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Towards a Standardization in Scheduling Models: Assessing the Variety of Homonyms

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***Abstract*—**Terminology is a critical instrument for each researcher. Different terminologies for the same research object may arise in different research communities. By this inconsistency, many synergistic effects get lost. Theories and models will be more understandable and reusable if a common terminology is applied. This paper examines the terminological (in)consistence for the research field of job-shop scheduling by a literature review. There is an enormous variety in the choice of terms and mathematical notation for the same concept. The comparability, reusability and combinability of scheduling methods is unnecessarily hampered by the arbitrary use of homonyms and synonyms. The acceptance in the community of used variables and notation forms is shown by means of a compliance quotient. This is proven by the evaluation of 240 scientific publications on planning methods.

***Keywords*—**Job-shop scheduling, JSP, terminology, notation, standardization.

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I. INTRODUCTION

THE research area of the Job Shop Scheduling is concerned with the search after an efficient sequence of orders to create a machine allocation plan [1]. For this work, orders will be chronologically associated with limited production resources under varying goals and constraints.

Job Shop Scheduling (Job-shop problem - JSP) stands out through a very large diversity of basic optimization approaches. For each approach there are a lot of variants and refinements, so that more constraints or more optimization goals can be considered. Optimization algorithms will be developed to make them more comprehensive, effective or efficient. To prove a finding, a rated comparison will be carried out with the already existing algorithms. For a reliable comparison it is critical to identify appropriate compare candidates. This includes algorithm variants as well as algorithms with completely different basic approaches, which work with the same constraints and goal variables. In the scientific practice there is a problem in this respect. The relevant model elements of the papers for the representation of comparable processes are difficult to identify. Even though the same problem class is handled with a comparable problem model, this similarity is unintentionally obscured by a different terminology. When naming model elements, homonyms and synonyms appear on both the textual and the mathematical notation.

An identification of suitable algorithms is not made impossible, but without necessity more complicated. Of course, every author has the freedom to name his variables and concepts. However, a common terminology is advantageous for the connectivity of his work and this research area as a whole. The aim of the study described in this article is to show the differences in the terminology used in the literature on scheduling problems. This is intended to encourage activities to standardize the terminology for scheduling problems. A proposal for this is the approach of the documented design knowledge applied to scheduling models. For this purpose, a text analysis of existing literature on scheduling algorithms was carried out.

II. PROBLEM AND TARGET ANALYSIS

Terminology is a critical instrument for the scientist. It is necessary to be able to describe a problem (and also the approach and the findings) clearly, conclusively and comprehensibly so that other scientists can also build on this work. Areas of research, which are served by several disciplines, have the problem that each specialized discipline has its own specialist language. For the JSP, the relevant disciplines are not only mathematics or computer science with their theoretical perspectives but also production science, business informatics and business management with a more application-oriented perspective. When dealing with specific research questions on JSP algorithms, the creation of a discipline-spanning, common terminology is not one of the primary activities. The scientist has his clearly defined research question and can edit it in a self-limited model. At this time, he has already dealt with the state of research and other models. From the multitude of found models, he will compile his own notation for his mathematical models or use his own notation. Implicitly, he had to deal with the problem of non-uniform model representation and, with his own model, contributes inadvertently to a continuation of this disunity.

The use of terminology standards has proved its worth in many areas of the industry. Terminology norms deal with terms as general definitions for an area and sometimes also contain definitions, remarks, pictures or examples [2]. The use of a common technical language and a common mathematical notation for research areas, which are characterized by a clear focus on a common problem object, a common basic model, large publication activities and high requirements for scientific connectivity, provide benefits in several ways:

- *Clarity:* An overview of unified terminology reflects the current state of research. On the basis of the concepts taken into account, it is possible to see what the research has

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already dealt with. If this overview is to be revised as a periodic document, the development of the research area can also be tracked.

