CLASSIFICATION OF THE EXISTING KNOWLEDGE BASE OF OR/MS RESEARCH AND PRACTICE (1990-2019) USING A PROPOSED CLASSIFICATION SCHEME

NAVONIL MUSTAFEE
The Centre for Simulation, Analytics and Modelling (CSAM)
University of Exeter Business School
Exeter EX4 4ST, UK
n.mustafee@exeter.ac.uk
https://orcid.org/0000-0002-2204-8924

KORINA KATSALIAKI
School of Economics, Business Administration & Legal Studies
International Hellenic University
Thessaloniki, 57001, Greece
k.katsaliaki@ihu.edu.gr

ABSTRACT

Operations Research/Management Science (OR/MS) has traditionally been defined as the discipline that applies advanced analytical methods to help make better and more informed decisions. The purpose of this paper is to present an analysis of the existing knowledge base of OR/MS research and practice using a proposed keywords-based approach. A conceptual structure is necessary in order to place in context the findings of our keyword analysis. Towards this we first present a classification scheme that relies on keywords that appeared in articles published in important OR/MS journals from 1990-2019 (over 82,000 articles). Our classification scheme applies a methodological approach towards keyword selection and its systematic classification, wherein approximately 1300 most frequently used keywords (in terms of cumulative percentage, these keywords and their derivations account for more than 45% of the approx. 290,000 keyword occurrences used by the authors to represent the content of their articles) were selected and organised in a classification scheme with seven top-level categories and multiple levels of sub-categories. The scheme identified the most commonly used keywords relating to OR/MS problems, modeling techniques and applications. Next, we use this proposed scheme to present an analysis of the last 30 years, in three distinct time periods, to show the changes in OR/MS literature. The contribution of the paper is thus twofold, (a) the development of a proposed discipline-based classification of keywords (like the ACM Computer Classification System and the AMS Mathematics Subject Classification), and (b) an analysis of OR/MS research and practice using the proposed classification.

Author Keywords: OR/MS Education, OR/MS Knowledge Base, Classification Scheme

Note: *The proposed classification scheme (Appendix 1) has been included in the submission as supplementary material.*

1 INTRODUCTION

Operations Research/Management Science (OR/MS) has traditionally been defined as the discipline that applies advanced analytical methods to help make better and more informed decisions. This definition of OR/MS is used by both INFORMS and the Operational Research Society (ORS) in the UK. OR arrives at optimal or near-optimal solutions to complex decision-making problems by employing techniques from other mathematical sciences and is a term that is closely related to Management Science and, of late, to Analytics. Because of the computational and statistical nature of most of its techniques, OR/MS also has strong ties to computer science and statistics. In terms of context of application, there is considerable overlap with disciplines such as Operations Management and Industrial Engineering. The growth of the OR/MS field has meant greater specialization and division into subfields (Miser, 2000). A topical example here is the emerging research area of Big Data, Business Intelligence and Analytics. They enable introspection of a large corpus of data and provide both data-driven and predictive insights for organizational decision making; this again is a fertile area of enquiry for OR/MS research, as also for computer science (e.g., technologies associated with big data storage and retrieval), information systems (e.g., business intelligence dashboards) and mathematics & statistics (e.g., algorithms for data mining, machine learning, predictive analytics). The multi-faceted nature of the discipline has given rise to debates on emerging knowledge that can be incorporated into the aegis of OR/MS, on existing knowledge that fall within the scope of OR/MS, those on its periphery that may perhaps be considered as inter- and trans- disciplinary research and practice, and finally those that are outside its scope (Libertore and Luo, 2011; Pidd, 2001).

With the purpose of describing the extant knowledge base of OR/MS, we conducted retrospective research which highlights important concepts, problems, methods and applications which have been a part of our discipline. More specifically, for our analysis we selected 26 leading journals in OR/MS and used *author keywords* from approx. 82,000 articles published from 1990 to 2019 (Sep). A conceptual structure was necessary to place 'in context' the findings that emerged from the keyword analysis. We therefore considered the existing discipline-specific classification systems, for example the *2012 ACM Computer Classification System* (ACM, 2020), and developed the OR/MS keyword classification scheme for the following reasons: it would help report the content and give structure to our discipline by providing not only a set of keywords but also a hierarchical approach for greater comprehension of the OR/MS methods and techniques, sector of application and applications context; it would provide a description of the field, prevent the proliferation of synonyms, enable the development of OR/MS research databases with hierarchical indexing, and introduce a common and agreed-upon vocabulary for OR/MS researchers.

The proposed keyword classification scheme could also serve as a training set for machine learning algorithms which classify literature based on a full-text analysis. For example, Gore et al. (2019) used pre-classified documents in scholarly repositories, including the ACM archives which store articles as per the ACM Computing Classification System (ACM, 2020), as a key resource in the training set for machine learning. These models were subsequently used by Diallo et al. (2017) to perform content analysis on three sets of abstracts from projects that were funded by the US-based National Science Foundation (NSF) and the National Institutes of Health (NIH) and used modelling and simulation as one of the methods of investigation.

Why is a keyword classification scheme with controlled indexing useful? In controlled indexing the terms available for content identification are rigidly controlled and it limits the chances for ambiguity and error. It controls spelling and eliminates synonyms by referring to unique accepted terms for each synonym class, and by identifying semantically related terms (Salton and McGill, 1983). A keyword classification scheme is such a controlled indexing language. To be successful, it should be exhaustive, clear, systematic, flexible, expandable, and have a clear terminology (Barki et al., 1993). Other widely accepted and used, domain-specific classification schemes are the *American Institute of Physics' (AIP) Physics and Astronomy Classification Scheme* (AIP, 2020); the *American Mathematical Society's 2000 Mathematics Subject Classification* (AMS, 2020), the most common point of reference in Mathematics (Lange et al., 2012). The Information Systems discipline has also developed one such classification scheme (Barki et al., 1988; Barki et al., 1993) and continues to extend this work further (Bang, 2015). There is also the *Association for Computer Machinery (ACM) Classification System* (ACM, 2020) for the computing field which was initially published in 1964 and has been updated in 1991, 1998 and most recently in 2012. Authors submitting their work to the more than 50 journals and around 170 conference proceedings published by the ACM, are required to include indexing information that conforms to the ACM classification. For example, the indexing notation included in a paper published in the *2015 ACM Conference on Principles of Advanced Distributed Simulation* (Mustafee et al., 2015) has three categories and subject descriptors - 1.6.3 Simulation and Modeling - Applications; 1.6.5 Simulation and Modeling - Model Development (Modeling Methodologies) and 1.6.8 Simulation and Modeling - Types of Simulation (Combined, Discrete event, Distributed).

The existing OR/MS keyword lists and classification schemes (e.g., INFORMS ACI, IAOR – refer to section 2) cannot be compared with the aforementioned schemes as they do not have an underlying methodological basis for keyword selection and, instead, adopt a high level approach. However, the primary means by which a scholarly discipline signals its boundaries and its intellectual core is through the topics that populate discipline-specific research activities (Benbasat and Zmud, 2003). For the purpose of our OR/MS keyword classification we considered authors' keywords that appeared in papers published in OR/MS journals for the past 30 years. The time-frame was essential for an in-depth analysis as the longitudinal approach in analyzing OR/MS issues is more effective than the snapshot approach (Lane et al., 1993). In this regard, an additional contribution of this paper is the presentation of the evolution of the OR/MS discipline over these years through the keywords analysis mechanism. The keywords to be included in the classification scheme were determined by their frequency in the underlying dataset; the selected keywords were then classified based on references to OR/MS theory and research, supplemented by the authors' understanding of the field as well as referring to the existing classification lists**.**

The remainder of the paper is structured as follows. The next section critiques the existing classification schemes. Section three presents the methodology for the selection of keywords. The classification scheme is described next (the full scheme is included as an appendix). Section five lists the most frequently used keywords on OR/MS problems, modeling techniques and the applications of OR/MS and depicts their evolution over-time. Section six is the concluding section of the paper followed by the research limitations and future work on the classification scheme.

2 A CRITIQUE OF THE EXISTING OR/MS KEYWORD SCHEMES

Our review of literature focuses on existing OR/MS keyword lists. The list available through the *INFORMS* website presents keywords from the *American Annual Comprehensive Index (ACI*). The ACI keywords are based on the OR/MS classification system and are accompanied by a three-digit code (INFORMS, 2020) concluding with code 983; yet not all entries are unique, as it incorporates duplications, non-assigned or missing codes. The number of keywords in this list has been on the rise; from 442 in 2009 to 795 in 2013 to 842 in 2016, remaining stable until 2018.

The *International Abstracts in Operational Research* (IAOR) indexes abstracts from OR/MS journals. It is maintained by the *International Federation of Operational Research Societies* (IFORS, 2018a) and consists of 68,000 abstracts from over 145 journal titles (Miser, 2000); the number of journals has now increased to approximately 180. In the IAOR database all entries are classified and indexed by keywords. Presently this consists of 204 words and expressions, each of which is associated with a four-digit code (183 unique codes). It is also accompanied by a list of 1600+ words and phrases not structured in a scheme (IFORS, 2018b). Over the years, the IAOR editors have modified the classification scheme from the original list that was created over 50 years ago (Rand, 2001).

Keyword lists are also available through certain OR/MS journals. Such lists are usually included in the section pertaining to author submission guidelines wherein the authors are advised to select pre-defined keywords. However, it is common practice to leave some flexibility on the selection of keywords, thus allowing for *authors' keywords*. The journal *Management Science* has a keyword list that resembles a classification scheme, and although it does not incorporate any coding, the 417 keywords are organised under 55 categories in three levels. Yet, there are remarkable differences between the ACI, IAOR and Management Science schemes both in terms of the keywords used as well as to the categories adopted for classification. There are several other keyword lists of well-known OR/MS journals with no classification and with limited keywords (usually between 100-350). For example, the journal *Operations Research* has a keyword list comprising of 390 keywords (345 of which are unique). The

European Journal of Operational Research (EJOR) and the *Journal of the Operational Research Society* (JORS) keywords lists are alphabetically presented with 122 and 191 keywords respectively.

Although these schemes are informative, it can be argued that they are not comprehensive, especially when they are considered in relation to literature pertaining to keyword classification schemes (Foskett, 1977; Salton andMcGill, 1983; Wessel, 1974). According to Foskett (Foskett, 1977) four components are required for a keyword classification scheme. These are: schedules, a notation, an index, and an organization for maintaining and revising. The *schedules* are the set of index terms, listed in a systematic manner to show their relationships. The *notations* are symbols, usually numbers or letters, which distinguish the different categories in a classification scheme. Therefore, the notation shows the existing order of the schedules and enables easy and rapid identification and organization of the different categories. An *index* facilitates the identification of the terms employed in the classification scheme and therefore it makes the keyword search comparatively easy. Finally, the fourth component of the scheme is an *organization* employed to maintain and revise the classification scheme to keep it up-to-date. Experience has shown that continuous revision and maintenance are of utmost importance if the scheme is to remain useful and usable (Ralston, 1981). Although the OR/MS keyword schemes conform to some of Foskett's four components, e.g., most lists include *notations*, IAOR has an editor and is maintained by *Palgrave Macmillan* and the *International Federation of Operational Research Societies (IFORS)*, it is also true that these schemes are limited as they do not outline the methodology for the construction of the *schedules*. Supplementary sources like literature reviews and research frameworks can potentially provide a methodological exploration of schedule construction, however they tend to focus on specific research areas such as specific OR/MS problems (e.g., Boysen et al., 2010; Desrochers et al., 1990), specific practice/applications (e.g. Banker and Kauffman, 2004; Chopra et al., 2004,) or profiling a specific OR/MS journal (Mustafee et al., 2012; Katsaliaki et al., 2010) and therefore do not fully explore the OR/MS field.

It is arguable that the systematic selection and listing of keywords requires the greatest effort and time for the development of a classification scheme, and therefore the importance of the methodology cannot be underestimated. With reference to Foskett's four components of keyword classification (Foskett, 1977), in our work the *index terms* are the OR/MS keywords and the *schedule* concerns with the systematic organisation of the keywords. The keywords can be single-term or multiple-term expressions with each regarded as an indivisible whole. According to Wessel (1974), in any given field the number of descriptors should range from 500 to 5,000. Below 500 descriptors, the resulting indexing will probably be too general and lacking in detail for useful retrospective searches. Above 5000, great complications arise within the systematisation often leading to inconsistency of usage and the chaos of free-text indexing. In our study, we have selected approx. 1300 index terms based on a methodological approach that is discussed in the next section.

3 METHODOLOGY

The development of a keyword classification scheme is, in many ways, an introspective look into the field for which it is being built. Our OR/MS keyword classification methodology aims at selecting prominent OR/MS journals, identifying the most frequently used keywords in articles published in these journals, and finally using these keywords to structure a keyword classification scheme. The work is divided into five phases: identification of journals, retrieval of keywords, Porter Stemming Algorithm (PSA), PSA meta-data selection and the construction of the OR/MS classification scheme.

For our initial list of journals, we referred to four different sources for identifying, objectively, the most influential and important OR/MS journals. The first two of these sources are two well-known journal ranking databases: a) the InCites *Journal Citation Reports*® (JCR) which lists the impact-factor journals under different subject categories (Clarivate Analytics, 2019). The *"Operations Research & Management Science"* (OR&MS) category includes a list of over 80 scholarly journals, ranked by their impact factor. b) The SCImago Journal Rank (SJR indicator) which is a measure of scientific influence of journals that is based both on the number of citations received by a journal and the importance or prestige of the journals where such citations come from. We considered the first quartile of its OR/MS category which includes the first 36 most influential journals in the sector. The other two sources come from two papers published in Omega (Merigo & Yang, 2017) and Interfaces (Oslon, 2005) respectively. The most recent one is a ranking study of JCR OR/MS category journals and sorted according to the H-Index, analysing the first 30 journals. The second one is a survey that asked the top-25 business-school professors to rate OR/MS journals and presents the first 39 of them. The criterion for inclusion of an OR/MS journal in our list was to belong to at least 3 out of the 4 sources, as defined above. Finally, 26 journals were incorporated in our dataset, of which 16 were found in all four sources and 10 in three of the sources. Future research may extend the journals' base by considering inclusion of more journals while at the same time ensuring that the sample is unbiased.

Table 1 includes data on the number of papers that were published in each of the journals in three specific time periods: 01/JAN/1990 to 31/DEC/1999; 01/JAN/2000 to 31/DEC/2009; 01/JAN/2010 to 25/SEP/2019 (the date the search was conducted, and records downloaded).

Table 1: List of 26 influential "OR&MS" journals.

