{k,j,t'} \leq 1 \quad \forall j \in J, \forall t = 1, \dots, T \quad (1)$$

The optimization criterion for scheduling problem is based on tardiness (minimize inventory):

$$C_{stock} = \sum_{t=1}^T \sum_{s \in S} l_s \cdot S_{s,t} \quad (2)$$

Step 2 - Estimation of utility requirements: Based on the task scheduling and the utility requirement of each task the overall utility demand for the manufacturing unit is estimated.

$$TBatch_{k,t} = \sum_{j \in J_k} \sum_{\theta=t}^{T-p_k+1} B_{k,j,\theta} \quad \forall k \in K, \forall t = 1, \dots, T \quad (3)$$

$$CGlob_{v,t} = \sum_k Cop_{v,k} \cdot TBatch_{k,t} \quad \forall k \in K \quad (4)$$

The utility requirements are classified as high pressure (HP), medium pressure (MP), low pressure (LP) steam and electricity demands based on following equation:

$$Dem_{v,t} = CGlob_{v,t} \quad \forall v \in UTIL, \forall t = 1, \dots, T \quad (5)$$

Step 3 - Operational planning of utility system: The final step of sequential approach is to carry out the operational planning of the utility system. This part of mathematical model is based on the work that was initially proposed by Soylu et al.⁶ The initial model was further extended by Agha et al.⁷ to include part load behavior of boiler as well as time delays and costs incurred during boiler shutdown and restart. A multi-objective criterion was used to optimize the operational planning of the utility system.

$$COST = \sum_t \sum_{j \in BOIL} \sum_{i \in FUEL} cf_i \cdot (I_{t,j,i} + SI_{t,j,i}) + \sum_t ELP_t \cdot CEL + \sum_t \sum_{j \in BOIL} XSOX \cdot CSOX \quad (6)$$

The operational planning of utility system minimizes the energy costs (fuel & electricity purchase) and penalty costs (for emission of harmful gases) while fulfilling the utility demands of manufacturing unit.

Integrated Approach

The sequential approach results in sub-optimal solution as unlike other resources classically considered in the scheduling problems (machinery or work force), utilities have special characteristics which must be taken into account. Utilities are not only present in many different forms (steam at different pressure levels, electricity, etc) but they are also a resource that can not be stored in its ultimate form. Hence unlike materials they must be consumed immediately at the time of their generation. This makes the operational planning aspect of utility system vitally important for overall energy efficiency of industrial unit.

The drawback of the preceding approach is removed in integrated approach where the task scheduling of manufacturing unit and operational planning of the utility system is simultaneously carried out. Integrated approach concurrently solves:

- production and capacity constraints of manufacturing unit (Kondili et al.⁴),
- allocation constraints of manufacturing unit (equation 1),
- utility estimation constraints (equations 3, 4 and 5) and
- operational planning constraints of utility system (Agha et al.⁷)

The optimization criterion used in the integrated approach is the minimization of equation 6, i.e., reducing the energy and emission penalty costs. Hence, at the time of task allocation the integrated approach cross checks for the availability of utilities based on the operational planning of the utility system. Trade-offs are made and a greater synchronization between the manufacturing unit and utility system is achieved. This results in an optimum operating condition for the industrial unit.

EXAMPLE

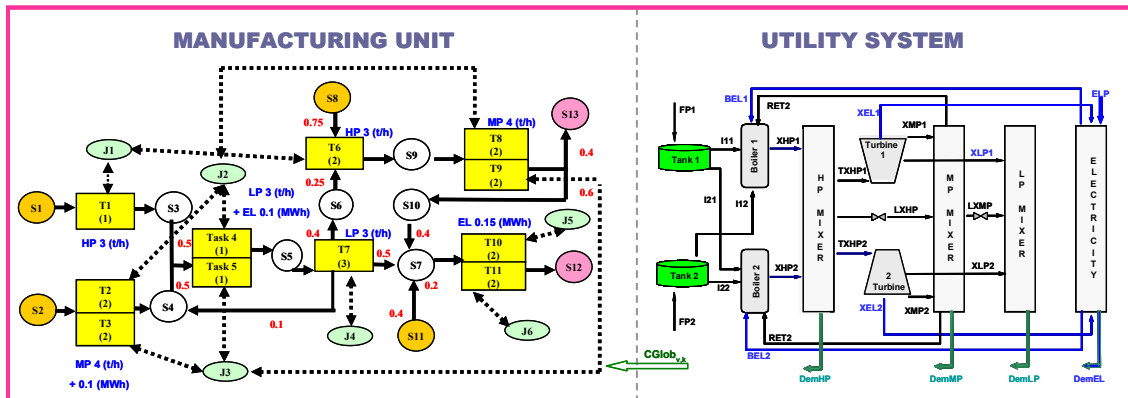


Figure 1: An industrial unit comprising of two distinct units

To compare integrated approach with sequential approach an example was formulated and resolved using software Xpress-MP release 2008A⁸. The problem was solved on an Intel(R) Core(TM) 2 Duo CPU @ 2.00 GHz and 1.00 GB of RAM. The industrial unit considered for this example is presented in the figure 1. The left hand side shows the Resource Task Network (RTN) representation of the manufacturing unit while the right hand side demonstrates a combined heat and power (CHP) based utility system. CHP plants are a popular choice as onsite utility system as they simultaneously generate steam (at different pressure levels) and electricity.

