A Review of Planning Production and Energy Efficiency Models

Bonnel Mejía-Maya, Vanessa Sierra-Zuluaga and Javier Darío Fernández-Ledesma
Department of Industrial Engineering
Universidad Pontificia Bolivariana
Medellín, Antioquia, COLOMBIA
Bonnel.mejia@upb.edu.co, vanessa.zuluaga@upb.edu.co, javier.fernandez@upb.edu.co

Abstract

The aim of this article is to provide a comprehensive review of specialized literature that includes models concerned with production scheduling focused on production and energy efficiency; seeking to determine the progress that has been achieved in recent years in these areas.

They are rated in accordance with the field that they addressed; either, production efficiency, energy, or the inclusion of both as an essential part in the search for the optimization of scheduling production in the industrial sector. Following this, an analysis of the most relevant variables will be carried out, with the aim of framing what will be the definition or improvement of a production scheduling model with optimization of production and energy efficiency.

Keywords
Scheduling and planning production Models, energy efficiency

1. Introduction

Globally, the industrial sector is the largest energy consumer; using close to 37% of the produced energy. Additionally, this consumption is expected to grow by around 33% by 2030, as it compares to 2010's, which will bring along with the generation of the respective contamination quota [1].

The effect of production (surplus and products), is sought to be less contaminant with the passage of every day. However, this effect is still inherent to the process and has not been avoided in its entirety, generating, among other gases, CO2, SO2, NOX, and CO; of which we already know the consequences [2]. It has even been argued that human-induced climate change is directly related to energy consumption around the world, and it is expected to represent an additional cost in the future [1].

In addition, when analyzing current production planning methods and models, it can be seen that they don't include the optimization of energy consumption among their main objectives, as they do with issues such as productive efficiency, regulated flow, management inventories, just-in-time, optimization of processing times, amid others; Leaving aside other elements such as downtime, processes, and effects that spring out from this way of planning, and are equally relevant.

The energy issue is most often addressed at the level of components (machines and equipment). However, little progress has been made and implemented on the optimization of energy efficiency at the level of plants as a system [1].

Most likely this is due to the fact that there are no models to incorporate these variables from the planning process, as it will be seen in the assessment, and only the effects are known only when they occur; generating extra costs, additional times and consumption of resources which are never considered, and that increase the total productive cost, thus reducing the profitability of the different goods and services that are produced.

In order to take a responsible position on international issues through sustainable development, it has become important to establish energy efficiency as a priority factor in production systems. What is intended is not a minimum energetic consumption, but an optimal consumption; in accordance with the production guidelines of each company [1]. Moreover, it seeks to go beyond current approaches, which deal with the reduction of energy in the unproductive phases, contributing to the overall efficiency of automated production systems [3].

2. Methodology

The present study began with a search through databases and publications available at Bolivarian Pontifical University, with the aim of framing the problem and learning about the inclusion of energy efficiency in production planning and scheduling, as well as determining the progress what that has been made in this regard.

Thereafter, a review of articles on mathematical models was carried out, limiting the search to studies from 2010 to the present. Although, articles from previous years considered relevant were not discarded, such as: "Modeling energy consumption in the manufacturing industry" [4], due to its focus on energy consumption impact assessment derived from production schedule. [5] with about 200 analyzed studies and [6], in which the analysis of more than 300 documents was carried out; the latter ones because of their relevance as complete studies on the analysis of production issues that involve setup times as the essential element for production optimization.

For articles selection, we looked up on databases Science Direct and Scopus, using key words such as: "Production planning", "Production scheduling" "Energy efficiency" and "Production modeling", then other words were included on it in order to refine the search, the results are in Table 1.

Subsequently, a classification was made in accordance with the purpose of the study, 56 articles were found to meet the objectives of production scheduling optimization and/or energy efficiency in the industrial sector; of which 20 include both approaches simultaneously as a modeling objective. The present study has focused in these last ones.

3. Background

Currently, production planning models are focused on local efficiencies, which means that although they optimize production in terms of costs, their definition intrinsically simplifies the elements that they consider or focus on, in order to make the optimization models easily manageable, generally leading to global inefficiencies, as they don’t involve relevant variables that increase the total productive cost, and only involve, sometimes in a separated fashion, topics such as: tardiness, makespan, processing times, solutions to specific details or particular cases.

