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Alternative Objective Function in Planning and Scheduling

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Abstract

For many years, the Operations Research (OR) discipline has been primarily concerned with economic aspects. The objective of traditional Planning and Scheduling has been mainly considered from a productive viewpoint like optimizing time and cost. However, human factors have gained increased attention since the 2000s, propelled by growing public concerns about sustainable development on the same grounds as economic and ecological ones. Applying conventional optimization models to Planning and Scheduling appears not to seem sufficiently effective, so alternative approaches must be employed to obtain insight into the most critical drivers of socially responsible operations to apply standard Operations Research (OR) models appropriately. The purpose of this study is to analyze and classify how the works dedicated to alternative objective functions by the Operations Research community to integrate human and environmental considerations into production and logistical systems have been captured. Moreover, several gaps in the literature are addressed, and some recommendations for appropriately integrating human and ecological factors in OR problems are given. There were several aspects that could not be analyzed and classified due to a lack of or insufficient research material in these areas. This work can be used as a basis for further research into non-productive objective functions that could bring about new perspectives in this field.

Keywords
Optimization, Ecological, Ethical, Ergonomics, Human-Factors

1. Introduction
The notion of Objective Function in modeling Planning and Scheduling Problems has been studied for a very long time. This concept is very critical because it determines whether we can arrive at an optimal solution to a problem or not. Before we define what an Objective function is, it is important to look at a little bit of context. Scheduling deals with the gradual distribution of limited resources to jobs. It is a collection of methods for decision-making to maximize one or more objectives. These resources could be employees, materials, machines, routes, computer central processing units (CPU), and so forth.

Ronald Graham, Eugene Lawler, Jan Karel Lenstra, and Alexander Rinnooy Kan (Graham et al., 1977, 1-40) introduced a convenient notation for classical scheduling problems below, based on three different fileds, respectivle named **α|β|γ**, where **α** denotes the machine environment, **β**: refers to the process, characteristics, and constraints of the problem and **γ**: refers to the objective function to minimise.

This paper will mainly focus on discussing alternative or non-productive objective functions (**γ**) in Planning and Scheduling scenarios across different industries.

The Objective of a Planning/Scheduling requirement refers to the goal or outcome of an activity towards which efforts and resources are directed. A way to maximize (or minimize) these goals and outcomes are described as the objective function. For many years, the objective of traditional planning and scheduling has been viewed strictly from a

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productive perspective (related to optimizing time and cost). Examples of productive objective functions include makespan, maximum lateness, total weighted completed time, weighted number of tardy jobs, and global costs just to mention a few. However, with the occurrence of many new ethical and ecological issues, there have been a lot of recent studies dedicated to alternative objective functions to address these challenges. These new criteria are normally difficult to capture and model using an exclusive linear function. Hence, they are approached using a combination of hard and soft constraints and multifaceted objective functions.

Several ethical and ecological issues led to investigations into the notion of "non-productive" objective functions. Some of these problems bother on human dignity, health and safety hazards, and environmental pollution. For example in the Oxfam America report for the continuation of their campaign to advocate for improved conditions for US poultry workers, some of these concerns were succinctly captured as follows: "While the poultry industry today enjoys record profits and pumps out billions of chickens, the reality of life inside the processing plant remains grim and dangerous. Workers earn low wages, suffer elevated rates of injury and illness, toil in difficult conditions, and have little voice in the workplace. Despite all that, though, workers say the thing that offends their dignity most is simple: lack of adequate bathroom breaks and the suffering that entails, especially for women". (OXFAM America, 2016, 3). This is just one of several high-profile cases relating to human working conditions.

There are also several cases of ecological disasters that have raised these concerns as well. For instance, the website https://www.cfr.org/timeline/ecological-disasters (Ghoshal & Rothaus), details how the members of Peru's indigenous Achuar population claimed that the nine billion barrels of oil wastewater that were dumped into the Amazonian watersheds have resulted in cancers, skin conditions, miscarriages, and unexplained maladies. The Achuar community sued Occidental Petroleum, a company with U.S. headquarters, for environmental and health damages brought on by the contamination in 2007. The plaintiffs asserted that the business disregarded industry norms and broke international, American, and Peruvian law. According to Occidental, there was no proof that there were negative health repercussions. 2015 saw the two parties come to an out-of-court settlement, the details of which have not been disclosed.