- *Researchability:* Research papers on algorithms that take certain scenarios or model approaches into account can be researched more easily if uniform technical terms are used for the central concepts. Homonyms, in particular, make the searches more difficult and require systematic processing of alternative search terms, without guaranteeing that all relevant papers are taken into account.
- *Comparability:* Two approaches for optimization are better comparable by a uniform terminology. The danger or control and conversion effort of homonyms and synonyms is eliminated. It is immediately apparent (uniform notation) and understandable (uniform semantics) which model elements are used. This includes the side conditions and model assumptions.
- *Modelability:* The development of new algorithmic approaches is simplified because a terminological unification also includes an overview of the central concept of the research object. This makes it easier for developers to get started and to expand, because they can directly select the relevant model elements or can deliberately decide to exclude specific conditions. For the working phase of the formal specification of the new algorithms, the unified mathematical notation can be used directly. This eliminates the need for investigation and selection decisions for consistent naming.
- *Combinability:* Optimization algorithms are not only related to one another or as a selection option in a simulation application but can also be combined directly. This is the case with complex processes that use a different approach, depending on the specific composition of the upcoming production plan. However, different algorithms can also be combined in the roles of opening procedures and main procedures. One approach provides an output solution, which is then iteratively improved by another approach. By means of standardization, preliminary calculation steps can be undertaken directly and in the original presentation form.
- *Comprehension:* Common technical terms and notation increase the comprehensibility of specialist contributions for readers. Since both the formal models and the explanatory flow text encounter familiar concepts and symbols known in their meaning, there is no abstraction stage. Readers do not have to carry out an implicit translation of the technical terms, but have direct linguistic access.
- *Implementability:* Algorithms are implemented for validation and verification as executable simulation programs. A non-uniform terminology and mathematical notation are thus passed on to the programmers and to the source code. This requires an individually adapted documentation of the variable names and variable meanings. This is necessary to facilitate future maintenance or re-use of the source code. On the one hand, a standardization can replace its documentation because ready documentation templates or entire program parts with partial model classes can be used. On the other hand, it is easier to integrate foreign source code for further procedures into the simulation framework and to maintain it further because all modules, classes or plug-ins use the same convention for variable naming and meaning.

Against this background it has to be clarified whether there is already a de facto standard with regard to terminology. As a question of investigation, we investigate the size of the terminological differences in the literature on scheduling algorithms. A particular focus is on the mathematical notation used as a central display for the formal specification of scheduling algorithms.

III. Research Design and Methodology for the Study

The literature analysis is used as research method. “A systematic review is a defined and methodical way of identifying, assessing, and analyzing published primary studies in order to investigate a specific research question.” [3]. With it, different objectives can be pursued [4]. This is not just about deepening the state of research and its current developments. Further goals, which are also pursued by this work, are the identification of relevant variables or different conceptual understandings within a research area [5]. The literature analysis is carried out in three main steps [6], [7]: Planning, Searching & Selecting and Analyzing.

The planning includes the motivation for the investigation and specifies the research question (see Section II). In addition, the review protocol is prepared and reviewed. For this purpose, a preliminary investigation has been carried out, in which ten basic articles on the scheduling with respect to central concept names and model components have been analyzed (e.g. Table I). From these the initial search terms for the search phase have been worked out. The period 2006 to 2020 has been set as a relevant publication period. On the one hand, this takes the past developments into consideration. On the other hand, however, it is ensured that several researcher generations or project run times are recorded without giving too much weight to general standard and teaching models. Furthermore, the search is limited to four professional journals, which focus on the topics of production and production planning. On the one hand, a high number of specialist articles can thereby be ensured for scheduling algorithms. On the other hand, it is assumed that, if terminological differences are already apparent within these journals, these cannot be any smaller all in all.

The search is performed as a database-based search. EBSCO was used to search the selected journals for the selected period. The “International Journal of Production Research” and the “Journal of Scheduling”, “The European Journal of Operational Research (EJOR)” and “Operational Research - An International Journal (ORIJ)” were selected. The central search term is the word “scheduling”. Within the framework of an iterative refinement of the search, specific concepts have been incorporated into the search terms “parallel” and “identical machine” and “independent job”, “minimization”, “maximization”, “optimization”, “mean value”. As a result, about 240 sources of literature have been collected. In the selection phase, only those papers are selected which have both an independent scheduling process and a mathematical model for this. For this, not only the title and the abstract but the full paper content were considered. This can reduce the risk of multiple detection of an algorithm. And it is ensured that the subsequent text analysis is always applied to complete and formally specified optimization methods. This resulted in a quantity of 101 relevant specialist articles.