Over the years, these models have evolved, considering more and more elements. Nevertheless, they have just begun to consider the energetic variables as important factors in the decision making process of the scheduling stage; in the best of scenarios they are solely measured or managed without considering the entire productive environment, only parts of it.

In addition, current models usually separate production models, i.e. single machines, parallel machines, and the type of flow configured in the production line (normal flow, regulated flow, flexible flow, assembly flow, among others).

They also separate models according to the way in which products are generated, called continuous or batch processes. It is also separated among dependent sequence models; that is, where to perform an activity or process an earlier one is required, or independent sequence models, where no previous processes are required to generate the product or by-product.

Then, they consider the constraints of the manner in which they operate in the already defined and identified processes, such as the arrival of orders, machines and resources availability, production setup times of lines and machines, etc. [6].

Besides the production models optimization, strategies have been developed to solve the optimization problem of energy resources, which fundamental purpose is to develop a management oriented towards energy efficiency. This efficiency can be achieved from 3 complementary paths:
• Energy management savings.
• Energy savings derived from technological changes.
• Energy savings originated in a policies and regulations.

Table 1. Searching results

SEARCHING CRITERIA	2010	2011	2012	2013	2014	2015	TOTAL
Production scheduling	8.025	8.600	9.373	10.029	10.794	9.188	206.855
Energy efficiency	38.713	47.015	51.063	61.503	68.686	61.057	887.454
Production planning with energy efficiency	4.380	5.320	6.202	7.431	8.842	7.657	104.494
Production scheduling and energy efficiency	1.486	1.704	1.999	2.297	2.780	2.453	36.289
Decision making/process AND Production scheduling AND energy efficiency AND Model AND Multi variable AND Deterministic	56	65	94	115	169	170	1.385
Decision making/process AND Production scheduling AND energy efficiency AND Model AND Multi variable AND Heuristic	63	71	88	130	173	174	1.510
Decision making/process AND Production scheduling AND energy efficiency AND Model AND Multi variable AND Meta heuristic	12	19	30	37	52	49	347
Decision making/process AND Production scheduling AND energy efficiency AND Model AND Multi variable AND Stochastic	75	103	124	178	221	206	1.936
Decision making/process AND Production scheduling AND energy efficiency AND Model AND Multi variable AND Mixed integer program	65	68	77	129	181	176	1.215
Decision making/process AND Production scheduling AND energy efficiency AND Model AND Multi variable AND DEA (Data Envelopment Analysis)	19	16	21	23	27	35	313
Decision making/process AND	33	28	28	49	70	73	683

Production scheduling AND energy efficiency AND Model AND Multi variable AND Annealing Algorithm							
Applicable to the purpose of this review	2	6	3	15	12	18	56
Models with productive and energetic efficiency	0	2	0	5	4	9	20

Energy management corresponds to the different strategies that are sought to be implemented, in order to minimize costs and energy losses without affecting quality and production, and minimizing environmental effects. An energy management system must be incorporated as to achieved effective energy management, that should include 4 main sections:

1. Historical Data Analysis.
2. Energy Audit.
3. Engineering Analysis and investment proposals that improve energy consumption based on feasibility and return on investment analysis.
4. Trained staff and information.

With these elements, it is possible to control and optimize the energy resources that are consumed; achieving great savings, which are measurable, quantifiable, manageable and maintainable.

The development of this approach has allowed the standardization in this respect, which helps to guide the way this energy improvement scheme is faced by companies and the productive sector. The energy management process is a continuous improvement one, and the standard ISO 50001 standardizes it [2].

4. Specialized literature review

As it was mentioned in the background section, three paths were taken to address energy consumption optimization in the industry:

1. Via optimization of productive efficiencies, that as a principle seek costs and times optimization, with the help of mathematical models, and that can bring energy efficiencies or inefficiencies as an indirect consequence.

2. Via optimization of energy resources, as a result of an energy management system that seeks to manage energy resources without affecting production; however, although it is known to improve energy efficiency is not enough at the time of optimization in its entirety.

3. Via the integration of both energy and productive elements; that is in its initial stages and is precisely in the field this analysis is intended to deal with in more detail.