Journal Title	Articles in the dataset			
	1990-99	2000-09	2010-19 (Sep'19)	Total
Journal of Operations Management	6	445	388	839
Management Science	1255	1310	1895	4460
Manufacturing and Service Operations Management		144	428	572
Omega	631	597	989	2217
Production and Operations Management	26	408	1096	1530
Transportation Research Part B: Methodological	334	520	1469	2323
Operations Research	964	879	1024	2867
European Journal of Operational Research	3719	5502	6414	15635
International Journal of Production Economics	1240	2108	3132	6480
Computers and Operations Research	885	1749	2404	5038
Journal of Quality Technology	437	383	309	1129
INFORMS Journal on Computing	35	393	506	934
International Journal of Production Research	1888	2783	4390	9061
Journal of Global Optimization	327	945	1346	2618
Mathematics of Operations Research	526	515	527	1568
OR Spektrum	274	312	382	968
Journal of Scheduling		290	474	764
International Transactions in Operational Research		44	633	677
Journal of the Operational Research Society	2051	2017	1749	5817
Naval Research Logistics	615	570	453	1638
Annals of Operations Research	788	1261	2350	4399
Interfaces	1048	879	622	2549
Mathematical Programming	923	828	1094	2845
Transportation Science	344	349	565	1258
IIE Transactions	760	918	563	2241
Networks	504	532	566	1602
Total	**19580**	**26681**	**35768**	**82029**

From the *Web of Science*® database, we downloaded bibliometric information for 82,029 articles. The ISI-format data included the title, authors, volume, issue number, journal, abstract and authors' keywords. We extracted 290,141 authors' keywords, an average of approx. 3.54 keywords per paper, from the data files using a text-parsing program that we developed in Java™. Out of the 290,141 keywords 90,911 were unique/distinct. We then used the Porter Stemming Algorithm (PSA) (Porter, 1980), and specifically the Visual Basic (VB) implementation of PSA (Mustafee, 2003), to group together the similar distinct keywords. PSA is used in information retrieval as a term normalization process in order to remove the commoner morphological and inflexional endings from words in English (Porter, 2006). For example, the keywords “integer programs:7”, “integer program:14”, “integer programming: 1599” are three distinct keywords (frequencies are included after the colon). However, PSA treats the three instances as one unique word with a PSA meta-data. The meta-data or the stemmed word "integ program:1620" (with frequency 1620) is the sum of the individual occurrences. The automated PSA process was supported by manual work in order to integrate, under a PSA meta-data, keyword synonyms in the forms of acronyms, use of dash in between words, numbers instead of numerals, US-UK word spelling, mixed-order of words, etc. For example, the keyword “programming: integer:12” was added in the PSA meta-data “integ program:1632” and other similar cases which increased the specific keyword frequency to 1640. After the completion of this phase the PSA meta-data stood at 82,321, representing 90.6% of the unique keywords (90,911) from the 82,029 papers.

Table 2 presents the cumulative contribution of the first 10 most popular keywords, listing the PSA meta-data values, their corresponding frequencies, their percentage contribution to the total number of keywords and their running/cumulative contribution. Using this analysis, we are able to state that, in terms of cumulative percentage, approx.1160 most frequently used PSA meta-data (with 30 or more occurrences) account for 45% of the 290,141 keyword occurrences. Of the 82,321 PSA meta-data, the vast majority had very low frequencies. This indicated that they are not in popular use. Thus, we selected PSA meta-data having 30 or more occurrences; this resulted in approx. 1,160 stemmed words. As the PSA meta-data comprises incomplete words, our strategy for the classification tree was to replace them with the most representative distinct keywords. For example, the PSA meta-data *“simul”* (which includes “*simulations”* and “*simulation”*) was replaced with the word *“simulation:1654”* in the classification scheme. Every keyword in our classification ends with a colon (:) followed by total number of occurrences.

Table 2: The top ten PSA meta-data together with their individual and cumulative contributions to the total number of keywords in our dataset.

PSA Meta-data	Frequency	% contribution to the total number of keyword instances	% *cumulative* contribution to the total number of keyword instances
schedul	2832	0.98%	0.98%
heurist	2587	0.89%	1.87%
data envelop analysi dea	1799	0.62%	2.49%
suppli chain manag	1762	0.61%	3.10%
optim	1742	0.60%	3.70%
simul	1654	0.57%	4.27%

integ program	1640	0.57%	4.83%
inventori	1543	0.53%	5.36%
dynam program	1290	0.44%	5.81%
genet algorithm	1179	0.41%	6.21%

The next phase of the methodology relied on the authors' domain knowledge, supplemented with OR/MS textbooks, book indexes and literature review papers, and through references to the *Springer Encyclopaedia of Operations Research and Management Science* (Gass andFu, 2013), *Wiley Encyclopaedia of Operations Research and Management Science* (Cochran et al., 2011) and the *Web of Science®* search engine (OR/MS subject category). Further, the INFORMS and the IAOR keyword classification schemes were meticulously studied, as were the keyword lists of the journals *Operations Research*, *Management Science*, the *European Journal of Operational Research (EJOR)* and the *Journal of the Operational Research Society (JORS)*. This helped the authors to further clarify the keywords' placement. In cases where a particular keyword could not be positioned under an existing parent category, the decision whether to include a new category was taken through reference to theory and in consultation with textbooks, dictionaries and articles on various OR/MS topics. As we continued the process of classification it became apparent that certain keywords needed to be treated as nearly synonyms, while for the others it was essential that further meaning had to be attributed to the keywords. We have used ***keyword* nearly *synonyms*** and ***keyword identifiers*** respectively for this purpose. This led to the revised strategy of building the classification scheme consisting of only relevant keywords, irrespective of whether they were included in the original dataset of approx. 1160 keywords. In our classification (Appendix 1),

- Keyword synonyms are separated with a '/'; For example, *Empirical research:173/ Empirical study:86/ Empirical research methods:23/ Empirical analysis:42 /Empirical:37*.
- Keyword identifiers are used to attribute further meaning to the keyword. They appear along-side the keywords and are identified by the term USE. For example, *Replenishment:35* [USE Inventory replenishment]

The inclusion of new keywords was kept to a minimum so as to ensure that the classification scheme predominantly comprised of words that were methodologically selected. There are two categories of these newly included keywords: (a) the keywords with less than 30 instances and (b) new keywords that were introduced by the authors of this paper. The former categories of keywords were usually selected if it was thought to be crucial for the completion of a sub-category itself. For example, *"Strategic Options Development and Analysis (SODA)"* has only 5 instances but it is an important problem structuring method in Soft OR. Thus, this keyword has been included under *"Soft OR → Problem structuring →Problem Structuring Methods"*. The latter categories of author-defined keywords were added primarily because they were good descriptors for keyword categories (e.g.,

"TYPE OF RESEARCH", *"MODELING TECHNIQUE"*). With these additions, the keywords number reached 1300. In the classification scheme, keywords with less than 30 instances are shown in red and new keywords are indicated with a green background.

4. THE OR/MS CLASSIFICATION SCHEME

The classification scheme is a hierarchical grouping and ordering of approx. 1300 keywords into a total of five levels (more specifically, one top-level with a maximum of four sub-levels). In this section we describe the rationale for selecting the top-level keywords and provide further details on the structural aspects of the classification scheme.

We applied a consistent classification approach whereby, for defining keywords at the top-level category (level-1 keyword), we tried to follow the reasoning that authors may use while selecting/providing keywords as descriptors for their papers. Our first category is "*TYPE OF RESEARCH"* and it underlines the importance of defining research presented in a scientific paper, e.g., whether it is a paper on methodology, a review paper, a viewpoint, etc. Indeed, many journals require authors to be specific on the type of research during the paper submission process or during keyword selection. Our first category consists of 14, level-2 keywords (excludes the synonyms).

When the development of a model is involved, which is common in OR papers, some authors like to highlight this, especially if this is crucial to their research. With this in mind, we define the second top-level category *"MODELING TECHNIQUE"*. This category encompasses the quantitative techniques that are most commonly used by the OR/MS researchers as well as overarching theories that may form the basis of such modelling (e.g., game theory and decision theory). Concepts and terms generally associated with specific techniques and theories are included in the more detailed keyword levels. Since the 1970s, soft OR has increasingly been applied in our discipline. As opposed to the traditional quantitative OR/MS methods, our third category *"SOFT OR"* underpins the methodological relevance of qualitative systems' enquiry.

In OR/MS literature we find an obscure boundary between the OR/MS techniques used to solve problems (these are predominantly derived from Mathematics) and certain groups or classes of similar OR/MS problems which have been labeled by researchers and are considered typical of the field, i.e. *bin-packing*, *branch and bound*, *machine scheduling*, *transportation model*, *assignment problem*, etc. Many of the popular OR/MS textbooks include seamless chapters in linear programming, Markov chains but also inventory methods, transportation models, scheduling, etc. (Hillier and Hillier, 2002; Taha, 2007) combining techniques and problems as the real-world demands. In our classification scheme, there is an attempt to separate them, when possible, and thus we have distinct top-level categories for *"MODELING TECHNIQUE"* (described earlier) and *"PROBLEM"*.

The next category is the *"APPLICATIONS OF OR/MS"*. It identifies the broad disciplines (e.g., *accounting, economics, operations management, organizational studies*), sub-disciplines (e.g., *auditing, experimental economics, supply chain management, performance management*) and application context (e.g., *pricing, forecasting, scheduling, efficiency analysis*) that overlap with OR/MS. Several management-related sub-topics are included in this category, such as, *capacity management* and *quality management* and this illustrates the importance of OR/MS tools and techniques in managerial decision-making. Our penultimate category is *"INDUSTRY"*. The keywords that belong to this category are mostly compatible with the industry classification taxonomies of the *North American Industry Classification System (NAICS)* of the U.S. Department of Commerce and the *Industry Classification Benchmark (ICB)* launched by Dow Jones and FTSE. Our last category is *"COUNTRY"* with only two keywords with 30 or more occurrences, namely, *"Developing countries:65"* and *"China:76"*. Every top-level/level-1 keyword category has a level-2 *'GENERAL'* category, the purpose of which is to group keywords which could not be placed under any other level-2 category. As the classification scheme expands, it may be possible to move a keyword from *'GENERAL'* to a new level-2 category with the same name. This makes our classification scheme expandable. For example, under the top-level *"COUNTRY"* we have two level-2 categories – **CO.Gen** ('General') and **CO.Dco** (*Developing countries:65*). The keyword *China:76* is presently grouped under **CO.Gen**. In future, there may be OR/MS studies specific to many other countries, and the editors may then decide to create several country-specific level-2 categories. For example, we have also added the following countries under **CO.Gen**: *India:19; Australia:10, Greece:9, Spain:8, Brazil:8, Sweden:5, Finalnd:5, Germany:5 and UK:4*. We take this rationale further and include *"General"* category for levels 3, 4 and 5. Table 3 lists the top-level keyword categories together with their corresponding level-2 keywords. Apart from the top-level categories, the subsequent keyword levels are listed alphabetically.

Table 3: The seven top-level keyword categories and their corresponding level-2 keywords.

Level-1 classification	Level-2 Classification (please refer to the appendix for levels 3-5)					
TR TYPE OF RESEARCH	**Gen**	General	**Int**	Interdisciplinary	**Sur**	Survey
	Cst	Case study	**Met**	Methodology	**Tax**	Taxonomy
	Emp	Empirical research	**Por**	Philosophy of OR	**Thr**	Theory
	Exp	Experiment	**Rev**	Review	**Vwp**	Viewpoint
	Hor	History of OR	**Met**	Meta-analysis		
ME MODELING TECHNIQUE	**Gen**	General	**For**	Forecasting	**Pth**	Possibility theory
	Alg	Algorithms	**Flo**	Fuzzy logic	**Prb**	Probability
	Afi	Artificial intelligence	**Gth**	Game theory	**Prg**	Computer programming
	Chm	Choice models	**Grt**	Graph theory	**Qth**	Queuing theory
	Cma	Combinatorial analysis	**Ift**	Information theory	**Sth**	Set theory
	Cxt	Complexity analysis	**Ith**	Inventory models	**Sim**	Simulation
	Coa	Computational analysis	**Mod**	Modeling	**Sta**	Statistics
	Cth	Control theory	**Mdm**	Multicriteria decision making		

	Dea	Data envelopment analysis	**Opt**	Optimization		
	Dmi	Data mining	**Oth**	Organization theory		
SO SOFT OR	**Gen**	General	**Prs**	Problem structuring	**Syt**	Systems thinking
PB PROBLEM	**Gen**	General	**Jrp**	Joint replacement problem	**Spp**	Set partitioning problem
	Asp	Assignment problem	**Ksp**	Knapsack problem	**Shp**	Shortest path problem
	Cmp	Complementarity problem	**Flp**	Location problem	**Scp**	Scheduling problem
	Cvp	Covering problem	**Nwp**	Network problems	**Spp**	Set partitioning
	Csp	Cutting stock problem	**Nvp**	Newsvendor problem	**Shp**	Shortest path
	Cpp	Cutting and packing problem	**Orie**	Orienteering problem	**Ssp**	Stable set problem
	Fpp	First passage problem	**Pkp**	Packing problem	**Tsp**	Traveling salesman problem
	Ivp	Inverse problem	**Rop**	Routing	**Vip**	Variational inequality problem
PR OR/MS APPLICATIONS	**Gen**	General	**Mgt**	Management	**Prm**	Project management
	Cta	Cost analysis	**Mnt**	Maintenance	**Qum**	Quality management
	Dmk	Decision making	**Mkg**	Marketing	**Rel**	Reliability
	Eco	Economics	**Mkt**	Markets	**Rep**	Repair
	Emr	Emergency response	**Ned**	Network design	**Rde**	Research and Development
	Ent	Entrepreneurship	**Opm**	Operations management	**Rsa**	Robustness and sensitivity analysis
	Enm	Environmental management	**Ors**	Organizational studies	**Sch**	Scheduling
	Fpd	Facility planning and design	**Pem**	Performance measurement	**Str**	Strategy
	Fim	Financial management	**Poa**	Policy analysis	**Scm**	Supply chain management
	Fos	Forecasting	**Pri**	Price/pricing	**Sde**	Sustainable development
	Hcm	Healthcare management	**Prd**	Product development	**Sym**	Systems modelling
	Inm	Inventory management	**Prp**	Product policy	**Tem**	Technology management
	Knm	Knowledge management	**Pro**	Production		
IN INDUSTRIES	**Gen**	General	**Edu**	Education	**Pse**	Public service
	Acc	Accounting	**Ecm**	E-commerce	**Res**	Recreation and sports
	Agi	Agriculture	**Eng**	Engineering	**Ret**	Retailing
	Aud	Audit	**Fin**	Finance	**Rdv**	Research and development
	Aui	Automotive industry	**Fst**	Forestry	**Ser**	Service/services
	Cmm	Communications	**Hse**	Health services	**Tra**	Transport/ tranportation

	Inf	Information technology	**Mnf**	Manufacturing	**Uti**	Utilities
	Def	Defense	**Poi**	Process industry		
CO COUNTRY	**Gen**	General	**Dco**	Developing countries		

Our *notation* assigns a two-letter acronym to the top-level category (level-1 keyword) and a three-letter acronym to the level-2 keyword. For example, we use the acronym **PR** for the level-1 keyword *"OR/MS APPLICATIONS"* (please note that when synonyms are present we specify a *keyword identifier*) and **Gen and Fim** for level-2 keywords *"General"* and "*Financial management"* (Table 4). The **Gen** category is used in every level. The level-3 notation comprises the parent level-2 acronym followed by a numbering scheme that starts with 00. Thus we have index values **PR.Fim00**, **PR.Fim01** and **PR.Fim02** for *"Financial audit"*, *"Budget/budgeting"* and *"Investment analysis"* respectively (Table 5). The level-4 notation is made up of the parent level-3 acronym followed by a character suffix beginning with 'a', e.g. *"Asset pricing"* which is assigned the index **PR.Fim02.a**. The notation for level-5 is again made up of level-4 together with a number suffix (e.g.**PR.Fim02.g.00** for *"Options"*).

Table 4: An excerpt from the OR/MS classification scheme showing the six-level hierarchy for the top-level keyword 'OR/MS APPLICATIONS'.