1.1 Objectives

The purpose of this study is to look extensively at several Operations Research Models dedicated to the non-productive objective and categorize them according to how they are demonstrated and captured and provide a specific idea of the way it answers, or not, to real issues, leading a general conclusion and evaluation of perspectives

1.2 Significance of the Study

This study is important because there has been a lot of emphasis on productivity without thinking of long-term sustainability. Sustainability has three major pillars which are profit, planet, and people (3Ps). While most previous research efforts have been focused on the economic aspect, there is also a need to emphasize the social and environmental areas to ensure sustainability. Concentrating on certain fields at the expense of other fields would eventually culminate in the decline of the enterprise or system.

2. Methods

In line with the objective of this paper, the methodology did not entail experimental research. The steps involved with this analysis and categorization of the non-productive Operations Research Models are as listed below:

2.1 Search and analysis of papers

We sourced for 81 different papers and then checked for the relevancy of each paper to the research. We were able to determine the relevancy by checking first if the write up was on non-productive objective function and if this function was mathematically modelled. We finally decided on 59 papers to be used for the project.

2.2 Preparation of research outline

Thereafter, the research outline was prepared and was reviewed with the project supervisor. After completion of approval was then followed by writeup development.

2.3 Write up, review and proof reading

The next step that followed was the analysis of the papers. Inductive reasoning was used to arrive at the classification of the various papers and then preparation of the write up based on the classification. This was then followed by regular review with all of the authors and the supervisor. The final step was iterative proof reading by all authors and the supervisor, where corrections and updates were made with each iteration.

3. Results and Discussion

3.1 Numerical Results

The Non-Productive Objective Functions seen from the vast majority of papers consulted for this study are broadly grouped under two major sections - Ecological and Ethical Non-Productive Objective Functions. These are further subdivided as shown in figure 1 below. Ecological Non-Productive Objective functions refer to any alternative function that deals with non-human factors while Ethical Non-Productive functions deal with human factors. A few decades ago, environmental issues were regarded as a one-way interaction between society and the natural environment (Aldeia & Alves, 2019). The misconception that natural resources and the earth's reserves are inexhaustible and do not require maintenance led to their overexploitation and destruction by humans. The relationship between society and the environment is no longer a theoretical concept but a pressing concern. Global social and economic development has been greatly impacted by environmental issues (Barreto & Kypreos, 2004).