4.1 Productive Efficiency

[5] presents an analysis on the significance of reducing costs and times adjustment in the production processes, which indirectly impacts energy efficiency, because if adjustment times are reduced, equipment consumption during stand-by and idle states decreases as well. It also mentions how Krajewski et al. highlight the fact that reducing set-up times and batch sizes, is the most effective way to lower inventory levels and improve customer service.

In [7] an extensive review of programming models from 1998 to 2006, is carried out with adjustment times classified per production model (continuous, by lot), or type of process (single machine, parallel machines, flow type, etc.).

It can be seen in both articles, that setup times, total production times, work identification, delivery death line, among others; are determining factors for all the authors under review.

Finally, the opportunity to develop multi criteria models is highlighted, given that very few documents have been produced about this, that is evident in table 1, which presents the finding of only 56 documents where modeling either of productive or energetic models was done, and of which only 20 involve both, from spectrum of about 104,500 articles.

[8] present problem solving of programming changes in flow-type production systems with sequence-dependent set-up times on each machine (known as SDST flow production) using advanced meta-heuristics. The effectiveness of models with genetic algorithms is evaluated. We also present the way of calibrating the parameters for these algorithms by means of the experimental design approach (DOE).

[9] present a mathematical study of the maximization of the profitability of the company based on the relation sales-production according to the costs of production and storage. The respective theorems are presented and demonstrated.

[10] find a proposal for complementation of discrete event simulation (DES) models for dynamic production systems (CPS) with Dynamic Systems (SD) in which the DES and SD modeling system is included as complementary tools for the scheduling of production.

[11] involve the development of a fuzzy model that includes the supply chain as an object of analysis, that is, production, storage and consumption multi period and multi product and solved by genetic algorithms.

[12] propose a model of mixed mixed programming (MIP), which aims to optimally plan the energy savings for a given production schedule.

4.2 Energy Efficiency

As in the review of productive efficiency, we found two authors presenting papers with an extensive bibliographic review.

The first analyzes energy consumption according to the type of energy world-wide and focuses on some of the most developed countries with more industry (USA, China, India). It outlines the implementation of energy management systems based on ISO 50001, in addition to the implementation of energy saving technologies and how to calculate their savings, such as VFD (Variable Frequency Drivers), high efficiency motors, among others [2].

The same thing they do [13] in the power generation sector, classifying the literature according to the following types of models:
• Energy planning models.
• Supply - demand models.
• Forecast models.
• Optimization models for energy production, based on the location, consumption and type of resource to be used.
• Power models based on neural networks.
• Emission reduction models.

For their part [14] present a review of about 87 documents where sustainable development in the supply chain of companies is the main feature. In addition, where mathematical models have economic, environmental and social factors for this.

On the other hand, [15] develop a model based on the representation of the production operations as segments of energy consumption specific to each state of operation of the production equipment; Model of blocks called ENERGYBLOCKS.

It proposes its use to make predictions of energy consumption according to production scheduling by analyzing Gantt diagrams in which each operation corresponds to a segment that is added to determine the optimum Gantt between production time and energy consumption and thus determine what the production program should be.

[16] present a guide for the implementation of an energy management system, taking as a model the case study of a car manufacturing company Serbia that is in line with ISO 50001. The same thing is done by [17], but this time for a German bakery factory. Likewise, [18] present the program implemented in the Swedish industry that although it is not the norm, is directed towards her. The same happens with [19] which bases the construction of the proposed methodology on the results of a bibliographic review of 44 documents.

On the other hand, [20] perform an analysis of energy use in the industrial sector in Denmark. What is your status to 2006 in terms of energy management. Analysis of Danish policies and regulations as well as of the companies subject to the analysis is done.

[21] analyzes the use of energy and its efficiency in small and medium-sized enterprises in the manufacturing sector in Turkey. It presents a modeling system called DEA (Data Envelopment Analysis) which is a technique that does not require as many data requirements as other tools. Additionally, the result obtained with this tool provides a quick evaluation and is sensitive to the data that is supplied. There are two approaches to the DEA solution:
• Input oriented: minimizes inputs.
• Output oriented: seeks to maximize the result.

[22] analyze how from the social and engineering perspectives, the understanding of energy efficiency and its policies in Europe can be improved. How it is more effective in the generation of these, given the barriers to their implementation, these are: economic, organizational, behavioral.