PR	PRACTICE OF OR:172/ PROCESS OF OR:27 **[USE OR/MS APPLICATION]**				<- Level-1 Keyword **(PR)**
	Gen	GENERAL			<- Level-2 **(PR.Gen)**
	Fim	*Finance:418* **[USE Financial management]**			<- Level-2 **(PR.Fim)**
		Gen	General		<- Level-3 **(PR.Fim.Gen)**
		Fim00	*Auditing:34* **[USE Financial audit]**		<- Level-3 **(PR.Fim00)**
		Fim01	Budget/budgeting:25 e.g., Capital budgeting:55; Net present value:83;		<- Level-3 **(PR.Fim01)**
		Fim02	Investment analysis:116/ Investment:127 **[USE Investment analysis]**		<- Level-3 **(PR.Fim02)**
			Gen	General	<- Level-4 **(PR.Fim02.Gen)**
			Fim02.a	*Asset Pricing:43* e.g., *Arbitrage:23;* Asset allocation:40;	<- Level-4 **(PR.Fim02.a)**
			Fim02.g	Portfolio:23	<- Level-4 **(PR.Fim02.g)**
				Gen General	<- Level-5 **(PR.Fim02.g.Gen)**

	Fim02.g.00	Portfolio analysis:18	<- Level-5 **(PR.Fim02.g.00)**
	Fim02.g.01	Portfolio choice:32	<- Level-5 **(PR.Fim02.g.00)**

Although our classification scheme has been developed by referencing OR/MS encyclopedias, books, journal papers and existing classifications, we recognise that there is an element of subjectivity in our assignment of keywords to specific levels and sub-levels, in the grouping of keywords as synonyms, and in suggesting alternate keywords using the *"[**USE** ..]"* identifier. We recognise that there exists further opportunities for refinement of the scheme, and it is with this purpose that we endeavor to maintain and update the OR/MS classification scheme (included as Appendix 1) and ensure its wide dissemination through the development of a website.

5 MOST FREQUENTLY USED KEYWORDS

In this section, we present the most frequently used keywords, initially for all keywords regardless of their classification, and then from the following four top-level keyword categories: **ME** Modelling Technique (section 5.1), **PB** Problem (5.2), **PR** OR/MS Applications (5.3), and **IN** Industries (5.4). Additionally, the changes in the frequency of popular keywords in each top-category is shown over three distinct time periods of 10 years each, namely, 1990-1999, 2000-2009, 2010-2019 (more accurately 2019 Sep). The keywords are listed in descending order based on frequency of occurrence in the dataset (we refer to this as count).

The 10 most popular PSA meta-data for the whole time-frame is presented in Table 2 (in Section 3). *"Scheduling:2832"* is first, followed by *"Heuristic:2587"and "Data envelopment analysis:1799"* respectively; the two top keywords each have over 2000 instances, from the 13th keyword fall below 1000 instances and from the 295th under 100. Taking a closer look into the evolution of these popular keywords, we see in Figure 1 the ten most popular keywords per identified time-period. Altogether 11 keywords are presented because the top-10 list varies to some extent per period, with new keywords taking the place of others. The numbers presented in the middle of the columns indicate the keywords frequency per time-period. The number on the top of the column shows the position/ranking of the particular keyword in the top-down popularity list of keywords for that time-period. From Figure 1 we notice that there is an increasing trend in the number of popular keyword occurrences over-time, amongst the three time-periods. This is not surprising as the number of all keyword occurrences per time-period in our dataset increases due to the progressively increase of the number of papers published in the journals over-time (see Table 1). It might also be that more keywords are assigned to each article in the most recent years. However, this observation is not true for specific keywords, such as *"Inventory"*, *"Genetic algorithm"* and *"Linear programming"*, where fluctuations are present amongst the time-periods. It may be that these keywords lost some of their glow as time passed, no matter the general trend of increased keyword occurrences. The changes in the popularity of some keywords over-time is dramatic. Looking at the rankings of the keywords between the time-periods it is hard to miss the stunning upward trend of *"Supply chain management",* which held the 252nd position in the keywords list of the period 1990-1999 but in the next time-period of 2000-2009 goes up in popularity and hits the 3rd position and continues to climb up reaching the 2nd position in the most recent period of 2010-2019. A more modest upward route follows the *"Genetic algorithm"* keyword from the 48th position in the first period to the 8th in the second, then goes down again to the 15th position for the last decade. The 10th most frequent keyword of the period 1990-199 is *"Product"*. The specific keyword, however, only appears in the 20th position in the period 2000-2009 and the 27th position in the last period. Overall, it holds the 20th position in the total keywords count of the 30 years and therefore does not appear in our graph.

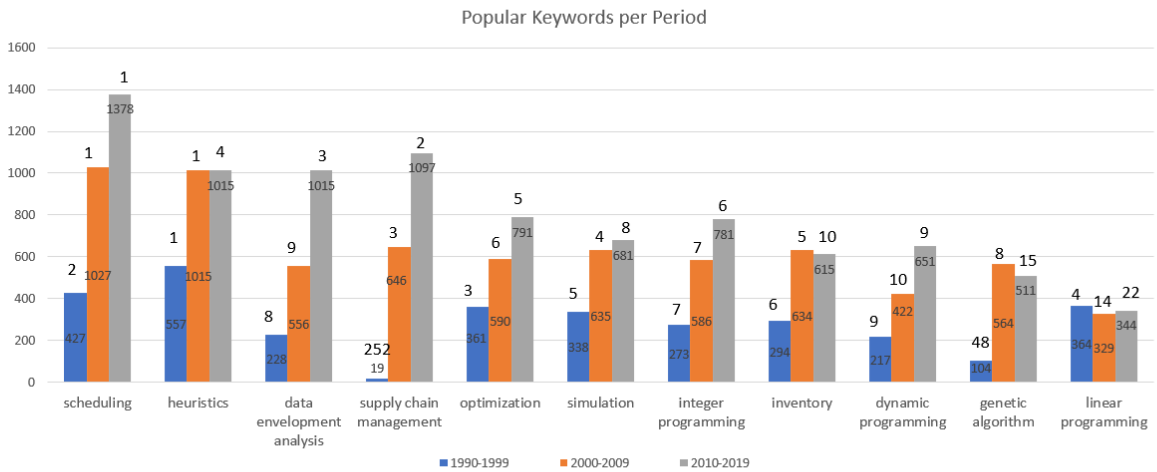

Figure 1: Changes over-time of the top 10 keywords.

5.1 Keywords related to Modeling Techniques

Table 5 presents the top-25 modelling techniques. The keywords in the second column are listed in descending order based on count and in some cases keywords are grouped together as they have similar meaning. This is on top of the automatic and manual aggregation of PSA meta-data. The individual instances are also shown below the representative keyword, in parenthesis, e.g. *(Heuristics:2587/ Heuristic methods:30)*. These words appear individually in the classification tree but are usually followed from the term *"[**USE** ..]"* to denote interchangeability. The middle columns of the table show the total count, and the break down into the three sub-periods. The last column shows the keyword's level-2 categorization in the classification scheme. In order to ascertain the relative position of the keywords in the overall classification tree we have further included the indexing notations. For example, Table 5 lists the level-4 keyword *"Heuristics"* (index: **Alg08.e**; "*MODELING TECHNIQUE/Algorithms/Heuristic algorithms/Heuristics"*) as the most frequently used technique for modeling. Following this is *"Data envelopment analysis"* (index: **Dea**; "*MODELING TECHNIQUE/Data envelopment analysis"*). Whereas the former keyword is classified under Level-2

"Algorithms" (see column 3), the latter is itself a level-2 keyword and indicated accordingly. The same approach is followed in the analysis of Problems **PB**, Applications **PR** and Industries **IN**.

"Heuristics" is identified as the most frequently used technique with 2617 occurrences, this is closely followed by "*Data Envelopment Analysis"* which accounts for 1799 occurrences. Next we have *"Optimization"* (1742), followed by *"Simulation"* (1654) and *"Integer Programming"* (1654). It is perhaps not surprising that 13 out of the 25 keywords are related to optimization. *"Heuristics"* is a technique of problem solving and therefore it has been classed under Level-2 "Algorithms"; however, it is arguable that numerous papers which included this keyword would have used heuristic optimization. "Metaheuristics" is also identified in the 13th position with 852 occurrences.

Table 5: Top-25 keywords under Modelling Technique.

	Modeling Technique	1990-1999	2000-2009	2010-2019	Total	Level-2 classification
1	Heuristics - **Alg08.e** *(Heuristics:2587/ Heuristic methods:30)*	562	1027	1028	2617	Algorithms **(Alg)**
2	Data envelopment analysis (DEA) -**Dea**	228	556	1015	1799	Data Envelopment Analysis **(Dea)**
3	Optimization - **Opt**	361	590	791	1742	Optimization **(Opt)**
4	Simulation - **Sim**	338	635	681	1654	Simulation **(Sim)**
5	Integer programming -**Opt05.b** *(Integer programming:1640/ Integer optimization:14)*	273	588	793	1654	Optimization **(Opt)**
6	Dynamic programming – **Opt06** *(Dynamic programming:1290/ Dynamic optimization:36)*	221	438	667	1326	Optimization **(Opt)**
7	Genetic algorithms **- Opt11.b**	104	564	511	1179	Algorithms **(Alg)**
8	Linear programming **– Opt10** *(Linear programming:1037/ Linear optimization:21)*	367	339	352	1058	Optimization **(Opt)**
9	Game theory – **Gth**	70	245	710	1025	Game Theory **(Gth)**
10	Multicriteria analysis - **Mdm02** *(Multicriteria analysis:425/ Multicriteria decision analysis (MCDA):123/ Multicriteria decision making:356/ Multicriteria decision aid (MCDA):52)*	148	394	414	956	Multicriteria Decision Making **(Mdm)**
11	Branch and bound algorithm - **Opt05.a**	212	362	381	955	Optimization **(Opt)**

	(Branch and bound:776/ Branch and bound algorithm:136/ Branch and bound method:43)					
12	Combinatorial optimization -**Cma00**	66	340	510	916	Combinatorial Analysis **(Cma)**
13	Metaheuristics – **Opt11**	11	308	533	852	Optimization **(Opt)**
14	Global optimization – **Opt07**	178	299	341	818	Optimization **(Opt)**
15	Multiobjective optimization – **Opt12** *(Multiobjective optimization:481/ Multiobjective programming:333)*	45	232	537	814	Optimization **(Opt)**
16	Tabu search - **Opt11.k**	135	342	299	776	Optimization **(Opt)**
17	Mixed integer programming - **Opt05.c** *(Mixed integer programming:720/ Mixed integer optimization:19)*	59	188	492	739	Optimization **(Opt)**
18	Stochastic programming – **Opt19**	77	196	452	725	Optimization **(Opt)**
19	Queueing – **Qth01 and Qth00** *(Queing:450/Queues/Queues:165)*	*156*	228	231	615	Queuing Theory **(Qth)**
20	Column generation – **Alg16**	25	180	362	567	Algorithms **(Alg)**
21	Nonlinear programming - **Opt14** *(Nonlinear optimization:427/ Nonlinear programming:102)*	127	201	201	529	Optimization **(Opt)**
22	Forecasting – **For**	91	196	233	520	Forecasting **(For)**
23	Simulated annealing - **Opt12.j**	98	215	182	495	Optimization **(Opt)**
24	Lagrangian relaxation – **Alg10**	82	182	216	480	Algorithms **(Alg)**
25	Approximation algorithms – **Alg02**	40	169	268	477	Algorithms **(Alg)**

Figure 2 analyses changes in the use of modelling techniques in order to reveal gains or losses in influence over the length of the study period and thus obtain a dynamic picture of the transformations that have taken place within the OR/MS discipline. Figure 2 records changes in the occurrences' percentages for the different sub-periods considered. The grey bar shows the percentage gain or loss of influence, from the first sub-period (1990–1999) to the second (2000–2009), and the black bar the percentage difference from the second sub-period (1999–2009) to the third (2010–2019). We have identified four patterns of Modelling Techniques impact amongst the 25 most popular ones presented here. One common pattern is Modelling Techniques to increase their occurrences from the first to the second sub-period and to repeat the process from the second to the third, meaning that in Fig.2 both grey and black bars are on the right hand-side with positive percentages (gain-gain pattern). This pattern has two possible ways of happening: A) The increase of influence of the Modelling Technique to have an upward trend over-time (the increase from the second to the third period to be higher than the increase from the first to the second period - the black bar is longer than the grey). There are no examples of Modelling Techniques exhibiting this up-up pattern (but it is seen in OR/MS Problems category) and almost all of the results belong to the next pattern. B) The increase of influence of the Modelling Techniques to have a downward trend over-time (the increase from the second to the third period to be lower than the increase from the first to the second period - the grey bar is longer than the black bar). Such examples, from smaller to larger differences in the percentages between the compared periods (smaller to larger loss of momentum of influence) are: *"Stochastic Programming", "Optimization", "Queueing", "Dynamic Programming", "Global Optimization", "Mixed Integer Programming", "Nonlinear Programming", "Game Theory", "Data Envelopment Analysis", "Branch and Bound Algorithms", "Simulation", "Heuristics"*, *"Forecasting", "Integer Programming", "Langrangian Relaxation", "Multicriteria Analysis", "Approximation Algorithm","Multiobjective Programming", "Combinatorial Optimization", "Column Generation" and "Metaheuristics. Overall,* the techniques that feature in the up-up trend of occurrences is proof of their extraordinary contribution to the continuous development of the discipline.

Another discernible pattern is the one exhibited by techniques with a rising profile between the first and second sub-period (in Fig.2 the grey bar is displayed on the right hand-side-positive changes) but a declining towards the second and third (negative percentage, the black bar is on the left hand-side). This may indicate that the technique in question reached and passed its maximum weight of influence during the period in question, and appears to suggest that those with the up–up pattern, mentioned earlier, have not yet reached such a point. Techniques displaying this gain-loss pattern (from the smallest to the largest difference) are: *"Simulated annealing"* (119%,-15%)*, "Tabu Search"* (153%,-13%) *and "Genetic Algorithms"*(442%,-9%). Another pattern is to begin by losing influence only to gain it later. There is only one such loss-gain (-8%,+4%) Modelling Techniques in the list of the 25 most popular techniques and this is *"Linear Programming"*. There is lastly the loss–loss pattern followed by techniques whose influence declines in both comparison sub-periods of the 30-year study. Theoretically we could also divide it in 2 sub-categories according to the dynamic of loss from the second to the third period. However, none of the top-25 Modeling Techniques exhibits such behavior. Hard to miss in Figure 2 is *"Metaheuristics"*, a modelling technique which displays a tremendous increase of occurrences in research between the 1990-1999 and the 2000-2009 periods at around 2,700%. Such a trend is not apparent in other presented techniques here which means that researchers embraced the use of metaheuristics once its mechanics became known and used it to solve cumbersome problems. An increasing trend is recorded in the next period too, but at a much smaller level (73%).