TABLE I
MATHEMATICAL NOTATION FOR SCHEDULING MODELS ACCORDING TO [8]-[10]

Neural Network Based Generalized JobShop Scheduler [8]		Scheduling with unexpected machine breakdowns [9]		From Fluid Relaxations to Practical Algorithms for High Multiplicity JobShop Scheduling: The Holding Cost Objective [10]	
m	machine	J	set of jobs	O	scheduling algorithm
n	job	C	makespan	a,I,i	job type
N	set of jobs	p	processing time	J	machine
M	set of machines	A	scheduling algorithm	p	processing time
k	operation	c	competitive	w	weights
O	operation of job	S	total number of intervals where machines are available	k	stage
S	starting time	m	machine	DC	completion time
C	completion time	T	total time	C	lower bound
E	earliest start	a	available machines	t	time
P	processing time	t	time	Z	cost of an optimal
D	deadline	r	remaining processing time	u	instantaneous fraction of effort
L	critical type	I	time interval	c	average holding cost
V	set of operation pairs	l	largest job index	v	effort
SP	spent time	q	sequence	R	number of pieces
		n	number of jobs with positive remaining processing time	N	queue length
		B	breakdown	DS	discrete start time
				C	congestion
				U	workload
				DC	discrete completion time
				FS	fluid start time

In the analysis phase, each subject has been examined with regard to the presentation of the respective scheduling procedure. On the one hand, the problem representation was treated and the model elements considered, e.g. „jobs“, „tasks“, „setup times“, „machine park“, etc. On the other hand, the optimization objectives pursued in each case have been extracted. Elements and target variables have been collected in a first step for each individual article. As an illustration, an overview of three representative articles was prepared (see Table I).

In a second step, a comprehensive overview of the terms used has been prepared. Homonyms (identical naming different concepts) and synonyms (different naming of the same concepts) have not been completely resolved. The model elements have however been assigned to thematic groups. The mathematical notation for model elements and target variables used in the specialist articles have been extracted from each article and compared. Finally, 187 different model elements and 73 different target variables were found, which were divided into a total of 37 groups. Of these, 25 groups (see Table XII) are presented as model elements used in specialist articles of scheduling algorithms and 12 groups (see Table XIII) as target values used in specialist articles of scheduling algorithms.

IV. RESULTS OF JSP LITERATURE ANALYSIS

This section presents the findings from the evaluation of the scientific papers under consideration. The structure depends on the model elements (input variables) and target variables. They are also analyzed for similarities, differences and peculiarities as well as homonyms/synonyms. For this purpose, the distribution of the use of mathematical identifiers for model components is quantitatively described.

The input variables with the largest part in all the work are “job” [11], “machine” [12] and “processing time” [13]. These variables are represented by more than 80%. There is only a difference between “set of job” [14] and “independent job” [15]. Secondary tasks were first identified as “operations” [16] and “stage” [17]. The variable machine is expressed in “set of machine” [18], “identical machine” [19], “parallel machine” [20], “group of machine” [21] and “single machine” [22]. In addition to machines, “resource” [23], “product” [24] and “parts” [25] could still be identified. “Reactor” [26], “server” [27] and “manufacture” [28] were only used in one paper. The processing run time is also expressed in “processing speed” [29], “fixed processing time” [30], “processing start time” [28] and “lower/upper bound of processing time” [31]. In addition, there are several types of time variables, such as “starting time”, “finish time”, “deadline”, “ready time”, “due time”, “release time”, “completion time”, “unloading time” and “breakdown time”. Special features are, above all, the time variables, which were used especially for a single production process. These are expressed by “the time required for the robot to execute the void move from machine” or “time of switching from production of product”. In addition, further input variables could be identified, which were classified into the groups “age”, “capacity”, “cost”, “speed”, “matrix” and “else”. The group

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"age" contains expressions such as "maximum mold age" [32] and "maximum machine age" [32]. The capacity refers only to the machine. Costs are expressed in "changeover cost" [26]. "Speed" refers only to the operating time. Matrices "processing operation matrix" [33] and "processing time matrix" [33] were determined. The "else" group contains all remaining input variables, which could not be assigned. Contents are "nonnegative weights" [10], "critical type" [34], "heterogeneous batch processors" [34], "set of all AGVs" [35], "set of due window sizes" [36] and "any subset" [37].