[23] propose a production planning option through the use of MES (Manufacturing Execution System) software that allows to evaluate the energy consumption and to schedule the production according to the condition that in this case consists of minimizing the cost by energy consumption.

[24] present the results of installing a power management system called the Energy Management System EMS, which has the function of assisting decision making through the generation of operational recommendations and indicators to make use of the supply network at a minimum cost.

[25] proposes a system of "Enterprise Energy Management" (AEE), a methodology that applies basic concepts of statistics and mathematics to the understanding of the phenomena of energy consumption in a machine, production line or general process which was implemented in a Colombian company. It highlights the fact that energy efficiency is different from energy saving, since this is given during production. To this purpose, the following stages of energy control are proposed:

1. Process optimization.
2. Reduction of technical losses.
3. Good maintenance management.
4. Implementation of the energy management program
5. Identification of major problems in energy systems.

[26] propose a comprehensive methodology for the reduction of energy costs and CO2 emissions: application to cogeneration industries and plants, in which they perform a systematic analysis of improvements in equipment, energy recovery of the process and simulation of cogeneration plants and Networks of energy services, similar to an energy management system.

They also state that in industry, energy consumption can be seen as a supply chain with the following links: generation, distribution, transformation and transfer; In this way, it is possible to identify losses and causes of energy inefficiency at each scale. This helps maintain a comprehensive vision that takes into account both the interactions and the different links in the chain.

An exploratory study on optimization of energy use in a water-based textile process was developed in order to reduce processing costs; it also uses an experimental Box-Behnken design and a multivariate linear regression analysis to model the tensile strength in response to the variables [27].

[28] propose an energy management model for the Colombian productive sector, called the Integral Energy Management Model (MGIE), which was developed from the successful experiences of national and international energy management experienced between 1993 and 2008 , With the aim of reducing energy consumption and energy costs.

4.3 Energetic and Productive efficiency

It is important to remember that the purpose of the present study is to determine the existence of one or more models that involve both efficiencies as part of the planning of production scheduling and thus know the starting point, or identify if the approach that is intended Is already developed.

As follows are the models found:

A programming model of data analysis in computational systems based on heuristics in order to save energy [29], in which a multiobjective programming algorithm based on Pareto analysis is used.

It shows an evaluation of different scenarios considering three types of optimization solution, MOHEFT and HEFT (Heterogeneous Earliest Finish Time) with Pareto. It is found that energy optimization brings with it an increase in total data processing time, however, in some cases a 34.5% reduction in energy consumption is achieved, representing only a 2% increase in total processing time.

[30] present a production scheduling model for a workshop that considers peak loads, energy consumption, cycle time and associated carbon footprint. The dependence between the total time of processing and the energy consumption is presented, and how the optimization of the consumption increases that time. It also shows how the carbon footprint ceases to be sensitive after a certain level of optimization.

Likewise, [31] propose a programming model of parallel machines in a machining workshop in which it is possible to change the processing speeds during the execution of the work, where 2 heuristic models and a swarm optimization model of Particles (PSO). They compare the performance of the heuristic models with the swarm model, concluding that the swarm model is faster, and gives acceptable results and similar to the heuristics.

[32] Propose a deterministic NSGA II multiobjective programming model of an on-line workshop composed by 4 machines, whose purpose is the reduction of the total energy consumption and the total weighted processing time. For its solution, a genetic algorithm is used, which has two operators: the procedure of non-dominant classification and the procedure of classification of distances' clusters.

[33] propose a meta-heuristic optimization of ant colony algorithm (MOACO), where the solution was coded via a permutation of works and a list of algorithm of programming was applied to construct the sequence of artificial ants generating a complete planning. The results indicate that the efficiency and effectiveness of the proposed MOACO are comparable with NSGA II and SPEA2.
In addition, this model takes into account the cost of electricity consumption according to date and time.

[34] propose a programming model of a single machine workshop in order to minimize the cost of energy without exceeding the maximum delivery date. They present the advantages of the type of model used (MILP solved from a particle swarm model) compared to the others also developed to present the benefit in time calculations on the PSO for the degree of accuracy of results that it offers.