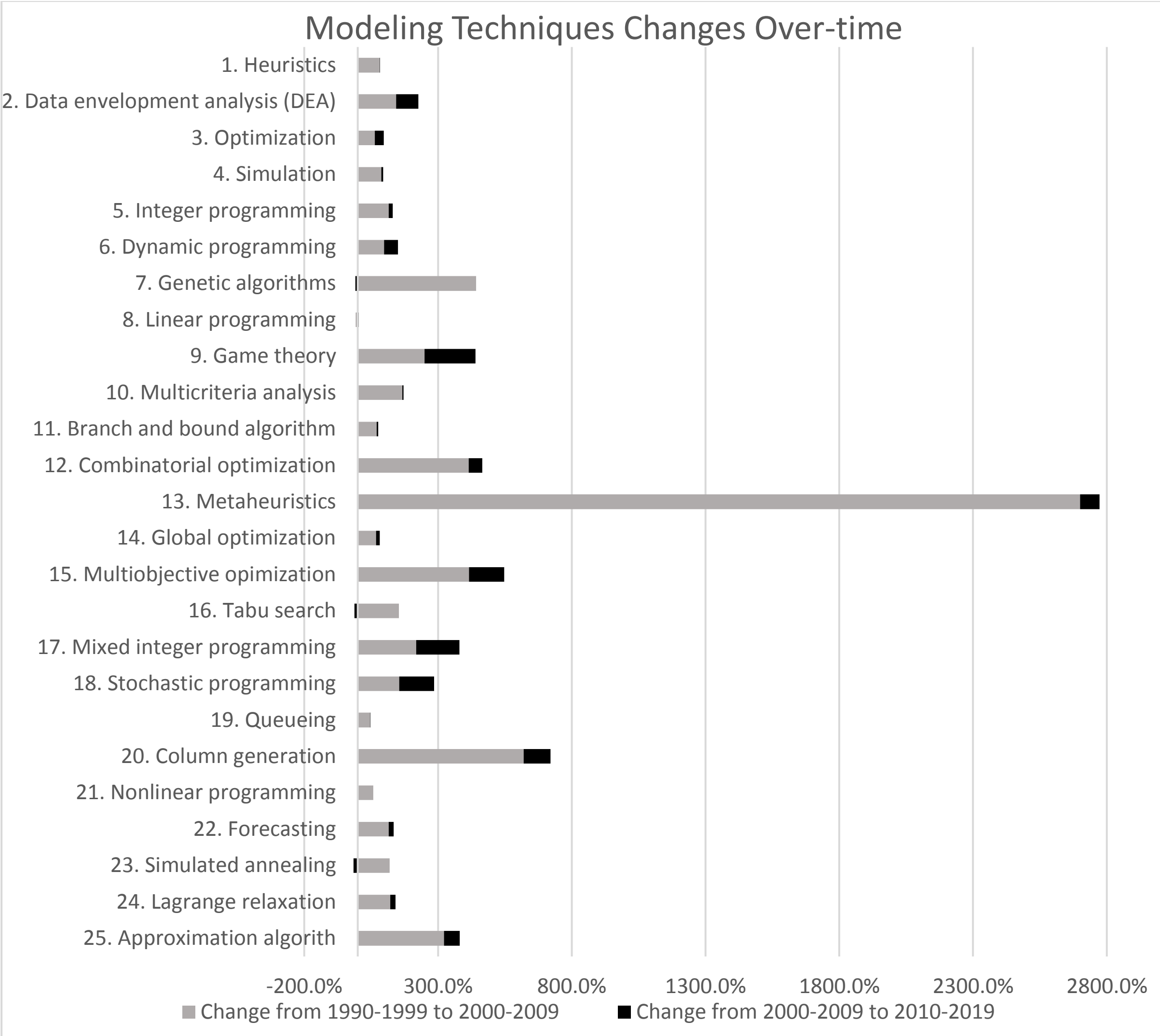

Figure 2: Changes over time of the top-25 keywords in *Modelling Technique (ME)*.

Table 6 presents the top-7 Soft OR techniques. This category presents overall low frequencies and therefore we have incorporated it into the analysis of the Modelling techniques as a sub-section. *"System Dynamics"* comes first as the most used author keyword in the selected journals. The *"Strategic choice"* (11) and the *"SODA- Strategic Options Development and Analysis"* (5) problem structuring methods have very low frequencies and therefore are not presented in the table.

Table 6: Top-25 keywords under Soft OR.

	Soft OR	1990-1999	2000-2009	2010-2019	Total	Level-2 classification

1	System Dynamics -**Prs03**	56	91	131	278	Problem Structuring **(Prs)**
2	Problem Structuring -**Prs** *(Problem structuting:70/ Problem structuring method:59)*	5	50	74	129	Problem Structuring **(Prs)**
3	Theory of constraints – **Syt01** *(Theory of constraints:55/ TOC:13)*	3	40	25	68	Systems Thinking **(Syt)**
4	Soft OR - **SO** *(Soft OR:55/ Soft Operations Research:5)*	6	30	24	60	Soft OR - **SO**
5	Cognitive mapping -**Prs01**	11	24	12	47	Problem Structuring **(Prs)**
6	Soft Systems Methodology -**Prs04** *(Soft Systems Methodoloy:55/ SSM:5)*	7	16	22	45	Problem Structuring **(Prs)**
7	Systems Thinking -**Syt** *(Systems Thinking:31/ Critical Systems Thinking:13)*	6	12	26	44	Systems Thinking **(Syt)**

Figure 3 shows the change of the use of keywords between the two sets of decades. Three patterns are apparent. The up-up pattern is depicted in *"Systems Thinking"* with a constant increasing trend of use. There are 3 keywords which fall under the gain-gain pattern with a downward trend: *"System Dynamics"*, *"SSM"* and *"Problem structuring"*. And finally, there are three keywords that present the gain-loss pattern, and these are: *"Soft OR"*, *"Theory of constraints"* and *"SSM" "Cognitive mapping"*.

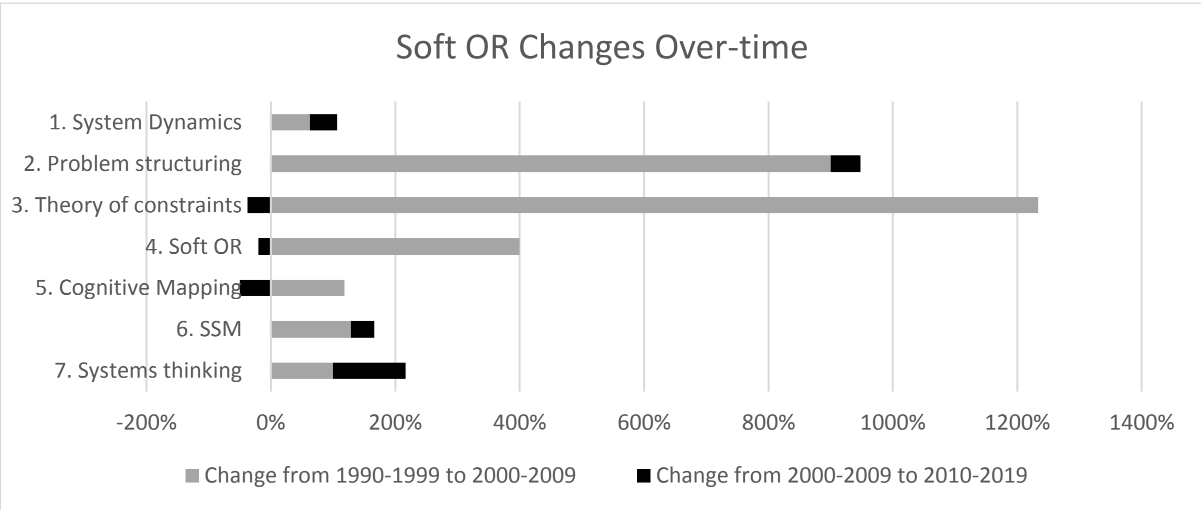

Figure 3: Changes over time of the top-7 keywords in *Soft OR.*

5.2 Keywords related to OR/MS Problems

The keywords under our Level-1 category ***"PB** PROBLEM"* are organised into maximum four sub-levels. The maximum number of sub-levels is reached for the related keywords under the Level -2 **PB**

"Scheduling Problems. In the context of OR/MS problems (Table 7) *"Vehicle Routing Problem"* has been the most frequently used keyword with 795 occurrences and scores higher than the general term "Routing" (444), which comes 3rd and together belong to the level-2 **PB** classification *"Routing Problems"*. The second most frequent keyword is *"Lot Sizing"* (551) which belongs to the level-2 **PB** classification *"Scheduling Problems"* and it is by far the largest category, as 8 of the top-25 OR/MS problems belong here [*"Single Machine Scheduling"* (355), *"Parallel Machine Scheduling"* (318), *"Project Scheduling"* (252), *"Production Scheduling"* (195), *"Flowshop Scheduling"* (152), *"Jobshop Scheduling"* (142) and *"Vehicle Scheduling"* (87)] . The most frequently used packing problem, after the general term *"Packing"* (229), is *"Bin Packing"* (116). The *"Knapsack Problem"* is related to the bin packing problem and also features in the list with 194 occurrences. *"Newsvendor/Newsboy Problem"* and *"Newsvendor/Newsboy Model"* have been identified as two separate keywords and are placed in the 9th and the 19th positions respectively. However, if they were to be considered together then the combined total of 408 would make the newsvendor problem the 5th most commonly used keyword in OR/MS problem type.

Table 7: Top-25 keywords under OR/MS Problems.

	OR/MS Problem	1990-1999	2000-2009	2010-2019	Total	Level-2 classification
1	Vehicle routing problem - **Rop2** *(Vehicle routing:592/ Vehicle routing problem:208)*	69	225	501	795	Routing Problem **(Rop)**
2	Lot sizing scheduling - **Ith00.Gen** *(Lotsizing:514/ Lotsizing scheduling:27/ Lotsizing problem:15)*	98	175	278	551	Scheduling Problems **(Scp)**
3	Routing - **Rop**	51	140	253	444	Routing Problem **(Rop)**
4	Networks - **Nwp**	100	123	197	420	Network Problem **(Nwp)**
5	Traveling salesman problem - **Tsp** *(Traveling salesman:127/ Traveling salesman problem:258/ Traveling salesperson problem:10)*	101	101	193	395	Traveling Salesman Problem **(Tsp)**
6	Single machine scheduling - **Scp04.b** *(Single machine scheduling:178/ Single machine:177)*	67	83	205	355	Scheduling Problems **(Scp)**
7	Parallel machine scheduling - **Scp06.a** *(Parallel machine scheduling:101/ Parallel machines: 217)*	25	133	160	318	Scheduling Problems **(Scp)**

8	Cutting Stock Problem - **Csp** *(Cutting:126/ Cutting stock problem:85/ Cutting stock:80)*	64	121	106	291	Cutting Stock Problem **(Csp)**
9	Newsvendor/Newsboy problem - **Nvp** *(Newsvendor problem:95/ Newsvendor:119/ Newsboy problem:58/ Newsboy:14)*	19	83	184	286	Newsvendor Problem **(Nvp)**
10	Project scheduling - **Scp11**	44	70	138	252	Scheduling Problems **(Scp)**
11	Variational inequality - **Vip**	52	100	90	242	Variational Inequality Problem **(Vip)**
12	Packing – **Pkp** *(Packing:199/ Packing problem:30)*	41	84	104	229	Packing Problem **(Pkp)**
13	Assignment - **Asp** (Assignment problem:96/ Assignment:109)	55	69	81	205	Assignment Problem **(Asp)**
14	Production scheduling – **Scp07**	66	65	64	195	Scheduling Problems **(Scp)**
15	Knapsack problem - **Ksp** *(Knapsack problem:156/ Knapsack:38)*	43	63	88	194	Knapsack Problem **(Ksp)**
16	Shortest path - **Shp** *(Shortest path:140/ Shortest path problem:51)*	36	75	80	191	Shortest Path Problem **(Shp)**
17	Flowshop scheduling - **Scp02** *(Flowshop scheduling:144/ Flowshop scheduling problem:8)*	23	66	63	152	Scheduling Problems **(Scp)**
18	Jobshop scheduling - **Scp02** *(Jobshop scheduling:134/ Jobshop scheduling problem:8)*	30	50	62	142	Scheduling Problems **(Scp)**
19	Newsvendor/Newsboy model - **Nvp** *(Newsvendor model:116/ Newsboy model:6)*	2	31	89	122	Newsvendor Problem **(Nvp)**
20	Set partitioning problem - **Spp** *(Set partitioning problem:14/ Set partitioning:73/ Partitioning:35)*	22	48	47	117	Set Partitioning Problem **(Spp)**
21	Bin packing - **Pkp00** *(Bin packing:106/ Bin packing problem:10)*	16	36	64	116	Packing Problem **(Pkp)**

22	Location/Allocation Problem – **Lfp** *(Location problem:48/ Location allocation problem:14/ Location allocation: 39/ Allocation problem: 5)*	7	49	50	106	Location Problems (**Lfp)**
23	Set covering problem - **Cvp00** *(Set covering problem:24/ Set covering:64)*	19	37	32	88	Covering Problem **(Cvp)**
24	Vehicle scheduling – **Scp10** *(Vehicle scheduling:83/ Vehicle scheduling problem:4)*	15	29	43	87	Scheduling Problems **(Scp)**
25	Transportation problem – **Nwp02**	25	25	26	76	Network Problem **(Nwp)**

Figure 4 illustrates changes in research volume pertaining to OR/MS problems. The upward trend of the OR/MS problems over-time (the increase from the second to the third period to be higher than the increase from the first to the second period) is exhibited in the following OR/MS problems: *"Single machine scheduling", "Traveling salesman", "Project scheduling", "Networks" and "Transportation problem"*. Notably, these OR/MS problems have a progressive dynamic in research. The gain-gain pattern (i.e., +'ve change from 1990-1999 to 2000-2009 and also +'ve change from 2000-2009 to 2010-2019) but with a downward trend of increase over-time is exhibited in *"Knapsack problem", "Assignment problem", "Lot sizing", "Vehicle scheduling", "Jobshop scheduling", "Bin packing", "Packing", "Routing", "Shortest path", "Vehicle routing", "Newsvendor/Newsboy problem", "Parallel machine scheduling"* and *"Newsvendor/Newsboy model"* from smaller to larger changes in the percentages. All these problems with the gain-gain pattern are still under investigation from OR researchers for a better, more customised solution, and practitioners still face challenges which fall under these problems categories to be addressed. On the contrary, Problems displaying a gain-loss pattern (from the smallest to the largest difference) are: *"Cutting Stock Problem", "Variational inequality", "Set Covering Problem", "Set Partitioning Problem"* and *"Flowshop scheduling"*. The loss-gain pattern is not present in the top-25 OR/MS Problems. However, the loss–loss pattern is exhibited in *"Production scheduling"*, with a very small decrease in all periods (-2%,-2%). Its presence in the literature has been slightly diminished, either because it has been well investigated in the past or because new Problems have come to take their place, or simply because the authors related to production scheduling research choose different keywords to describe the content of their papers. We shall not forget that the specific keyword is still in the list of the most popular techniques. From Figure 3 we notice that the *"Newsvendor model"* presents a very large increase from the first to the second period.