In many cases, similar or logical symbol assignments are used for variable abbreviations. For example, "j", "machine" "m", or "processing time" "p" are used for "job". The higher the complexity of the input variables, the less correlated is the symbol assignment for variable abbreviation with the input variable. For example, the variable "the time required for the robot to execute the void move from machine" is abbreviated as "e". The variable identifiers for model elements are explained in more detail in the following. The textual names for the model elements were first selected from the specialist articles. Only the exact formulation is decisive. The respective mathematical identifiers were then selected for the model elements used, as formally used in the optimization model (examples, Tables II and III). Case-sensitivity and indices are taken into account.

TABLE II
VARIANTS OF MATHEMATICAL NOTATIONS FOR "SET OF JOBS"

	Notation										∑
Variants	n	N	I	J	V	m	j	*n*0	J_j	T	10
Entries	11	5	1	47	1	1	2	1	4	1	73

TABLE III
VARIANTS OF MATHEMATICAL NOTATIONS FOR "SET OF MACHINES"

	Notation						∑
Variants	M	m	$M_{i,j}$	J	i	M_k	6
Entries	27	17	1	1	2	1	49

A simple matching quotient is formed over the number of uses of a model element and the number of its different mathematical identifiers. This is made up of the ratio of the difference from the total number of nominations and the number of different identifiers to the number of total number of nominations minus 1.

$$\text{Compliance quotient} = \frac{\#\text{nominations}-\#\text{variants}}{\#\text{nominations}-1} \tag{1}$$

This affects a value range from 0 (no matching identifiers) to 1 (all identifiers of the same name). Model elements which have only been used once have not been taken into account (see Table IV).

A standard is not recognizable. The authors of the analyzed papers use their freedom to freely label variables and associated indices (see Table IV). This applies not only to compulsory model elements (e.g. "set of machines" with six variants for a total of 45 uses) but also for special elements, which are only taken up in a few works (e.g. "set of independent machines" with five variants for a total of five uses). This diversity is also preserved when the indices are disregarded. For example, the number of variants for the mathematical identifier for processing time is reduced from 24 to six variants (see Tables V and VI). However, this obscures another aspect, namely that different conventions are used for the representation of indices (up/down, parenthesis, separators), which cannot always be explained by a concerted intention of expression.

TABLE IV
VARIANTS OF MATHEMATICAL IDENTIFIERS FOR MULTIPLE NAMED MODEL ELEMENTS IN SCHEDULING ALGORITHMS

Variable	Nominations	Different identifiers	Compliance quotient
Weight of job	23	3	0,91
Set of machines (> 1)	45	6	0,89
Due date	29	4	0,89
Set of jobs (> 1)	65	10	0,86
Processing time	121	24	0,81
Completion time	30	9	0,72
One or more parallel machines	14	5	0,69
Release date	8	5	0,63
Release time	12	5	0,63
Set of operations (> 1)	22	10	0,57
Parallel batch machine	3	2	0,5
Starting time	7	5	0,33
Number of products	5	4	0,25
Set of independent jobs (> 1)	5	5	0
Set of stages	4	4	0
Ready time	2	2	0
Due time	2	2	0
Processing start time	3	3	0
Deadline	4	4	0
Processing time of each part	2	2	0
Completion time of job	3	3	0