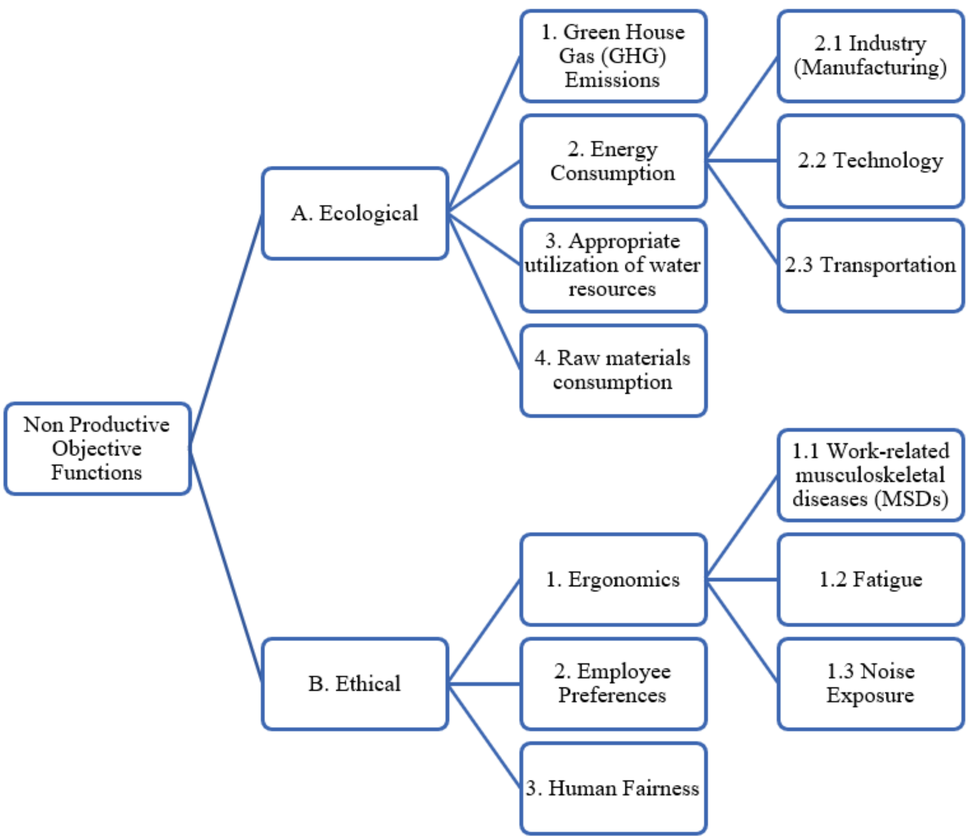

Figure 1. Classification of the Non-Productive Objective Functions

Below Table 1 and 2 gives a brief explanation of each classification and the captured mathematical models

Table 1. Ecological Non-Productive Objective Functions

CLASSIFICATION	**EXPLANATION**	**PAPERS**	**OR OBJECTIVE FUNCTION CAPTURING APPROACH**
1. GreenHouse Gas (GHG) emissions	With the increasing focus on climate change, numerous research papers have modeled GHG emissions and incorporated them into optimal scheduling or planning mathematical models.	(a) Elkamel, A et al. et al., 2008 (b) Laing, H et al., 2022 (c) Shao, S, et al. 2022 (d) Liao, W., & Wang, T. ,2018 (e) Boyan I. et al.,2022	Direct mathematical modelling considering emission quantity or cost as minimization objective
2. Energy consumption	Environmental issues are not limited to carbon emissions, but are also related to the consumption and use of other energy sources. Currently, as human activities developed in various sectors, the usage of energy to power the activities and processes are also increased significantly. Knowing the growth of energy consumption due to the rise of technology and various activities in the world and its effect on the environment, as well as the cost to generate these energies, it is necessary for considering energy consumption for planning and scheduling the activities.		
2.1 Industry (Manufacturing)	This massive energy consumption leads to a big concern for the companies and researchers, as currently there is much research that considers energy consumption for scheduling and planning the job assignment in manufacturing.	(a) Mansouri & Aktas (2016) (b) Wu et al. (2018) (c) Zeng et al. (2018) (d) Paper Duarte et al. (2020)	Directly considers energy as an objective function or considering the energy cost function as an objective function to be minimized.
2.2 Technology	Technology usage consumes a lot of energy and produces carbon emissions (Ghafari et al., 2022; Gao et al., 2021). Therefore, many researchers and parties are also started to be concerned and considered the energy usage of the technologies when planning or scheduling tasks or activities to the technologies.	(a) Gao et al. (2021) (b) Seman et al., 2022 (c) Dong et al. (2015)	Two technologies that are in widespread use nowadays and researchers considered planning with energy efficiency are satellite for communication or capturing images of the earth, and computing technology, including cloud computing. The papers modelled Technology by minimizing energy consumption
2.3 Transportation	Transportation is another biggest energy end-user besides the industrial sector (Bányai, 2018; Huang et al., 2017). Transportation sectors covers all modes of transportation, including private and commercial for trasnporting goods or human.	(a) Huang et al. (2017) (b) Bányai, 2018 (c) Sigler et al., 2021	Wide range of researches in transportation scheduling have concerns to the resource allocation and integrates energy-efficient approach for planning the transportation. In general, for the papers that considers energy-efficiency in the scheduling, the energy variables or parameters are modeled directly as the objective functions.
3. Appropriate utilization of water resources	Although global water supplies are ample, this nonrenewable resource is under increasing strain, and the industrial sector frequently disregards the	(a) Saeedi, M and Hosseinzadeh , M (2006)	Paper (a), Directly modelled the maximization of wastewater recycling and reuse and minimization freshwater use from their flow rates.