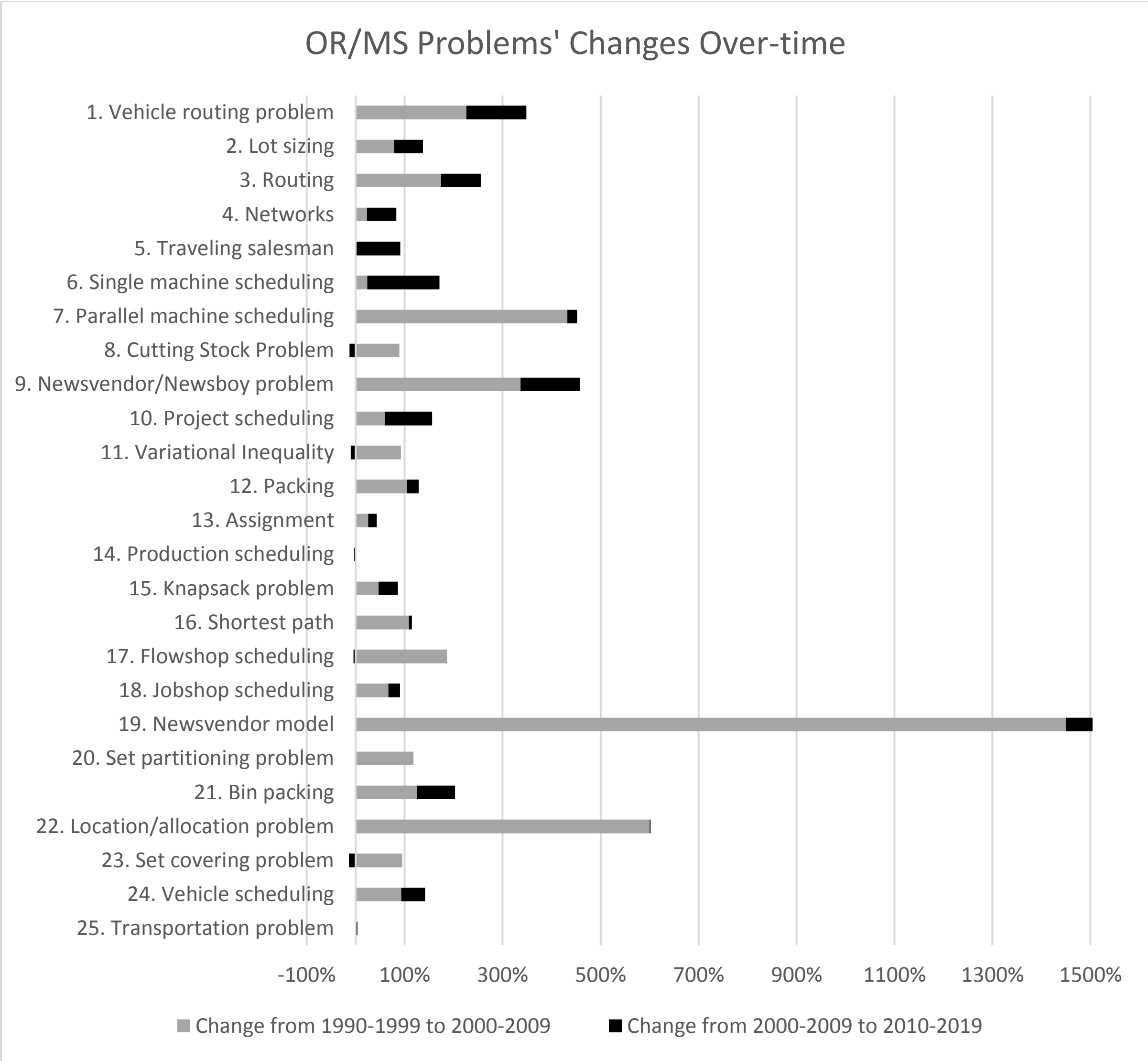

Figure 4: Changes over time of the top-25 keywords in *OR/MS Problems.*

5.3 Keywords related to OR/MS Applications

Our next analysis is on OR/MS Applications (indexing notation: **PR**) with five level-2 **PR** categories. Table 8 lists the 25 most frequently used keywords that are related to OR/MS Applications. *"Scheduling"*, *"Supply Chain Management"* and *"Inventory"* occupy the first three places with 2832, 1762 and 1543 occurrences respectively. In the 5th position the keyword "Supply Chains" (885) is listed which could be combined with *"Supply Chain Management"*. Both together still occupy the second position in the list with 2647 occurrences. Another keyword which falls under the Supply Chain Management area (Level-2 classification) is *"Logistics"* with a count of 559. A primary objective of OR/MS is to support decision making and this is evident with *"Decision Support Systems"* (651) and *"Decision analysis"* (577) occupying the 7th and 8th positions respectively. Combining these two keywords would bring them to the 4th position with 1208 occurrences. OR/MS techniques have been widely used for facility and location analysis and therefore it comes as no surprise that *"Location"*

(520) features among the top ten keywords. *"Production"* has always been a main application of OR/MS implementation and is placed prominently with 745 occurrences, which together with *"Production planning"* (452) would climb up to the 4th position with a total of 1197 occurrences. On the contrary, *"Marketing"* was the last of the major management areas in which OR/MS was applied (Meidan, 1981) and therefore it is notable that *"Marketing"* is placed 19th with 369 occurrences.

Table 8: Top-25 keywords under OR/MS Applications.

	OR/MS Applications	1990-1999	2000-2009	2010-2019	Total	Level-2 classification
1	Scheduling - **Sch**	427	1027	1378	2832	Scheduling **(Sch)**
2	Supply chain management - **Scm**	19	646	1097	1762	Supply Chain Management **(Scm)**
3	Inventory - **Inm00**	294	634	615	1543	Inventory Management **(Inm)**
4	Price/pricing - **Pri**	66	270	583	919	Price/pricing **(Pri)**
5	Supply chains - **Scm**	20	346	519	885	Supply Chain Management **(Scm)**
6	Production - **Pro**	197	248	300	745	Production **(Pro)**
7	Decision support systems - **Dmk04**	171	267	213	651	Decision Making **(Dmk)**
8	Decision analysis - **Dmk01**	113	216	248	577	Decision Making **(Dmk)**
9	Logistics - **Scm05**	38	203	318	559	Supply Chain Management **(Scm)**
10	Location - **Fpd05.a**	119	210	191	520	Facility Planning and Design **(Fpd)**
11	Inventory control - **Inm01**	55	175	249	479	Inventory Management **(Inm)**
12	Efficiency - **Pem03**	90	173	207	470	Performance Measurement **(Pem)**
13	Production planning – **Pro04**	96	149	207	452	Production **(Pro)**
14	Reliability - **Rel**	70	153	209	432	Reliability **(Rel)**
15	Inventory Management - **Inm**	26	136	264	426	Inventory Management **(Inm)**
16	Finance - **Fim**	71	118	229	418	Financial Management **(Fim)**
17	Uncertainty – **Fim.02.Gen**	33	107	272	412	Financial Management **(Fim)**

18	Flowshop - **Pro02.a.00**	57	162	171	390	Production **(Pro)**
19	Marketing - **Mkg**	89	130	150	369	Marketing **(Mkg)**
20	Maintenance - **Mnt**	74	127	165	366	Maintenance **(Mnt)**
21	Revenue management – **Pri12**	0	98	263	361	Price/pricing **(Pri)**
22	Makespan – **Sch02.c**	26	125	204	355	Scheduling **(Sch)**
23	Project management - **Prm**	86	120	130	336	Project Management **(Prm)**
24	Facility location - **Fpd04**	34	101	200	335	Facility Planning and Design **(Fpd)**
25	Risk Management - **Fim06**	6	82	242	330	Financial Management **(Fim)**

Figure 5 illustrates changes in research pertaining to OR/MS Applications. The up-up increase pattern is exhibited only in *"Finance"* and *"Revenue Management"*. The downward increasing trend over-time forms the largest category with 21 keywords. Applications displaying a gain-loss pattern are: *"Decision support systems", "Location"* and *"Inventory"*. The loss-gain and loss–loss patterns are not present in the Applications classification of the top-25 keywords too. The *"Supply Chain Management"* (together with *"Supply Chains"*) is the Application which display a tremendous increase of occurrences in related research between the 1990-1999 and the 2000-2009 periods at the level of around 3,300% and more. This is the period that SCM became a very hot topic in OR/MS with a real need to improve the flow of goods and the relationships between collaborating companies and revenue management together with smart pricing started being used at a greater scale as a business tool for market segmentation and increased revenues/profits (Simchi-Levi, 2004). The application keeps the increasing pattern the next period too but at a small proportion. *"Risk Management"* is a another notable application that shows a similar but less spectacular pattern.

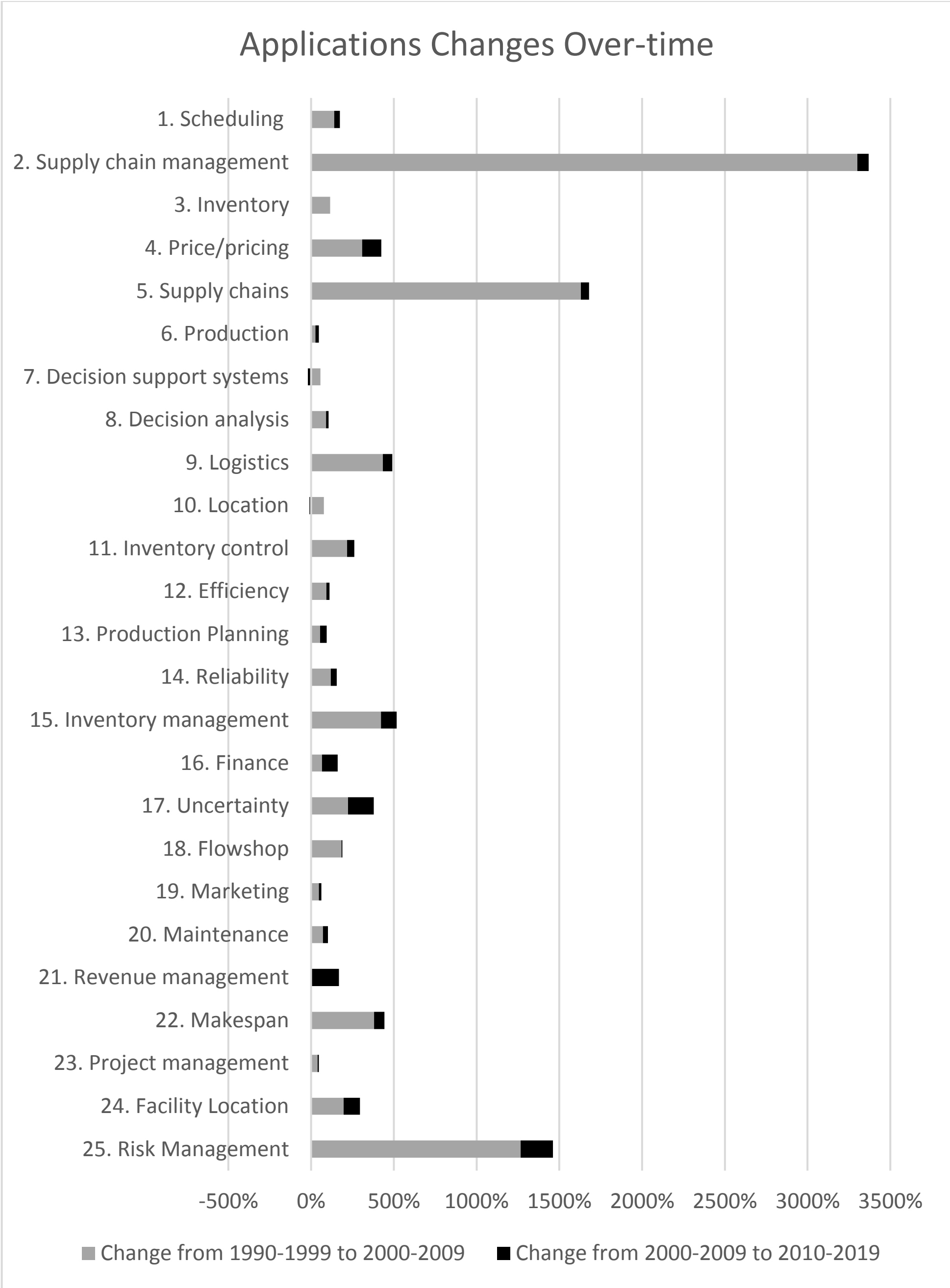

Figure 5: Changes over time of the top-25 keywords in *Applications.*

5.4 Keywords specific to Industry

The final analysis is for the *"Industry"* (**IN**) category (Table 9). The number of keywords in the classification scheme under this top-level category are relatively small compared to the earlier sections. Table 8 shows the popularity of the keywords *"Transport/transportation"* (1001), *"Health Services"* (737) and *"Finance & Banking"* (642) together with their many derivatives. When the results are seen in respect of the primary, secondary and the tertiary sectors of the economy, the primary sector is represented by *"Agriculture"* (112) and *"Forestry"* (34); *"Manufacturing"* (577), *"Utilities"* (396), *"Automobile Industry"* (116) and *"Process Industry"* (45) mainly represent the secondary sector.

However, it is the tertiary sector that supports the production and distribution function in an economy which is most represented in OR/MS studies with, among others, *"Transport/transportation"*, *"Finance and Banking"*, *"Health Services"*, *"Education"* (218), *"Communications"* (248), *"E-Commerce"* (193), *"Auditing"* (31), *"Accounting"* (50), *"Retailing"* (257) and *"Service/services"/"Call centres"* (192). The analysis shows that *"Recreation and Sports"* (216), when considered together with related keywords like *"Tournaments"* and specific sports types like *"Cricket"* and *"Football"*, is placed higher than *"Military and Defence"* (191).

Table 9: The top-24 keywords in top-level category *Industries (IN).*

	Industries	1990-1999	2000-2009	2010-2019	Count
1	Transport/tranportation - **Tra** *(Transport/tranportation:662/ Freight transportation:47/ Road transport: 26/ Sea transport:19/ Maritime transport:59/ Rail transport:37 or Railways:38 / Air transport:63/ Airlines:50)*	139	364	498	1001
2	Health services - **Hse** *(Health services:164/ Healthcare:264/ Health:36/ OR in health services:138/ Hospitals:105/ emergency medical services:30)*	102	194	441	737
3	Finance and Banking - **Fin** (Finance:418/ Financial institutions:30/ Bank/banking:160/ OR in banking:34)	99	184	359	642
4	Manufacturing - **Mnf** *(Manufacturing:409/ Manufacturing industry:47/ Semiconductor manufacturing:106/ Semiconductor industry:15)*	120	208	249	577
5	Utilities - **Uti** *(Utilities:48/ Energy:102/ Renewable energy:37/ OR in energy:130/ Electricity:49/ Power:30)*	68	82	246	396
6	Information technology - **Com** *(Information technology:131/ Computers:79/ Software:49/ Internet:75)*	92	166	76	334
7	Retailing – **Ret** *(Retailing:202/ Retail operations:55)*	20	66	171	257
8	Communications - **Cmm** *(Communications:86/ Telecommunications:129/ OR in telecommunications:33)*	50	127	71	248
9	Education - **Edu** *(Education:125/ Higher education:29/ OR education:49/ Education system:15)*	63	75	80	218

10	Recreation and sports - **Res** (Recreation and sports:16/ Recreation:16/ Sports:82/ Tournaments:37/ OR in sposrts:30/ Cricket:19/ Football:16)	31	70	115	216
11	E-commerce - **Ecm** *(E-commerce: 128/Electronic commerce:65)*	2	88	103	193
12	Service/services – **Ser** *(Services:107/ Call centers:85)*	19	85	88	192
13	Military and Defense - **Def** and **Edu00** *(Military:114/ OR in military:16/ Defense:19/ Defense studies:31/OR in defense:11)*	52	73	66	191
14	Public service - **Pse** *(Public service:20 /Public sector:31/ Homeland security:22/ Government:83/ OR in government:27)*	33	66	84	183
15	Automotive industry - **Aui**	4	31	81	116
16	Agriculture - **Agi** (Agriculture:80/ OR in agriculture:32)	17	49	46	112
17	Research and development (R&D) – **Rdv** *(Research and development:65/ OR in R&D:19)*	21	23	40	84
18	Technology - **Gen**	15	25	27	67
19	Accounting - **Acc**	12	9	29	50
20	Process industry - **Poi**	5	22	18	45
21	Insurance - **Fin02**	8	14	12	34
22	Forestry - **Fst**	6	13	15	34
23	Auditing - **Aud**	9	5	17	31
24	Engineering - **Eng**	10	4	11	25

Figure 6 records changes in the research about OR/MS Industries. The up-up increase pattern is exhibited by the *"Utilities"*, *"Health services"*, and *"Finance and "Banking"*. The downward increasing trend over-time forms the largest category with the Industries of *"R&D"*, *"Technology"*, *"Recreation and Sports"*, *"Retailing"*, *"Public Service"*, *"Forestry"*, *"Transport/transportation"*, *"Service/services"*, *"Automobile industry"* and *"E-commerce"*. Applications displaying a gain-loss pattern are: *"Military" and Defense"*, *"Insurance"*, *"Information technology"*, *"Agriculture"* and *"Communications"*. The loss-gain pattern is exhibited by the Applications: *"Engineering"*, *"Accounting" and "Auditing"*. The loss–loss pattern is again not present in the list. The *"E-commerce"* Industry displays a tremendous increase of occurrences in related research between the 1990-1999 and the 2000-2009 periods at the level of around 4,300%. This is a period that electronic commerce flourished and therefore OR/MS researchers had to solve problems related to the industry. An increasing trend remains the next period too but at a much lower level.