The manufacturing unit undertakes eleven tasks (K) using six processing equipments (J) to convert four raw materials ($S1, S2, S8$ and $S11$) into two finished products ($S12$ and $S13$). The industrial unit is supposed to be operating around the clock (planning horizon $T=24$) and after every eight hours the manufacturing unit must meet certain product demands. The utilities consumed ($Cop_{v,k}$) by each task in manufacturing unit are also given in figure 1.

Scenario 1: Reduction in energy costs and diminution in emissions of harmful gases

The demand for product1 (S12) at time period $t = 8, t = 16$ & $t = 24$ is 0, 80 & 100 tons respectively. The demand for product 2 (S13) at same time periods is 0, 40 and 80 tons respectively. Figure 2 presents the short-term scheduling of manufacturing unit and operational planning of utility system for both the sequential and integrated approaches. It is clear that in the case of the integrated approach the tasks in manufacturing unit are arranged in such a manner that their utility demands are synchronized with the utilities being generated in utility system. This not only results in fewer variations in steam load curves of utility system but also minimizes the wastage of utilities. For example, during period 19-21 in the sequential approach manufacturing unit does not undertake any tasks that consume electricity. This is in spite of the fact that MP steam demands can be met by expanding HP steam in turbines and simultaneously generating electricity. Such opportunities are not missed in integrated approach where tasks that consume electricity are always aligned with tasks that consume MP and LP steam. There by, reducing the need for electricity purchase from external source.