	treatment of already-used water. The wasteful use of water resources and industrial wastewater can cause enormous harm to ecosystems, therefore reducing water consumption and wastewater discharge is a major priority.	(b) Wang, S., Cao, T., & Chen, B. (2007)	Paper (b), assessed water and energy consumption in the energy sector by analyzing the intensity of direct and indirect consumption of water resources in energy production using the input-output analysis approach
4. Raw materials consumption	Raw materials are the goods or inventories required by a firm to produce its products. Effective use and allocation of raw materials minimize raw material consumption, save money, and reduce environmental damage.	(a) Billaut, 2018 (b) Wang & Liu, (2014)	Paper (a) directly modelled the objective function by minimizing the cost and quantity of the lost product (two objectives). Paper (b) proposes a model for differentiating trim loss ratio and inventory distribution data based on schedule adjustments and inventory quantity limitations to improve the overall production efficiency in the paper industry. The objective function is to minimize trim loss

Table 2. Ethical Non-Productive Objective Functions

CLASSIFICATION	**EXPLANATION**	**PAPERS**	**OR OBJECTIVE FUNCTION CAPTURING APPROACH**
1. Ergonomics	Ergonomics is the scientific discipline concerned with the understanding of the interactions among human and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance		
1.1 Work-related musculoskeletal diseases (MSDs)	Work-related musculoskeletal diseases (MSDs) are mostly connected with poor ergonomic work conditions, and these disorders constitute a major source of work-related illness.	(a) Yoon et al., (2016) (b) Mossa et al., (2016) (c) Digiesi et al., (2018) (d) Zhou & Wang, (2021)	For paper (a), the modelling approach is direct. The objective function is to minimize between-worker variance in the cumulative daily workload and constraints to make sure workers are not assigned to successive workstations that place heavy stress on the same body region. In papers (b) and (c) the modelling was done using a dual approach. A dual approach is explored by either finding production maximization solutions under ergonomic constraints or, vice-versa, minimizing the ergonomic risk solutions, under production constraints. Paper (d) modelled ergonomics indirectly in the constraints (the model has 3 constraints related with ergonomics).
1.2 Fatigue	Fatigue is described as a state of mental and physical exhaustion that impairs a person's capacity to accomplish tasks. Worker tiredness can have a significant influence on system performance in terms of quality (Eklund, (2014)).	(a) Pei et al., (2022) (b) Othman et al., (2012)	In paper (a), a direct approach was used to model the objective function of flexible job shop problem (FJSP). The goal is to reduce tiredness or the allowed maximum working hours-oriented function. Paper (b) uses the dual modelling approach in a job shop setting. Weariness was incorporated both into the objective function and constraints.
1.3. Noise Exposure	Noise exposure can be defined as any disturbing and high-intensity sound that can affect human health negatively. High noise	(a) Lu et al., (2018) (b) Lang & Lit, (2011)	In paper (a), the noise exposure was modelled directly as part of the objective function with the productive aspect of the make span.