[35] proposes an optimization model for the programming of the lathe machines from the optimization of the operating parameters. They show the bases on which the objective function of optimization is based. The flowchart on which the optimization algorithm is based is presented, which is a multiobjective meta genetic heuristic algorithm that makes use of the iteration optimization of the Pareto analysis of the selected variables.

[36] developed in his doctoral thesis an optimization model with workflow scheduling with energy consumption constraints. The research studies programming as a means to address growing concerns about energy consumption and the cost of electricity in manufacturing industries.

Two types of problems are considered: minimizing the total processing time (makespan) in a permutation work line with maximum power consumption restrictions (PFSPP) and minimizing the total cost of electricity on a single machine in relation to time rates of use (SMSEC).

[37] shows a paper that constitutes a part of the doctoral thesis mentioned previously and presents in particular a problem of programming about a flow line with a restriction in the limit of energy peak consumption through a model of formulation of Mixed integer programming.

[38] seek to optimize the adjustment times, heating and thus the energy consumption, through three models:
• Postponing method: Analysis of energy according to productive and idle times.
• Adjusting method: It seeks to optimize the adjustment times, heating and thus the energy consumption.
• Optimization method of operation parameters, which is done by means of programming blocks that conform to the imposed criteria and restrictions.

[39] propose mixed linear programming models, both linear and non-linear, with the aim of minimizing production costs, which are considered as the sum of electrical consumption, stand-by times, installation and costs of energy demand.

The MIP models allow to determine the optimal quantities for a period where each one is characterized by a cost of electricity, duration and maximum available power, using solver. The computational study indicates that the formulation of the nonlinear problem obtains the optimal solution within a shorter time than the formulation of the linear problem.

[40] develop a model of optimization of thermoelectric power generation and compare three optimization methods:
• Genetic Algorithm.
• Lagrangian relaxation.
• Hybrid: Lagrangian relaxation with evolutionary algorithms.

It is appreciated that the latter is faster and optimal for short-term programming. We perform simulation and analysis of results that allow visualizing the results of the three models, both for model of cooperative generation and for generation model with competence.

[41] develop an artificial neural network optimization model, with an innovative and systematic approach to the programming of the grinding process and presents the optimization of programming. It consists of two stages: process and system. Several intelligent algorithms, including Search Pattern, Genetic Algorithm and simulated annealing, are applied and compared to identify optimal solutions.

This research presents a systematic approach to sustainable process planning and programming optimization with integrated intelligent mechanisms for better adaptability and responsiveness to manufacturing dynamics. Multiple criteria such as power consumption, surface quality, productivity and total processing time are considered at the same time to account for constraint based multiobjective optimization.

[42] present a mixed Integer programming model MIP, which analyzes one of the possible approaches to improve energy efficiency during production, and is to carry out production scheduling while being efficient and environmentally friendly.

It is identified that the discrete time model behaves better by offering better solutions and competitive computational efficiency. The possibility of treating the time parameter as a continuous variable was discussed, but it was found through a theoretical analysis and experimental simulation that discrete time models are more suitable for this type of problem.

Taking into account the variable energy prices during a day, [43] propose a mathematical model of genetic algorithm to minimize the costs of energy consumption for production scheduling of a single machine during the production processes. On the other hand, to determine if the heuristic solution provides the lowest cost and best possible time to minimize energy costs, an analytical solution is run to generate the optimal solution.

The results indicate that significant reductions in energy costs can be achieved by avoiding periods of high energy prices. This minimization process also has a positive environmental effect by reducing energy consumption during peak hours, increasing the possibility of reducing CO2 emissions from power generating sites.

[44] propose a model of particle swarm optimization, in which they seek to propose models with a double focus in time and energy, to minimize cycle time and total energy consumption simultaneously.

The proposed models are useful for reducing energy consumption and the total time cycle in robotized assembly lines. It is observed that the calculation time for the time-based model is lower compared to the energy-based model.

[45] present a comprehensive analysis of energy saving options through the use of buffers as part of the solutions to the scheduling modes, implementation of energy management systems, energy integration and presents different scheduling production models. All of them based on production times and based on MILP models.

It is shown that through the use of the different models results can be obtained as the saving of 18% of the energy consumption through an adequate planning, and sequencing of the production via the coordination model, additionally reducing the storage time by 23% and the total processing time was reduced by 7% for one case in the steel production industry.