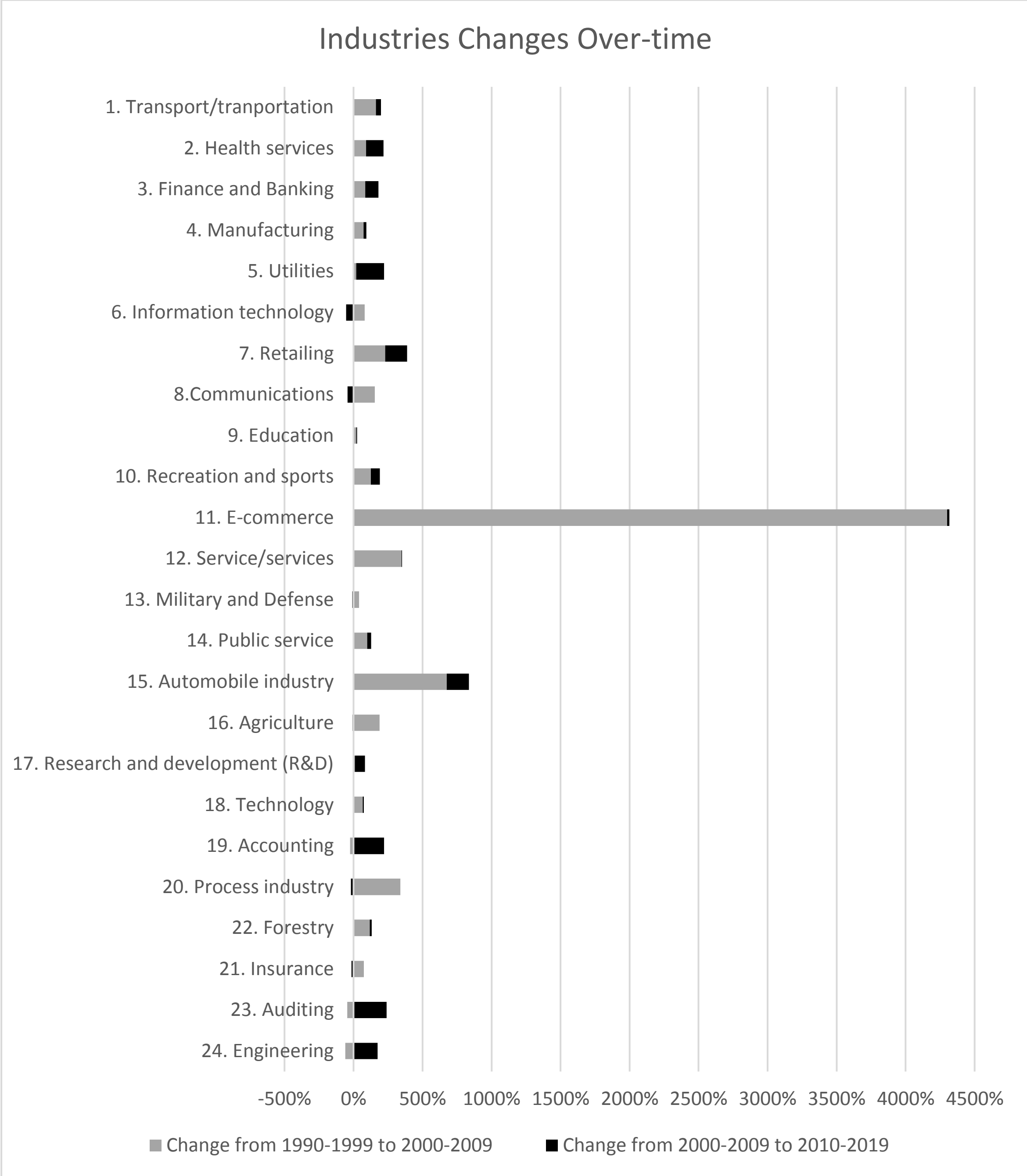

Figure 6: Changes over time of the top-24 keywords in *Industries.*

6 CONCLUSION

There is an ongoing debate among both academics and practitioners as to what constitutes the definition of OR/MS and how its evolving nature affects its practice (Fildes andRanyard, 1997; Liberatore et al., 2010). The fuzzy boundaries of the discipline are also evident by the fact that the terms *Operational Research* and *Management Science* have not been absorbed into one overarching term but both exist jointly and make the OR/MS discipline. Increasingly, the term *Analytics* and *Data Science* is being used to include OR/MS and related activities. The lack of boundaries reflects the philosophy, established by the pioneers of OR/MS, that the subject is interdisciplinary. Most of the models used by analysts during

World War II, and subsequently, were developed ad-hoc for problems of the time from techniques borrowed from the classical sciences. Since 1943, Blackett advised the OR/MS professionals that "these techniques must not remain rigid, but must change with the nature of the problems" (Blackett, 1962). Kendall (1960) realised that the width of the domain covered by OR/MS suggested the extent of the scatter of literature and this would not diminish. Although a decline in OR/MS groups and OR/MS professionals was observed in the 1970s (Ackoff, 1979) and there was debate on the future of OR/MS (Ackoff, 1979, 1987; Condor, 1988; Lilien, 1987), considerable developments have occurred in the OR/MS field over the last three decades. Moreover, OR/MS acquired increasing academic status as the body of theory behind the field expanded rapidly and these trends still continue (Corbett and van Wassenhove, 1993; Rand, 2001). If we use the *IAOR* as an indicator of the growth of OR/MS then we can report that in 1961 the first issue of IAOR listed work on models of common processes in 35 categories, on problems in 11 areas of application, and on 31 types of related theory development. By 1975, the numbers in these categories had reached 47, 34, and 53, respectively, and by 1998 they were 66, 43, and 77. These figures show that the growth of the variety of phenomena of concern was large, with equally numerous theoretical developments to understand and explain them (Miser, 2000). The growth of the OR/MS discipline has meant greater specialization as well as its division into subfields. Thus, the necessity for this research emerged from the fact that OR/MS is an interdisciplinary and ever-changing field with symbiotic relationships with computer science, information systems, mathematics and statistics (Gass andFu, 2013); consequently, it is difficult to conceive its richness and to draw the lines between OR/MS and other disciplines. A discipline-specific keyword classification scheme could help as it serves as a reference set and highlights important OR/MS techniques, methods and contributions which have been referred to by authors over the past decades. The goal of this research was to methodologically develop such a classification scheme for adoption by the OR/MS community. For example, classification schemes, such as the *ACM classification scheme*, have been widely adopted and embraced by their communities and the use of its indexing was made compulsory to the authors who wish to submit their papers to the ACM journals and conferences. They claim that this practice benefits the paper because "accurate categorization provides the reader with quick content reference, facilitating the search for related literature, as well as searches for the work in digital libraries and on other online resources" (cm.org/publications/class-2012).

The practical contributions of the classification scheme are as follows, (a) it provides a quick overview of the OR/MS discipline to academics, practitioners and managers not presently engaged in OR/MS research and practice but who are exploring the use of analytical techniques for problem solving; (b) it provides OR/MS specialists with a snapshot of the width and breadth of the field; (c) it provides OR/MS journals with a standardised keyword list for authors to use as descriptors for their papers; (d) it provides funding agencies with a reference set through which they are able to determine OR/MS research schemes in areas formed by combining the top-level categories of OR/MS techniques, problems, application and industries, (e) it acts as a source of information for academic societies and publishers who wish to constitute editorial boards/technical program committees for OR/MS journals/conference (f) it can potentially serve as a common language in the field, and finally (g) it strengthens the identity of the discipline which, in turn, enhances all the above. Yet another contribution is the identification of the most frequently used keywords relating to OR/MS problems, modeling techniques, applications of OR/MS and industries.

7 LIMITATIONS AND FURTHER RESEARCH

The proposed scheme is only one way of looking at the discipline and it is by no means final; it will probably contain errors, missing keywords and misclassifications. However, in an evolving application, this is inevitable and, to some extent, natural. Further enhancements of the scheme can be made only through feedback from the OR/MS community. A panel of experts with contributions to different OR/MS categories would greatly help in the preparation of an updated and better positioned version of this initial classification scheme. Other discipline-specific schemes (e.g. ACM and AMS) maintain their classification schemes through the volunteer work of researchers. We consider a classification scheme as a living scheme which by nature continually changes, grows by adding new branches and shrinks in certain parts by losing a few, and most notably its branches crossover one another and create interconnections. This is a healthy way a discipline must grow. Similarly, the OR/MS classification scheme will not remain static but will change according to the evolution of this discipline and further through the input of the researchers in the field.

Further research on the OR/MS classification scheme can look towards a poly-hierarchical ontology that can be utilised in semantic web applications. This advanced classification system could play a significant role in the construction of a user search interface in OR/MS digital libraries to supplement the traditional bibliographic search. Moreover, given the availability of big data and text analytics approaches, classification of literature through full text analysis with the use of machine learning would be both contemporary and instructive. However, for this to work, a machine learning classification model is first required to be developed. For example, in the work by Gore, Diallo and Padilla (2019), pre-classified documents in scholarly repositories were used as a key resource in the training set for machine learning. A similar approach has been used in a subsequent publication where machine learning classification model has been used to classify funding awards specific to M&S (Diallo et al., 2017). Our keyword classification scheme can serve as the training set for future work on using machine learning to classify an even larger corpus of OR/MS literature.

Appendix 1: OR/MS Classification Scheme

Please note that this is included as supplemantary material.

REFERENCES

Ackoff R L (1979). The future of operational research is past. *Journal of the Operational Research Society* **30** 93-104.

Ackoff R L (1987). Presidents' symposium: OR, a post mortem. *Operations Research* **35** 471-474.

ACM (2020). The 2012 Association for Computer Machinery (ACM) computing classification system. https://www.acm.org/publications/class-2012 (last accessed February 2020).

AIP (2020). American Institute of Physics' (AIP) Physics and Astronomy Classification *Scheme*® (PACS). *https://journals.aps.org/PACS* (last accessed February 2020).

AMS (2020). American Mathematical Society (AMS) 2000 Mathematics Subject Classification. http://www.ams.org/msc/msc2010.html (last accessed February 2020).

Bang C C (2015). Information systems frontiers: Keyword analysis and classification. *Information Systems Frontiers* **17** 217-237.

Banker R D and Kauffman R J (2004). 50th Anniversary Article: The Evolution of Research on Information Systems: A Fiftieth-Year Survey of the Literature in Management Science. *Management Science* **50** 281-298.

Barki H, Rivard S and Talbot J (1988). An Information Systems Keyword Classification Scheme. *MIS Quarterly* **12** 299-322.

Barki H, Rivard S and Talbot J (1993). A keyword classification scheme for IS research literature: An update. *MIS Quarterly* **17** 209-226.

Benbasat I and Zmud, R W (2003). The identity crisis within the IS discipline: Defining and communicating the discipline's core properties. *MIS Quarterly* **27** 183-194.

Boysen N and Fliedner M (2010). Cross dock scheduling: Classification, literature review and research agenda. *Omega* **38** 413-422.

Chopra, S., W. Lovejoy, C. Yano. 2004. Five Decades of Operations Management and the Prospects Ahead. *Management Science* **50** 8-14.

Clarivate Analytics (2019). InCites journal citation reports. http://jcr.incites.thomsonreuters.com/ (last access February 2020).

Cochran J J, Cox L A (Jr.), Keskinocak P, Kharoufeh J P and Smith J C (2011). *Wiley Encyclopedia of Operations Research and Management Science*. John Wiley, New York.

Corbett C and Van Wassenhove L (1993). Trade-offs? What trade-offs? Competence and competitiveness in manufacturing strategy. *California management review, 35*(4), 107.

Condor (1988). Operations Research: The Next Decade. *Operations Research* **36** 619-637.

Desrochers M, Lenstra J K and Savelsbergh M W (1990). A classification scheme for vehicle routing and scheduling problems. *European Journal of Operational Research* ***46*** 322-332.

Diallo S, Lynch C J and Mustafee N (2017). Funding an Academic Simulation Project: The Economics of M&S. In The Profession of Modeling and Simulation: Discipline, Ethics, Education, Vocation, Societies, and Economics, Tolk A and Oren T (eds). pp. 267-286. John Wiley & Sons.

Fildes R. and Ranyard J (1997). Success and survival of operational research groups-a review. *Journal of the Operational Research Society* **48** 336-360.

Foskett A C (1977). *Subject approach to information* (3rd ed.). Clive Bingley, London.

Gass S and Fu M (2013). *Encyclopedia of Operations Research and Management Science* (3rd ed.). Springer, New York.

Hillier F and Hillier, M (2002). *Introduction to Management Science.* McGraw-Hill, New York.

IAOR (2018). International Abstracts in Operations Research (homepage). http://www.palgrave-journals.com/iaor/ (last accessed June 2018).

IFORS (2018a). IAOR - International Federation of operational research societies. http://ifors.org/web/iaor/ (last accessed February 2010).

IFORS (2018b). International Abstracts in Operations Research (IAOR) database. The International Federation of Operational Research Societies (IFORS). https://iaorifors.com/ (last accessed February 2020).

INFORMS (2020). List of keywords used - American Annual Comprehensive Index (ACI). https://www.informs.org/Find-Research-Publications/Searchable-Databases/ACI-Bibliographic-Database/List-of-Keywords-Used (last accessed February 2020)..

Katsaliaki K, Mustafee N, Dwivedi Y K, Williams T and Wilson J M (2010). A profile of OR Research and Practice published in the Journal of the Operational Research Society. *Journal of the Operational Research Society* **61** 82-94.

Lane M S, Mansour A H and Harpell J L (1993). Operations research techniques: A longitudinal update 1973–1988. *Interfaces* **23** 63-68.