TABLE V
MATHEMATICAL IDENTIFIERS FOR "PROCESSING TIME" PART 1

	Notation												∑
Var.	$d_{i,j,k}$	$P_{\{i,h,k\}}$	$p_{\{i,j\}}$	$p_{\{ij\}}$	$p_{\{ijk\}}$	$P_{\{ik\}}$	$P_{\{j,i\}}$	$p_{\{ji\}}$	$p_{\{js\}}$	p_i	P_i	$p_{i,j}$	12
No.	1	1	1	6	1	1	1	1	1	7	2	5	28

TABLE VI
MATHEMATICAL IDENTIFIERS FOR "PROCESSING TIME" PART 2

	Notation													∑
Var.	$p_{i,j}$	$p_{i,k}$	P_{ik}	p_j	$P(i)$	p_i^A	P_i^I	p_i^u	p_j^X	$t_{\{ik\}}$	$t_{\{kij\}}$	T_r	U_i	12
No.	5	1	1	32	1	1	1	1	1	1	1	1	1	48

The target values are chosen so that 50% of the scientific work optimizes the operating time. In addition to the operating lead time, the remaining target sizes are only optimized in individual cases. In order to minimize the operating cycle time, other target variables can be optimized in the run-up, as these have an effect on the throughput time. For example, if the processes are slimmed down, machine fail times are reduced, or the machine utilization is increased, a reduction in the overall operating cycle time can also be achieved. In most cases, target values are minimized or maximized. For example, on the one hand the production rate, net profit, and late work are maximized. On the other hand, work delays, storage costs, running costs are minimized. A special feature is the minimization according to a special process "minimized the total robot travel distance" [31]. In addition, the "average total processing time" [38] and "average run time" [39] or absolute values like "absolute number of machine failures" [40] are optimized. A conspicuous group is defined as the time target variables, such as "longest processing time" [40], [41], "earliest finish time" [42], "machine breakdown" [43], "total number of times where machines are available" [40] and "delay time" [43]. In addition, there are other target variables which could not be assigned. These target variables are "active set" [43], "job with highest priority" [42], "job-scheduling problem" [44], [45] and "cost-to-go function" [46]. The symbol assignment for variable abbreviations is more extreme than for input variables. The minimization of the production time is abbreviated as "C" in almost all scientific works (see Table VII).

TABLE VII
VARIANTS OF MATHEMATICAL NOTATIONS FOR "MINIMIZES THE MAKESPAN".

	Notation						∑
Var.	*Cmax*	*CM*	*Cmax*^{OPT}	T	*Tmin*	*MCmax*	**6**
No.	46	1	1	1	5	1	**55**

TABLE VIII
VARIANTS OF MATHEMATICAL NOTATIONS FOR "MAXIMUM DURATION OF ALL OPERATIONS"

	Notation				∑
Variants	*Cmax*	*Cmax*	MaxDur	*Pmax*	**4**
No.	1	1	1	1	**4**

TABLE IX
VARIANT MATHEMATICAL IDENTIFIERS FOR MULTIPLE TARGET VALUES IN SCHEDULING ALGORITHMS

Targets	No.	Different identifiers	Compliance quotient
Min. the makespan	55	6	0,91
Max. duration of all operations	4	4	0
Min. weighted mean flowtime of jobs	2	2	0
Earliest start	2	2	0
Min. the total completion time of the jobs	2	2	0

Of the 73 target variables originally mentioned in papers on JSP, only five target variables have been repeatedly included in a mathematical model (see Table IX).

V. DISCUSSION AND CONCLUSION

In principle, terminological freedom and diversity are to be welcomed. However, this must not be in conflict with comprehensibility and comparability. This reinforces the usefulness of a uniform terminology. Other research areas also point to a uniform designation and notation for the central entities of the respective research area. However, the research area of scheduling has a special feature. There are a lot of always recurring models. However, this research area is dependent on a progressive specialization and extension of the application of its algorithms. Thus, there will always be new or refined models. Accordingly, a common terminology base must be extensible on the one hand and, on the other, have rules for deriving names for specialized model elements.

For the concrete implementation of a uniform terminology two approaches are to be discussed: the approach of the documented design knowledge and the approach of classical standardization.