[46] propose a method that uses the application of intelligent search algorithms for the identification of solutions of high quality of decision. The method of study consists of two stages:

The first one corresponds to the design of the initial configuration: In this stage, and based on the specifications of the product structure and assembly, an analytical way of calculating the necessary number of stations and resources is provided.
The second is regarding with the initial design of stage 1 is additionally detailed through an intelligent algorithm capable of selecting specific resources for each station. The selection is based on the characteristics of individual resources and the resulting system performance, which is estimated using discrete event simulation.

The method was tested and evaluated in a case study, inspired by an actual automobile assembly line, which demonstrates the algorithm's ability to derive better assembly line configurations.

5. Results and discussions

Although in the production scheduling field and energy efficiency there are many articles about this subject, more than 104,500, only 50 refer to the subject in question; That is, studies refered to production scheduling models and energy efficiency, and of these 50 only 20 focus on the analysis of both efficiencies in a joint way as models, since it is precisely in the field in which we intend to delve .

Of these models, [31], [34] and [44] proposed a model of particle swarm optimization; [Liu, Chengang ...] and [43] presented a genetic algorithm model.

The authors [30], [42] and [45] proposed a mixed linear programming model MIP; [39] proposed a mixed linear and non-linear programming model [40], of the authors studied, proposed a hybrid model of nonlinear mixed mixed programming, which combines lagrangian relaxation with evolutionary algorithms, in order to That the latter update the Lagrangian multipliers.

On the other hand, [29] and [35] address the problem through multi-objective algorithms based on Pareto analysis of the chosen variables.

In addition, [38] proposed a multi-objective optimization algorithm based on the learning goal model, [33] a metaheuristic ant colony model MOACO, [32] a multi-objective deterministic model, [36] an optimization model with Energy consumption constraints, [15] a block energy model, [41] an artificial neural network optimization model, and [47] intelligent search algorithms.

Now, there is a great vacuum in dealing with the problem of scheduling and production planning taking into account energy efficiency, since few authors have approached it from different models but have left out quantitative models that include variables as: cost, energy efficiency impacts into production chain and financial aspects.

On the other hand, the production planning studies that have been developed taking into account the energy efficiency factor within the scheduling variables are even more scarce, and most of them correspond to the inclusion of the analysis of the energy fees in different schedule times and therefore it becomes the element of definition for production optimization.

Besides, the solutions are very particular; that is, they refer to very specific industries such as metalworking, the computer industry specifically in the administration and data processing.

In many cases, only models are presented for two variables: the total processing time (makespan) and energy consumption. And in the best cases involve some additional variables such as: due date of work orders, work order number, energy costs and CO2 equivalent.

Many of the models look for local efficiencies and they don't consider the overall efficiency of the company. Not all of them include economic aspects as part of the model or analysis directly. In some, impacts on productive times are not analyzed and are not included as an analysis variable.

In no case the result of production scheduling is showed; that is, the sequence in which production is efficiently performed. Only the models are presented, and their results in terms of the variables they analyze.

Hence, there is a whole way to go and explore, so that these elements that are not included are part of the analysis and therefore of the model to be developed, and as a product this not only delivers the results of the variables, but its main result is the sequencing of the production program.

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Biography

Bonnel Mejía-Maya is an Mechanical Engineer, and Director of Engineering Projects in Nutresa Company. He earned Mechanical Engineering from Universidad Pontificia Bolivariana, Colombia.

Vanessa Sierra-Zuluaga is an Industrial Engineer, and Industrial Engineering in Caldas Hospital. She earned Industrial Engineering from Universidad Pontificia Bolivariana, Colombia. Specialist in Projects.

Javier Darío Fernández-Ledesma is currently a professor in Universidad Pontificia Bolivariana and Director of System Applied at Industrie Group Research in College of Engineering at UPB. Mr. Fernández Ledesma holds a degree in Industrial Engineering from Universidad de Antioquia, Specialist in Systems from Universidad Nacional de Colombia, Master of Science in Engineering from Universidad de Antioquia and PhD in Electronic Engineering. He has published journal and conference papers. His research interests include manufacturing, simulation, optimization, software engineering and automatization.