Lange C, Ion P, Dimou A, Bratsas C, Sperber W, Kohlhase M and Antoniou I (2012). *Bringing mathematics to the web of data: the case of the mathematics subject classification*. In: Extended Semantic Web Conference: Springer 63-777.Lilien, G.L. 1987. MS/OR: A mid-life crisis. *Interfaces* **17** 35-38.

Liberatore M J and Luo W (2010). The analytics movement: Implications for operations research. *Interfaces* 2010 **40** 313-324.

Liberatore M J and Luo W (2011). INFORMS and the analytics movement: The view of the membership. *Interfaces* 2011 **41** 578-589.

Meidan A (1981). Marketing Applications of Operational Research Techniques. *Management Decision*, **19** 3 – 86.

Merigó, J. M., & Yang, J. B. (2017). A bibliometric analysis of operations research and management science. *Omega*, 73, 37-48.

Mustafee N (2003). Visual Basic Implementation of Martin Porter's Stemming Algorithm. In the official homepage for the distribution of the Porter Stemming Algorithm. *http://tartarus.org/martin/PorterStemmer/vb.txt* (last accessed Februray 2020).

Mustafee N, Katsaliaki K, Fishwick P and Williams M D (2012). SCS – 60 years and counting! A time to reflect on the Society's scholarly contribution to M&S from the turn of the Millennium. *Simulation: Transactions of the Society for Modeling and Simulation International* **88** 1047-1071.

Mustafee, N., Sahnoun, M., Smart, A., and Godsiff, P. (2015). "An Application of Distributed Simulation for Hybrid Modeling of Offshore Wind Farms." In *Proceedings of the 2015 ACM SIGSIM/PADS Conference on Principles of Advanced Discrete Simulation*, June 10 - 12, 2015, London, UK. pp.171-172. ACM, New York, NY, USA.

Olson, J E. (2005). Top-25-business-school professors rate journals in operations management and related fields. *Interfaces* **35**, 4, 323-338.

Pidd M (2001). The futures of OR. *Journal of the Operational Research Society* **52** 1181-1190.

Porter M F (1980). An algorithm for suffix stripping. *Program: electronic library and information systems* **14** 130-137.

Porter M F (2006). The Porter Stemming Algorithm - Official homepage. *http://tartarus.org/~martin/PorterStemmer/* (last accessed August 2018).

Ralston A (1981). The proposed new Computing Reviews classification scheme. *Communications of the ACM* **24** 419-433.

Rand G K (2001). Forty years of IFORS. *International Transactions in Operational Research* **8** 611-633.

Salton G, McGill M J (1983). *Introduction to modern information retrieval.* McGraw-Hill, New York.

Simchi-Levi D, Wu, S D and Shen Z J M (Eds.). (2004). *Handbook of quantitative supply chain analysis: modeling in the e-business era* (Vol. 74). Springer Science & Business Media.

Taha H A (2007). *Operations research: an introduction*. Pearson/Prentice Hall, Boston.

Wessel A E (1974). *Computer-aided information retrieval*. Melville House Publishing, Los Angeles.

Appendix 1: OR/MS Classification Scheme

Please note that this is included as supplemantary material.

APPENDIX 1: OR/MS Classification Scheme

Legend - *Refer to Section 3.5 for further information*	
Keyword:XX	Every keyword in our classification ends with a colon (:) followed by total number of occurrences (XX). For example, *Empirical research:**173***
Keyword Aggregation	Synonyms and abbreviations have been incorporated into one representative keyword/phrase. For example, *"Data envelopment analysis" and "DEA" are incorporated under "Data envelopment analysis (DEA):1799"; "Defence" and "Defense" are represented by "Defense:30"*
Keyword Nearly Synonyms	Similar words are separated with a '/'. For example, Empirical research:173/ Empirical study:86/ Empirical research methods:19/ Empirical analysis:42 /Empirical:37
Keyword Identifies	Keyword identifiers are used to attribute further meaning to the keyword. They appear alongside the keywords and are identified by the term **USE**. For example, EOQ model:15 **[USE Economic Order Quantity model]**
Keywords appearing on a green background	New entry in keyword list made by the authors For example, Type of Research, Viewpoint
Keyword shown in green	The keywords appear more than once in the classification scheme (Section 4.3). This is because our classification scheme is poly-hierarchical since it makes logical sense for some keywords to belong to several keyword categories.
Keywords shown in red	Less than 15 occurrences in the underlying dataset
Gen	Every overarching keyword category has a sub-category called *'GENERAL'*, the purpose of which is to group keywords which could not be placed under any other sub-category. Applicable to levels 1-5.
e.g.,	The keywords, keyword synonyms and keyword identifiers that are grouped under **e.g.,** are to be classified using the indexing notation of the overarching keyword category For example, the keywords *Management science:23* and *Operational research:126* are to be classified under **TR.Gen (TYPE OF RESEARCH.GENERAL)**

TR TYPE OF RESEARCH (1 sub-level)

Gen	GENERAL e.g., *Application:224* Implementation:82/ OR/MS implementation:33 **[USE Implementation];** Operational research:126; Management science:23; Problem solving:28; Research:33 Framework:45 Ontology:38 Hypothesis testing:35
Cst	Case study:305/ Case study research:22 **[USE Case study]**
Emp	Empirical research:173/ Empirical study:86/ Empirical research methods:23/ Empirical analysis:42 /Empirical:37 **[USE Empirical research]**
Exp	Field experiment:43 Laboratory experiment:32 **[USE Experiment]**
Hor	History of OR:44
Int	Interdisciplinary:19 **[USE Interdisciplinary research]**
Met	Methodology:122; Multimethodology: 28
Por	Philosophy of OR:46/ Philosophy:31 **[USE Philosophy of OR]**
Rev	Literature review: 123/ Review:75
Met	Meta-analysis:25
Sur	Survey:169/ Survey research:40 **[USE Survey]**
Tax	Taxonomy:28/Classification: 173
Thr	Theory:34
Vwp	Viewpoint; Comment on: 39/ Professional: comment on: 32

ME MODELING TECHNIQUE (3 sub-levels)

Gen GENERAL

e.g.,
Numerical method:34/ Numerical analysis:11;
Computing:75;
Parallel computing:94/ Parallel processing:31;
Free disposal hull:36 **[USE Free disposal hull approach];**
Hybrid method:30 **[USE Hybrid problem solving methods];**
Preprocessing:36;
Prediction:54 **[USE Predictive analytics];**
Analytics:62
Big data:91

Alg Algorithms:294

Gen General
e.g.,
Asymptotic analysis:45;
Exact method:37;
Online algorithm:110;
Newton method:65;

Alg00 Algorithmic complexity:5

Alg01 Analysis of algorithms:78

Alg02 Approximation algorithms:477/ Approximations:222 **[USE approximation algorithms]**

Alg03 *Branch and bound algorithm:136*

Alg04 Computational geometry:32

Alg05 Decomposition:253 **[USE decomposition algorithm]**
e.g.,
Benders decomposition:232;
Dantzig-wolfe decomposition:51;
Decomposition methods:49;
Principal component analysis (PCA):44

Alg06 Exact algorithm:78

Alg07 Fixed points:59 **[USE Fixed points algorithm]**

Alg08 Heuristic algorithms:181

Gen General
e.g.,
Threshold accepting:21;
Adaptation:38 **[USE Heuristic adaptation]**;

Alg08.a Beam search:45

Alg08.b *Bounds:56* **[USE Heuristic bounding solution]**
e.g.,
Error bounds:87;
Lower bounds:166;
Upper bounds:26;

Alg08.c Greedy algorithms:48/ Greedy heuristics:33 **[USE Greedy heuristic algorithms]**
e.g.,
Constructive heuristics:32;

Alg08.d Heuristic search:35

Alg08.e Heuristics:2587/ Heuristic methods:30 **[USE Heuristics]**
e.g.,
Worst case analysis::145;

Alg08.f Hyper-heuristics:30

Alg08.g Tree search:18

Alg09 Interior point methods:241
e.g.,
Central path:16;
Interior point algorithm:58;
Proximate point algorithm:38;

Alg10 Lagrangian relaxation:/Lagrangean relaxation:480 **[USE Lagrangian relaxation]**
e.g.,
Lagrangian heuristic:42;
Augmented Lagrange:45;
Lagrangian decomposition:35;

Alg11 *Metaheuristics:852* **[USE Metaheuristic algorithm]**
e.g.,
Matheuristics:99;
Hybrid Metaheuristics:43;

Alg12 *Parallel algorithm:44*/ Parallel:25 **[USE Parallel algorithm]**

Alg13 Polynomial algorithm:86/ Polynomial time algorithm:87 **[USE polynomial algorithm]**
e.g.,
Approximation scheme:38 **[USE Polynomical-time approximation scheme];**
Fully polynomial time approximation scheme (FPTAS):42

Alg14 Randomized algorithm:33

Alg15 *Reference point method:22*
e.g.,
Reference point:34;

Alg16 *Simplex method:40*
e.g.,
Column generation:567;

Alg17 Stochastic approximation:54 **[USE stochastic approximation algorithm]**

Afi Artificial intelligence:193

Gen General

Afi00 Expert systems:86

Gen General

		Afi00.a	Case-based reasoning:39
	Afi01		Evolutionary computation:99 e.g., Evolutionary algorithms:181; Differential evolution:82;
	Afi02		Machine learning:120
		Gen	General
		Afi02.a	Feature selection:50
		Afi02.b	Reinforcement learning:44
		Afi02.c	*Decision trees:60*
		Afi02.d	Support vector machines:79
	Afi03		Neural networks:337 e.g., Artificial neural networks:70;
Chm			Choice models:63
	Gen		General e.g., Transitivity:18; Discrete choice model:54; Discrete choicel:44;
	Chm00		Bounded rationality:56
	Chm01		Preference modeling:30/ Preferences:44 **[USE Preference modeling]** e.g., *Preference relation:16*;
	Chm02		Prospect theory:68 e.g., Cumulative prospect theory:23;
	Chm03		*Utility theory:106* e.g., Multi-attribute utility theory:24 Expected utility:38; Utility:48; Utility functions:43; Value function:37 / Value:36 **[USE Value function];**
Cma			Combinatorial analysis:40
	Gen		General e.g., *Combinatorial auctions:54* Combinatorics:17
	Cma00		*Combinatorial optimization: 916*
	Cma01		Combinatorial problems:19
	Cma02		Polyhedral combinatorics:58 e.g., Facets:91; Polyhedra:35; Disjunctive programming:35 Polytope:52;
Cxt			Complexity:343/ Computational complexity:254 **[USE Complexity analysis]**
	Gen		General e.g., *Np-complete:70;* *Np-hard:132;*
Coa			Computational analysis:82
	Gen		General e.g., Computation:79;
	Coa00		Computational experiments:60
	Coa01		Computational results:24
Cth			Control theory:35 **[USE Control theory in modelling]**
Dea			Data envelopment analysis (DEA):1803 **[USE Data Envelopment Analysis]** e.g., Network dea:29 Assurance regions:16 **[USE DEA assurance regions];** Imprecise data:16 **[USE Imprecise data envelopment analysis];** Super-efficiency:49 **[USE DEA super-efficiency estimates];** Weight restrictions:46/ *Weights:31* **[USE Weight restrictions in DEA];**
Dmi			Data mining:276
	Gen		General e.g., Data association: 4; Data analysis:36; *Regression:123/ Regression analysis:63* **[USE Regression];**
	Dmi00		Aggregation:99 **[USE data aggregation]**
	Dmi01		Classification:185 e.g., *Decision trees:60* **[USE decision tree classification algorithm];**

	Dmi02	Clustering/clusters:193/ Cluster analysis:87 **[USE Cluster analysis]** e.g., *Overlapping:15* **[USE Overlapping clusters];** Garch:19
	Dmi03	*Prediction:29* **[USE Classification and Prediction]**
For	*Forecasting:520*	
	Gen	General e.g., Projection:54 **[USE Projected forecast];**
	For00	Delphi:11/ Delphi study:7 **[USE Delphi study]**
	For01	Exponential smoothing:34
	For02	Time series:120 [USE Time series forecasting] e.g., Interval data:22; Panel data:26 Kalman filter:35; exponential weighted moving average (ewma):55
Flo	Fuzzy logic:110	
	Gen	General e.g., Fuzzy numbers:52; Fuzzy random variable:23;
	Flo00	Fuzzy goal:11
	Flo01	Fuzzy programming:31 e.g., *Fuzzy goal programming:35;* *Fuzzy linear programming:18;*
	Flo02	*Fuzzy sets:274* e.g., Membership function:26;
Gth	Game theory:1025/ Games:98 **[USE Game theory]**	
	Gen	General e.g., Attack:10 **[USE Attack model];** *Fairness:65* **[USE Fairness in game theory];** *Incomplete information:77* **[USE Games with incomplete information];** Maximin: 9; *Minimax:43;* Mechanism design:101; Stackelberg game:104; *Experiments:100/Experimentation:21;*
	Gth00	Cooperative games:142/ Cooperative game theory:49/ Cooperative:63 **[USE Cooperative games]** e.g., Nucleolus:30; Shapley value:68;
	Gth01	Decision theory:113 e.g., Choquet integral:56;
	Gth02	Differential games:64/ *Differential:15* **[USE Differential games]**
	Gth03	Dynamic game:35
	Gth04	Noncooperative games:51 e.g., Nash equilibrium:172; Stackelberg equilibrium:18; Stackelberg game:104; *Utility theory:83;* Tu-game: 22 **[USE Transferable utility game]**
	Gth05	Repeated games:43
	Gth06	Search game:25
	Gth07	Simple games:24
Grt	Graph theory:147	
	Gen	General e.g., Matching:69 **[USE Graph matching];** Pairwise comparisons:61; Pairwise comparison matrix:16 Minimum cut:10;
	Grt00	Degeneracy:41 **[USE Degeneracy graphs]**
	Grt01	Graphs:96 **Gen** General e.g., *Petri nets:76;* **Grt01.a** Bipartit graph:15 **Grt01.b** Hypergraph:20
	Grt02	Graph coloring: /Graph colouring:61 **[USE Graph coloring]** e.g., Edge coloring:15;
	Grt03	Graph partitioning:55/ *Partitioning:35* **[USE Graph partitioning]**