The concept of design knowledge has been presented by Fettke et al. for design science-oriented business informatics [47], [48]. In design science research, a distinction must be made between technology-oriented research and knowledge-oriented research [48]. While technology-oriented research is concerned with the design of technology and its evaluation, knowledge about technology is developed and tested in knowledge-oriented research (within design science research) [48].

Procedures serve the real application of a technique and can be assigned as an inseparably linked component of the technique. A technique can be in the form of methods, conceptual models, software prototypes, conceptual frameworks, models of cross-company value chains, business models, and similar artefacts [48], [49]. Design knowledge about a technique represents the knowledge that is relevant or available to a design subset in system design, thereby influencing system design [48]. The actual relevance cannot always be determined reliably in advance. In the context of design knowledge, knowledge is understood as justified opinion with claim to truth or correctness.

The design knowledge must be distinguished from the technique itself. In particular, if the focal artefact consists of a linguistic description, as described, e.g. in the case of methods, the assignment as method knowledge or as design knowledge is usually not explicitly listed. A clear assignment would, however, always be possible. In order to classify, a content-based division of design knowledge is possible (see Fig. 1 according to [48]): There is therefore knowledge about the application context, the goals, variants (including extensions) and alternatives. The design knowledge itself consists of the central statement with regard to the particular consideration aspect and a demonstration of the evidence of this statement. The evidence can be demonstrated by referencing external documents in which this aspect is addressed. Not every one of these referenced sources will provide an absolute proof of the resilience of the statement. Therefore, the strength of the resilience is explicitly indicated by different degrees of the evidence [48]. The schema for the representation of the design knowledge provides a constant framework for the comparison and the orientation with regard to the use of techniques. The content itself can change over time, so that the empirically determined characteristics can be supplemented or updated by new experiences and insights. The level of evidence is an important key figure which evaluates the justification and the truth claim of an extent according to scientific standards. The preparation and the proof of evidence correspond to the approach of the stylized facts [49]-[53].

The ideal-type reference framework (see Fig. 1) can be applied directly to algorithms for scheduling. However, a reduction to the semantics, denotation and notation for model elements can dispense with the description of most technical characteristics. Only the scope and its evidence are relevant. In addition, the "technical variants" are to be considered as specialized representations, and the "alternative techniques" are to be used as language variants resp. as alternative mathematical representations (for example, used indices and their representation) (see Fig. 2). The documented design knowledge is suitable for dynamic but coordinated care by a scientific or expert community. Additional alternative names, new sources for the evidence and variants of the model elements can be supplemented at any time. A high-frequency update is not possible with a standard. There is a higher degree of commitment to the unified terminology, as the standard is published by an appropriately authorized and recognized organization. In terms of content, the standard will be similar to the approach to documented design knowledge. A specification defines which languages are to be considered for translations.

<table>
<tr><td colspan="4">Design knowledge about a technique</td></tr>
<tr><td colspan="4">Context and short description of the technique</td></tr>
<tr><td colspan="4">Superior design objective</td></tr>
<tr><td rowspan="11">Characteristics of the technique</td><td rowspan="3">Minimum requirements for the technique</td><td>Impact</td><td rowspan="11">Evidence</td></tr>
<tr><td>Repeatability</td></tr>
<tr><td>Impartiality</td></tr>
<tr><td rowspan="8">Comparison figures for the technique</td><td>Relevance</td></tr>
<tr><td>Scope of application</td></tr>
<tr><td>Side effects</td></tr>
<tr><td>Maturity level</td></tr>
<tr><td>Routine</td></tr>
<tr><td>Costs</td></tr>
<tr><td>Efficiency</td></tr>
<tr><td colspan="4">Technique variants</td></tr>
<tr><td colspan="4">Technique alternatives</td></tr>
</table>

Fig. 1 Framework for the Documentation of Design Knowledge [48]

<table>
<tr><td colspan="2">Design Knowledge about a model</td><td>Element</td></tr>
<tr><td>Designation for a model element</td><td colspan="2">Short name
Mathematical symbol
Source code variable name
Short description</td></tr>
<tr><td>Characteristics of the element</td><td>Scope of application</td><td>Evidence</td></tr>
<tr><td colspan="2">Element variations</td><td></td></tr>
<tr><td>Alternative names</td><td colspan="2">Synonyms Translations
Mathematical representation</td></tr>
</table>