	exposure not only affects physical health, such as causing dizziness and problem in hearing but also affects the mental health of humans that are exposed intensively to uninterrupted sound (Lu et al., (2018); Hajibabaei & Behnamian, (2022)).	(c) Lu et al., (2019) (d) Hajibabaei & Behnamian, (2022)	Paper (b) includes a noise exposure variable as part of the objective function in a job shop scheduling problem Paper (c) models three objective functions, with a productive objective, minimize makespan, and two non-productive objective of minimizing noise exposure and energy consumption for solving hybrid flowshop scheduling problem. In paper (d) noise exposure was not directly modelled in the objective function. The research does not include the noise variable directly, but included it with the speed increase of machine, as it is found that the lower the machine speed, the lower the noise resulted. Hence, the minimization of speed increase is equal also to minimizing the high disturbing and constant noise from the operations.
2. Employee Preferences	One of the common non-productive objectives considered in scheduling problems is the preferences of employees or staff. In this case, the scheduling problem is solved by including staff preferences related to their jobs (shifts, days off, working hours, job types). By incorporating the preferences, the scheduling result are optimizing not only the assignment but also the employee satisfaction, which leads also to the improvement of the worker performance that increases the work and service quality (Örmeci et al., (2014); Rerkjirattikal et al., (2020); Ruiz-torres et al., (2015)).	(a) Perreault-Lafleur, 2022 (b) Ruiz-torres et al., (2015) (c) Mohan, (2008) (d) Wright & Mahar, (2013) (e) Hamid et al., (2018) (f) Rerkjirattikal et al., (2020) (g) Shuib & Kamarudin, (2019) (h) Örmeci et al., (2014) (i) Sabar et al., (2008)	Papers (a), (b), (c), (d), (e), and (f) have employee preferences directly modelled in the objective functions Papers (g), (h) and (i) modelled employee preferences indirectly in the constraints
3. Human Fairness	The definition of fairness has received extensive study in the fields of psychology and economics. However, as the term is greatly influenced by the context, a universal definition of fairness is unlikely, if not worthless. According to (Shi et al., 2014, 5), there are two types of fairness. These are resulting fairness and targeted fairness. Resulting fairness deals with resource usage, whereas targeted fairness focuses on resource allocation.	(a) Trilling et al., (2006) (b) Hamid et al., (2018) (c) Ozder et al., (2019) (d) Devesse et al., (2022) (e) Blöchliger, (2004)	The objective function in paper (a) was modelled directly to minimize the maximum total punishment for each nurse in a Nurse Scheduling Problem Paper (b) approached the same problem using a multi objective function approach with two of the objective functions focusing on maximizing fairness and the other minimizing the costs designated to the nurses Paper (c) modelled fairness directly using a single objective function with a multi objective structure. The objective seeks to minimize the costs of overtime and unbalanced appointments and to pursue fair

			appointments without disregarding seniority levels and personnel skills Paper (d) modelled fairness indirectly in the number of worked hours and worked weekends in The Physician Scheduling Problem in Emergency Rooms using a reformulated mixed-integer programming model Paper (e) Modelled indirectly in the objective function by minimizing the distribution of unpopular shifts among employees using the concept of Cost of Time Table Blocks (TTB).

3.2 Proposed Improvements

It would be quite interesting if much more research is made into the Human Factors in an attempt to model them mathematically. Some of these factors include:

- Human stress
- Mental Health of workers
- Dignity

4. Conclusion

The papers were successfully classified in accordance with the original intent. On the Ecological factors, we looked into GreenHouse Gas (GHG) emissions, Energy consumption, Water consumption, and Raw material consumption and from the Ethical angle we considered Ergonomics (Work-related musculoskeletal diseases (MSDs), fatigue, noise pollution), Employee preferences and Fairness. To better understand these classifications, we gathered papers on the utilization of these unique factors in achieving new solutions, or improvements on existing models from a different perspective in operational research. Based on the conclusions from each classification above, we can deduce that Non-Productive Objective functions can indeed to a great extent address ecological and ethical concerns in Planning and Scheduling. However, there could be difficulty encountered in obtaining an optimal solution that reflects reality since human factors are difficult to model. In addition, the optimization focus could lead to bias at the expense of other equally important objectives (high sensitivity, since where you optimize you go). Furthermore, the extent to which constraints can be identified could determine accuracy of the model. Nevertheless, having such approaches in mind could be an interesting side step while try to model decision-making beyond short-term productivity.

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