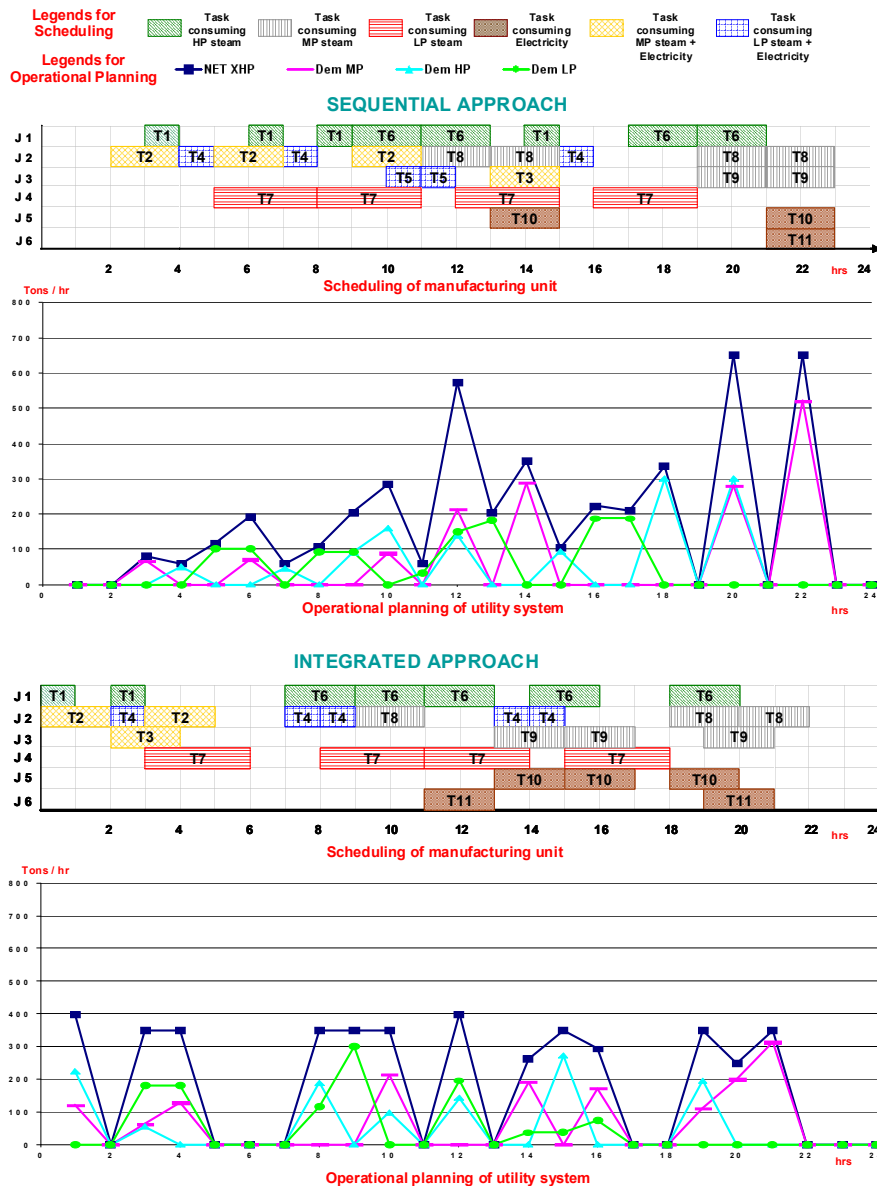


Figure 2: Results for scenario 1

Table 1 represents the comparison between sequential and integrated approach based on the energy costs and gas emissions. The use of integrated approach results in 13 % reduction in overall energy costs. The higher energy efficiency of integrated approach not only leads to lesser quantity of fuel being burnt in boiler but it also eliminates the need for electricity purchase from external source. Moreover it results in 30 % reduction in SO_x emissions and 13 % reduction in green house gas emissions.

Table 1: Comparison between sequential and integrated approaches for scenario 1

Approach	Fuel Cost (€)	Electricity Cost (€)	SOx Cost (€)	Energy Costs (€)	GHG emissions (tons)	SOx emissions (tons)
Sequential	33,941.8	1,022.9	268.7	35,233.3	1,734.8	11.68
Integrated	30,579.6	0	181.8	30,761.4	1,508.2	7.908

Scenario 2: Attaining of higher productivity

In this scenario the product demands are increased by roughly 60%. Hence demand of product 1 (S12) at time period $t = 8, t = 16$ & $t = 24$ is 0, 130 & 160 tons respectively. The demand for product 2 (S13) at same time periods is 0, 65 & 130 tons respectively. Figure 3 presents the short-term scheduling of manufacturing unit and operational planning of utility system for both the sequential and integrated approaches. The sequential approach fails to fulfill the product demands as the utility system is unable to meet the utility requirements of the manufacturing unit. The net steam requirements (at $t = 20$) surpass the maximum steam generation capacity of the boilers. In contrast, the integrated approach shifts and rearranges tasks in manufacturing unit in such a manner that utility requirements never exceed the capacity of utility system. Hence, higher productivity in the manufacturing unit can be achieved by using integrated approach.