Fig. 2 Design Knowledge for the Design of Model Elements

Both approaches are based on the fact that a thesaurus for the terminology for scheduling is developed (DIN 1463-1, ISO 25964-1 and ISO 25964-2) (DIN Deutsches Institut für Normung e.V., 2001 and Information and documentation — Thesauri and interoperability with other vocabularies — Part 1 and 2: Thesauri for information retrieval). A thesaurus can be used here as a scientific vocabulary collection for the specialist language of a research area. Relevant terms are not only mentioned here, but also placed in relation to each other. In this way specializations and refinements of model elements can be created and displayed clearly arranged.

It is critical to note that a medium number (< 240) of scientific papers have been evaluated. As the number of observations increases, the results obtained can change, and further peculiarities could be encountered. Another problem is the choice of sources. The work is primarily focused on four scientific journals, which leaves no room for other sources. Monographs, for example, have more scope to present larger scheduling models in detail, so that much larger symbol directories are used than in specialist articles (e.g. [54]).

Moreover, an exclusive way of looking at the manufacturing sector might be too one-sided, as, for example, the health sector or the development of operating systems and processors are also concerned with optimization procedures.

The use of a unified terminology also reaches certain limits. On the one hand, there is the possibility that the research activities in this area can be expanded more quickly to new model elements than a terminology consolidation can be operated. On the other hand, conflict potential exists when the research area of the scheduling is combined with other research areas so that the mathematical notation can again lead to display variants and double assignments.

For the scientific community, which is concerned with scheduling, however, this article is intended to provide an opportunity to choose a common language and notation for its basic subject matter. This unique but regularly updated task contributes to the fact that the introduction into the subject area, comparability and further use of knowledge as well as the intelligibility leads to a fundamentally better connectivity of scientific work.

APPENDIX

ITEMS USED IN SPECIALIST ARTICLES OF SCHEDULING ALGORITHMS

TABLE X
MODEL ELEMENTS USED IN SPECIALIST ARTICLES OF SCHEDULING ALGORITHMS

Element group	Model elements	Number of entries in scientific papers (n=101)	Element group	Model elements	Number of entries in scientific papers (n=101)
Age	Maximum mould (tool) age	1	Resource	Set of reactors	1
	Maximum machine age	1		Due date	29
	Age of machine	1		Set of resource allocation	1
Agent	Agent	2	Speed	Processing speed	2
Batch	Total number of batches	3	Stage	Set of stages	7
Capacity	Capacity of each machine	2	Time	Processing time	77
	Machine capacity	1		Fixed duration (processing time)	2
Cost	Cost	1		Non-zero release-dates	1
	Changeover cost	1		Prescribed job due-dates	1
Demand	Demand in the planning horizon	1		Completion time job	1
Else	Nonnegative weights)	1		Finish time	2
	Critical type	1	Time	Starting time	9
	Heterogeneous batch processors	2		Completion time	28
	Set of all AGVs	1		Earliest start	1
	Set of due-window sizes	1		Deadline (delivery)	3
	Any subset	1		Ready time	2
Flowshop	Flowshop of flexible machines	1		Due time	2
	Flowshop of dedicated machines	1		Processing start time	3
	Flowshop of flexible parallel machines	1		Release time	12
	Hybrid Flowshop machine	1		Deadline (job)	4
Job	Set of independent jobs (> 1)	5		Processing time of each part	2
	Set of jobs (> 1)	75		Start time of operation	1
	Priorities among jobs	2		Completion time of operation	3
	Identical parts of job	1		Group set-up time	1
	Size of job	1		Set of due-window starting times	1
Machine	Set of identical machines (Machines are non-continuously available (> 1)	29		Set-up time of machine	2
	Set of machines (> 1)	21		Completion time of job	3
	Related machines	1		Completion time of operator	1
	Unrelated machines	2		Start time of machine	2
	One or more parallel machines (> 1)	15		End time of machine	1
	Group of machine	1		Breakdown time machine	1
	Transportation time needed to move job j from machine i to machine	3		Repair time interval	1
	Single machine	1		Setup time of job	3
	Parallel batch machine	3		Release date	8
Manufacture	Number of manufacturers	1		Lower bound of processing time on machine	2
Matrix	Processing operation matrix	1		Upper bound of processing time on machine	2
	Processing time matrix	1		Time required to execute move	2
Operation	Set of operations (> 1)	20		Time required for the robot to execute the void move from machine	2
	Predetermined sequence of operations (> 1)	2		Start time of move	1
	Predecessor operation	1		Time of switching from production of product	2
	Total number of operators	1		Time at which the repair process is finished on machine	2
Parts	Number or parts demanded	1		Unloading time	1
	Number of parts	1	Weight	Weight of job	23
Product	Number of products	7	Server	Identical servers	1
Rate	Production rate	1	Product	Set of product classes	1
Reactor	Set of reactors	1			

TABLE XI
TARGET VALUES USED IN SPECIALIST ARTICLES OF SCHEDULING ALGORITHMS

Element group	Targets	Number of entries in scientific papers (n=49)	Element group	Targets	Number of entries in scientific papers (n=49)
Absolut	Time needed to update the set of available machines	2	Minimization	Minimise total actual flowtime of parts through the shop	2
	Total number of machine breakdowns	1		Total flow time minimisation	1
	Absolute performance guarantee	1		Minimise the total resource consumption cost	2
Average	Average total processing time	3		Minimisation of the steady-state cycle time for identical part production	1
	Average run time	1		Minimise the cycle time	2
Capacity	Remaining machine capacity	1		Minimise the total robot travel distance	2
Else	Active set	1		Minimise tardiness of job	2
	Highest priority	1		Minimise the total changeover cost	2
	Job-shop scheduling problem	2		Minimize the total completion time of the jobs	2
	Cost-to-go function	1		Minimize a regular step total cost function	1
Maximization	Maximum number of machines ever available	2		Minimize electricity cost in time period	2
	Maximum duration of all operations	4		Minimize project duration	1
	Maximum number of stages of any job type	2		Minimize total work-break time	1
	Maximize the net income	1		Minimize Idle time	1
	Maximisation of production rate	1		Minimize the total completion time of the job	1
	Maximum lateness of all jobs	13		Minimize total tardiness of jobs	1
	Maximum earliness of all jobs	4		Minimize total tardiness machine unavailability	1
	Maximise the net profit	1		Minimize the total cost of the assignments	1
	Maximum workload among machines	2	Minimization	Minimize the overall consumed energy during the idle periods of the schedule	1
	Maximise late work	1		Minimize the total integrated cost	1
	Utility maximization	1	Performance	Optimizes the performance of the job-shop scheduling system subject	1
	Total weighted overlap of all jobs is to be maximized	1	Schedule	Schedule	3
Mean value	Mean value of the makespan	1	Task	Set of tasks	4
Minimization	Minimizes the makespan	51	Time	Longest processing time	2
	Minimizes the total weighted tardiness	2		Earliest release-date	1
Minimization	Minimization of the weighted mean flowtime of jobs	4		Lastest release-date	1
	Minimization of the weighted mean tardiness of jobs	3		Earliest finish time	1
	Minimization of the maximum tardiness of jobs	6		Delay time	2
	Minimization of the weighted number of tardy jobs	2		Set of operations being processed at time t	1
	Minimizing the total holding cost	1		Earliest start	1
	Minimize the sum of weighted completion times of all jobs	4		Latest start time	1
	Minimize backtracking stages	1		Machine breakdown	2
	Minimize processing cost	1	Total	Remaining processing time	1
	Minimize cost	1		Total number of intervals where machines are available	1
	Minimising the total integrated cost of the two agents	2		Operations scheduled up	1
	Minimising the objective of one agent	2		Operations precedence feasible	3
	Minimise the negative impact on the performance of the system	2		Total load of machine	1

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