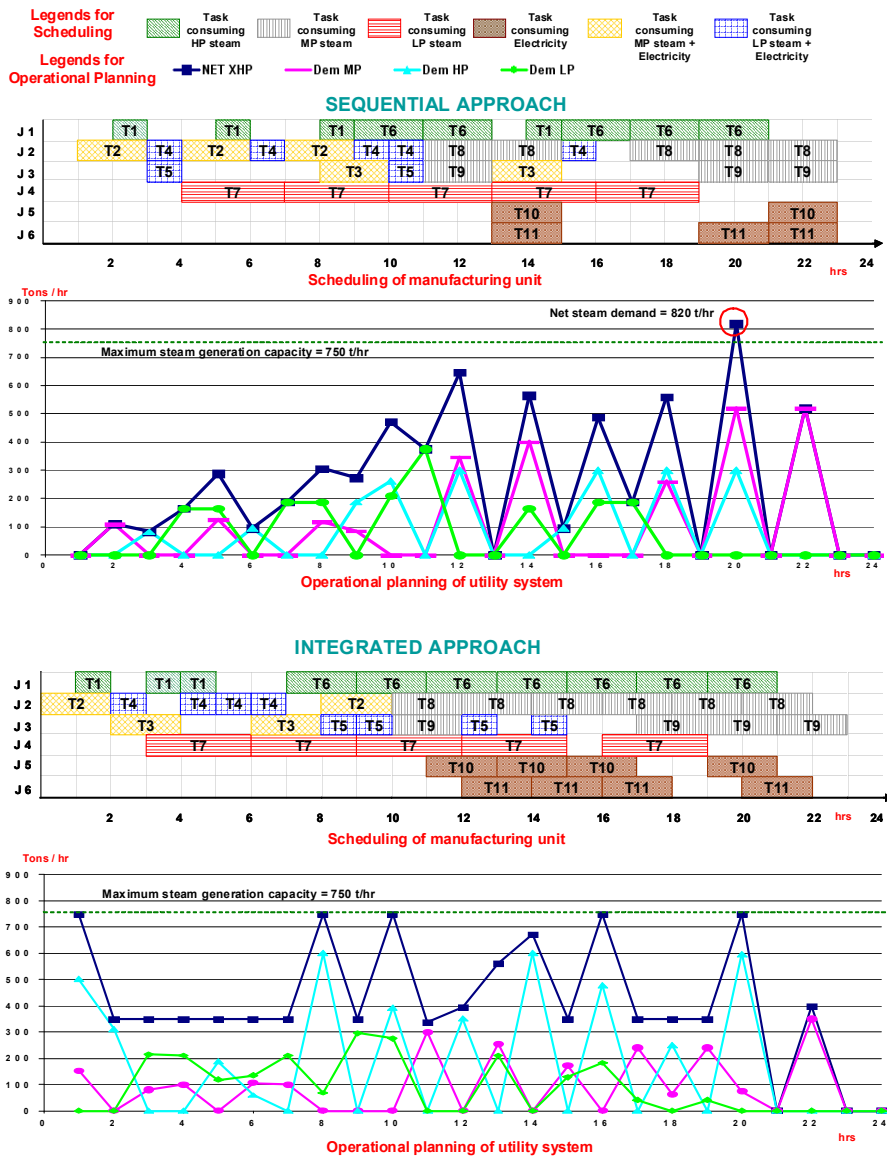


Figure 3: Results for scenario 2

CONCLUSION

Energy intensive industrial units normally generate their own utilities by using an onsite utility system. However even in these industrial units the emphasis is placed on production (manufacturing unit) and the utility system is treated as a subsidiary unit. This biased approach results in sub-optimal solutions as the utility system is never able to achieve its energy efficiency potential. This paper presents an integrated approach in which both the manufacturing unit scheduling and utility system operational planning are concurrently undertaken. The use of integrated approach not only displays energy cost reduction potential but it can also lead to significant decrease in emissions of harmful gases. Moreover, the multi-objective function (equation 6) can be used to simulate and develop scenarios in which emissions are more severely penalized, for example including a penalty cost for green house gas emission.

This study is a part of research being conducted at CNRS, whose objective is energy management solutions for mono and multi-sites. In future the discrete time model will be replaced by a continuous time formulation.

NOMENCLATURE

Indices		Sets		Parameters	
i	fuels	$BOIL$	set of boilers	cf_i	Cost of fuel
k	tasks	J	set of processing equipments	CEL	Cost of electricity
s	states	K	set of tasks	$CSOX$	Cost of emission of SO_x gas
t	time	S	set of states	$Cop_{v,k}$	Utility v consumed by task k for each ton of material processed
v	utility	$UTIL$	set of utilities	I_s	Inventory coefficient to obtain the tardiness starting date
j	equipments			T	Time Horizon

Variables

$B_{k,j,t}$	Amount of material being undertaken by task k in processing unit j at time period t
C_{stock}	Scheduling criterion used for minimizing inventory level
$CGlob_{v,k}$	Overall consumption of utility v during the time period t (tons/hr of steam and MWh/hr electricity)
$Dem_{v,t}$	Demand of utility v from processing unit j in time period t (with v in tons for steam and MWh for electricity)
ELP_t	Electricity purchased during time period t
$I_{i,j,t}$	Quantity of fuel i used in boiler j during time period t (tons)
$SI_{i,j,t}$	Quantity of fuel i used during the starting of boiler j from cold state in time period t (tons)
$W_{k,j,t}$	Binary variable that determines if task k is being carried out in processing unit j in time period t
$XSOX$	Quantity of SO_x released by boiler j during time period t (tons)

REFERENCES

1. IPCC, Intergovernmental Panel on Climate Change (1996). Climate change 1995: The science of climate change, Cambridge University Press, Cambridge.
2. Environment Information Administration (2006). Annual energy outlook 2007. Department of energy of USA government.
3. Gundersen T. (2000). Process integration PRIMER, SINTEF Energy Research.
4. Kondili E., Pantelids C.C., Sargent W.H. (1993). A general algorithm for short-term scheduling of batch operations – I. MILP formulation, Computers and Chemical Engineering, 17(2), 211-227.
5. Méndez C.A., Cerda J., Crossmann I.E., Harjunkoski I. and Fahl M. (2006). State-of-the-art review of optimization methods for short-term scheduling of batch processes, Computers and Chemical Engineering, 30, 913-946.
6. Soylu A., Oruc C., Turkay M., Fujita K. and Asakura T. (2006). Synergy analysis of collaborative supply chain management in energy systems using multi-period MILP, European Journal of Operation Research, 174, 387-403.
7. Agha M.H., They R., Hêtreux G., Hait A. and Le Lann J.M. (2008). Collaboration among companies for better energy management, In: Proceedings of European Symposium on Computer Aided Process Engineering – ESCAPE 18. Lyon (France): http://www.nt.ntnu.no/users/skoge/prost/proceedings/escape18/Topic_6/Poster/FP_00476.pdf
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