	Grt04	Networks and graphs/ Networks graphs:97 **[USE Networks and graphs]**
Ift		Information theory:33
	Gen	General
	Ift00	Entropy:73
Ith		Inventory models:83/ Production models:39/Processing models:3
	Gen	General e.g., *Backorders:52* **[USE backorder model];** Lost sales:98 *Lot sizing:514* Dynamic lot-sizing:40;
	Ith00	Inventory policies:36 *e.g.,* *Minimax:31* **[USE Minimax inventory ordering policy];** Fill rate:35; Optimal policies:54;
	Ith01	Inventory theory:36
	Ith02	*Continuous review:16*
	Ith03	Economic Order Quantity(EOQ):102 Economic product quantity(EPQ):54 e.g., *EOQ model:33* **[USE Economic Order Quantity model];** Discounting:41; Quantity discounts:90;
	Ith04	*Periodic review:53* e.g., Multiperiod:38
Mod		Modeling:365
	Gen	General e.g., Discrete-time:33/ Discrete:16 **[USE Discrete-time models];** Models:57; *Hierarchical models:15;* *Multi-period:17*
	Mod00	*Experiments:100/Experimentation:21;* **[USE Model experimentation]**
	Mod01	Mathematical modeling:129
	Mod03	Scenarios:51 **[USE Scenario modeling]**
	Mod04	Structured modeling:20
	Mod05	Validation:45 **[USE Model validation]**
	Mod06	Verification:3 **[USE Model verification]**
Mdm		Multicriteria decision making (MCDM):356
	Gen	General e.g., *Hierarchical models:21;* Dominance:42 **[USE Dominance approach];** *Preference relation:16*
	Mdm00	Analytic Hierarchy Process (AHP):412
	Mdm01	Analytic network process (ANP):88 **[USE Analytic Network Process]**
	Mdm02	Multicriteria decision analysis (MCDA):123/ Multicriteria decision making (MCDM):356/ Multicriteria analysis:425/ Multicriteria decision aid (MCDA):52 **[USE Multicriteria analysis]** e.g. Multicriteria:252
	Mdm03	Multi-attribute decision making: 80
	Mdm04	*Multiobjective programming:333/ Multiobjective optimization:481/ Multicriteria optimization:104/* ***Multicriteria programming: 31*** **[USE Multiobjective optimization]**
	Mdm05	Multiobjective decision making:33 **[USE Multiobjective decision]** e.g. Multiobjective:219 Bobjective optimization:51
	Mdm06	Topsis:58 **[USE TOPSIS]**
Opt		Optimization:1742/ Mathematical programming:414/ Optimization model:32 **[USE Optimization]**
	Gen	General e.g., Dynamic model:34; Deterministic: 39 Optimal control:231/ Control:130 **[USE Optimal control];** Optimal stopping:71; *Optimal strategy:21;* Finite horizon:19; /Infinite horizon:16; Rolling horizon:43; Infeasibility:27 **[USE Infeasible solution];** Duality theorem:13; Duality:208; Nonsmooth optimization:89 Symmetric duality:19;

		Metamodels:65;
Opt01		Constraint programming:161/ constraint optimization:83
	Gen	General e.g. *Constraints:31* *Constraints satisfaction: 31* *Constraints qualification: 54* Constraint propagation:31 Precedence constraint: 71; *Capacity constraints:68* *Resource constraints:75* *Availability constraints:33* *Penalty method:18*
	Opt02.a	Chance-constrained programming: 48 *Chance constraints: 73*
	Opt02.b	Unconstrained optimization:37;
Opt02		Continuous optimization:29
Opt03		Convergence:94 **[USE Convergence of optimization algorithms]**
	Gen	General
	Opt03.a	Global convergence:109 e.g., Line search:24; Trust:66/ Trust region:17/ Trust region method:33 **[USE Trust region method];**
	Opt03.b	Superlinear convergence:55
Opt04		*Differential:15* **[USE Optimization with differential equations] /** Subdifferential:50
Opt05		Discrete optimization:69/ Discrete:32 **[USE Discrete optimization]**
	Gen	General
	Opt05.a	Combinatorial optimization: 916 e.g., Bilevel programming:168/ Bilevel optimization:54; **[USE Bilevel optimization];** Branch and bound776 /Branch and bound method:43/ *Branch and bound algorithm:136* Branch and cut:314; Branch and price:240; Branch and price and cut:69; *Multiobjective combinatorial optimization:26;* Submodular function:38;
	Opt05.b	Integer programming:1640/Integer optimization:14 / Integer:145 **[USE Integer programming]** e.g., Integer linear programming:160 Integer nonlinear programming:46 0-1 integer programming:22; Lifting:35 **[USE Integer lifting];** *Np-complete:70;* *Np-hard:132;*
	Opt05.c	Mixed integer programming:720/ Mixed integer optimization:19 **[USE Mixed integer programming]** e.g., Cutting planes method:38/Cutting planes:239 **[USE Cutting plane method];** Cutting plane algorithms:48; Valid inequalities:160 **[USE Valid inequalities for mixed integer linear programming];** Mixed integer linear programming (milp):432 Mixed integer nonlinear programming:140; Outer approximation:47;
Opt06		Dynamic programming:1290/ Dynamic optimization:36 **[USE Dynamic optimization]**
	Gen	General e.g., Optimality:20;
	Opt06.a	Approximate dynamic programming: 109
	Opt06.b	Optimality conditions:125
	Opt06.c	Pareto optimality:89 / Pareto optimization solution:27
Opt07		Global optimization:818
Opt08		Inverse optimization:35
Opt09		Large scale optimization:143
Opt10		Linear programming:1037/ Linear optimization:21 **[USE Linear optimization]**
	Gen	General e.g., Linearization:69 Linear programming relaxation: 28
	Opt10.a	*Fuzzy linear programming:35*
	Opt10.b	*Goal programming:297* e.g., *Fuzzy goal programming:35;*
	Opt10.c	*Multiobjective linear programming:42*
	Opt10.d	*Sensitivity analysis:270* e.g., Parametric programming:54;
	Opt10.e	*Simplex method:40* e.g., *Dantzig-wolfe decomposition:51;* *Column generation:567;* *Benders decomposition:234;*

Opt11		*Metaheuristics:852* **[USE Metaheuristic optimization]**
	Gen	General e.g., Search:61 **[USE search metaheuristics];** *Matheuristics:99;*
	Opt11.a	Ant colony optimization:147
	Opt11.b	Genetic algorithms:1179 e.g., Hybrid genetic algorithm:37;
	Opt11.c	Greedy randomized adaptive search procedure (Grasp):156
	Opt11.d	Hybrid algorithm:57 e.g., *Hybrid method:30;*
	Opt11.e	Local search:392 e.g., Iterated local search:108;
	Opt11.f	Memetic algorithm:84
	Opt11.g	Particle swarm optimization:122
	Opt11.h	Path relinking:71
	Opt11.i	Scatter search:78
	Opt11.j	Simulated annealing:495
	Opt11.k	Tabu search:776 e.g., Ejection chains:25;
	Opt11.l	Neighborhood search:38 e.g., Variable neighborhood search:256 Large neighbourhood search:72 Adaptive large neighbourhood search:58
Opt12		*Multiobjective programming:333/ Multiobjective optimization:481/ Multicriteria optimization:104* **[USE Multiobjective optimization]**
	Gen	General e.g., Interactive method:51 / Interactive procedures:19 **[USE Interactive MCDM procedures];**
	Opt12.a	Compromise programming:38
	Opt12.b	*Goal programming:297*
	Opt12.c	*Multiobjective combinatorial optimization:26*
	Opt12.d	*Multiple objective linear programming/Multiobjective linear programming:42*
	Opt12.e	Outranking:10/ Outranking method:17 e.g., Electre:14; Promethee:32;
	Opt12.f	*Ranking:106* e.g., *Ranking and selection:47;*
Opt13		Network optimization:97
	Gen	General
	Opt13.a	Network flows:108 e.g., Maximum flow:34; Minimum cost flow:30; Multicommodity flows:84;
	Opt13.b	*Network design:336* e.g., Minimum spanning tree34; Spanning tree:72; Steiner tree:61;
	Opt13.c	Activity networks:23 e.g., *CPM:9;* *Pert:33;* *Shortest path:140 /Shortest path problem:51*
Opt14		Nonlinear programming:427/ Nonlinear optimization:102/ Nonlinear:32 **[USE Nonlinear optimization]**
	Gen	General e.g., Differentiability:15 **[USE Differentiability properties];**
	Opt14.a	Convex programming:173/ Convex optimization:116 **[USE Convex optimization]** e.g., Convex analysis:47; Convex hull:50; Convexity:79; Convex relaxation:43; Nonconvex optimization: 121/ nonconvex programming:35**[USE Nonconvex optimization]** Second-order cone programming:34 Semidefinite programming (sdp):274;
	Opt14.b	Fractional programming:82
	Opt14.c	Geometric programming:38
	Opt14.d	Nonlinear integer programming:46
	Opt14.e	Quadratic programming:213
Opt15		Extended formulations:50

		Reformulation:37 **[USE Reformulation in mathematical programming]/** Reformulation linear technique:45
	Opt16	Robust optimization:476
	Opt17	Semi infinite programming:65 **[USE Semi-finite Optimization]**
	Opt18	*Simulation optimization:153*
	Opt19	Stochastic programming:725/ Stochastic optimization:203/ Stochastic:161 **[USE Stochastic optimization]**
	Opt19 – Gen	General e.g., Sample average approximation:63; Stochastic control:59; Stochastic model applications:39; Stochastic modelling:187; Stochastic frontier:22 Uncertainty modeling:161; Martingales:23 Brownian motion:31
	Opt19.a	Multistage stochastic programming:42 e.g., Separation/separability:58; Two-stage:32 **[USE Two-stage stochastic programming];**
	Opt19.b	Stochastic dynamic programming:124
	Opt19.c	Stochastic integer programming:37
	Opt20	Vector optimization:55
	Opt21	Polynomial optimization:39
Oth		Organization theory:14
	Gen	General
	Oth00	Agency theory:41
	Oth01	Contingency theory:41
Pth		Possibility theory:16
Prb		Probability:130/ Applied probability:76 **[USE Probability]**
	Gen	General e.g., Fourier transform:11; Laplace transform:46; *Probabilistic analysis:32;* *Probabity model:39;* *Algorithmic probability:12;* *Rare event:23;* Survival analysis:34 / Survival/survivability:36 [USE Survival analysis];
	Prb00	Distributions:241 e.g., Copula:43 Normal distribution:27; Phase type distribution:66; Stationary distribution:28; Weibull distribution:46;
	Prb01	Markov processes:222 e.g., Embedded markov chain:9; Markov chains:210; Markov chain monte carlo:42; Markov decision processes:326; Markov model:46 Hidden Markov model:23 Partially observable markov decision process:23 Markovian arrival process:28; Matrix-analytic method: 28
	Prb02	Random walk:25 e.g., Random environment:20;
	Prb03	Renewal theory:24 e.g., Large deviations:35; Poisson process:31; Homogeneous poisson process:2 **[USE Non-homogeneous poisson process];** Nonhomogeneous poisson process:33 Renewal process:19; *Geometric process:15;*
	Prb04	Stochastic process:190 *e.g.,* Stochastic comparison:16; Stochastic dominance:101; *Stochastic networks:32;* *Stochastic ordering:55;*
Prg		Programming:103 **[USE Computer programming]**
	Gen	General
	Prg00	Software development:22
Qth		Queueing theory/Queuing theory:125 **[USE Queuing theory]**
	Gen	General

e.g.,
Queueing:450

Qth00 Queue/Queues: 165/ Queue system:89 **[USE Queue system]**
e.g.,
Finite buffer:31;
Heavy traffic:41;
Loss funtion:37;
Loss system:15;
M/G/1 queue:15;
Multi-server queue:30
Polling systems:19;

Qth01 Queueing models:56
e.g.,
Average run length:131;
Queue length:17;
Admission control:37;
Balking:29;
Batch arrivals:20;
Blocking:73;
Busy period:21;
Fluid models:29;
Make-to-stock queue:20;
No-wait:41;
Priority:55/ Priority queues:31 **[USE Priority queues]**;
Quasi-birth-and-death process:22;
Matrix-geometric solution:7
Reneging:27;
Retrial queues:48;
Tandem queues:33;
Time-dependent:44;
Vacation:6;
Vacation models:7;
Throughput:49;
Cycle time:35;
Waiting time:50;
Sojourn time:13;

Qth02 Queuing networks:152
e.g.,
Stochastic networks:32 **[USE Stochastic queuing networks]**;
Perturbation analysis:30/Perturbation:30

Sth Set theory:3

Gen General
e.g.,
Fuzzy sets:227;
Rough sets:42;

Sth00 Fuzzy set theory:33

Sth01 Monotonicity:37 **[USE Monotonic Function]**

Sth02 Polyhedral set theory:2

Sth03 Rough set theory:18

Sim Simulation:1654/ Computer simulation:25/ Simulation modeling:40 **[USE Simulation]**

Gen General

Sim00 Agent-based simulation:35/ Agent-based model:31
e.g.,
Behavior:51 **[USE Agent behavior]**;

Sim01 Discrete-event simulation:150

Sim02 *Hybrid method:30* **[USE Hybrid simulation]**

Sim03 Monte Carlo simulation:139
e.g.,
Cross-entropy method:21 / Cross-entropy:21**[USE Cross-entropy method]**;
Monte Carlo:34;
Monte Carlo method:33;
Variance reduction:33;

Sim04 *Rare event simulation:15*/ *Rare event:23* **[USE Rare event simulation]**;

Sim05 *Simulation optimization:153*

Sim06 Spreadsheets:31 **[USE Spreadsheet simulation]**

Sim07 *Systems dynamics:278*
e.g.,
Feedback:25 **[USE Feedback loop]**;

Sta Statistics:111/ Statistical analysis:54 **[USE Statistics]**

Gen General
e.g.,
Interval analysis: 47;
Confidence intervals:44;
Dependence:22 **[USE Dependence among variables]**;
Correlation:64
Autocorrelation:26;
Heterogeneity:53;
Statistical inference:18;
Variance:21;
Estimation:66 **[USE Variance estimation]**;
Large deviations:35;

Outliers:42;
Standard deviation:8;

Sta00	Conjoint analysis:40	
Sta01	Design of experiments:126/ Experimental design:47 **[USE Design of experiments]**	
Sta02	Multivariate statistics:65	
	Gen	General e.g., Discriminant analysis:67;
	Sta02.a	Principal component analysis:40
	Sta02.b	*Regression:123/ Regression analysis:63* **[USE Regression]** e.g., Logistic regression:48; Logit model:21;
	Sta02.c	Response surface methodology (rsm):101
	Sta02.d	Structural equation modelling (sem):173
Sta03	Nonparametric estimation:14	
Sta04	Parameter estimation:37 e.g., Maximum likelihood estimation:65/ Maximum likelihood:42 **[USE Maximum likelihood estimation];**	
Sta05	Parametric analysis:16	
Sta06	*Ranking:10+* **[USE Ranking methods in statistics]**	
	Gen	General
	Sta06.a	*Consistency:76* **[USE Consistency in ranking]**
	Sta06.b	Order statistics:33
	Sta06.c	*Ranking and selection:47* **[USE Ranking and selection statistics]**
Sta07	Resampling:4/ Resampling method:2	
Sta08	Sampling:47	
	Gen	General e.g. *Bias:26*
	Sta08.a	Bootstrapping:91;
	Sta08.b	Importance sampling:38
Sta09	Bayesian analysis:20 e.g., Bayesian inference:45; Bayesian methods:34; Bayesian networks:44; Bayesian statistics:20;	

SO SOFT OR:60 **(2 sub-levels)**

Gen	General	
Prs	Problem structuring:70	
	Gen	General e.g., Problem structuring methods:59;
	Prs00	*Collaborative planning:15*
	Prs01	*Cognitive mapping:47*
	Prs02	*Influence diagrams:22*
	Prs03	*Systems Dynamics:278*
	Prs04	Soft Systems Methodology (ssm):45
	Prs05	Strategic choice:5/ Strategic Choice Approach:6 **[USE Strategic Choice Approach]**
	Prs06	SODA:5 **[USE Strategic Options Development and Analysis(SODA)]**
Syt	Systems thinking:31	
	Gen	General
	Syt00	Critical systems thinking:13
	Syt01	Theory of constraints/toc:68

PB PROBLEM **(3 sub-levels)**

Gen	GENERAL
Asp	Assignment problem:96/ Assignment:109 **[USE Assignment problem]** e.g., Generalized assignment problem:36; Quadratic assignment problem:89 / Quadratic assignment:27 **[USE Quadratic assignment problem];** Traffic assignment:58 **[USE Traffic assignment problem];** Dynamic traffic assignment:68 Macroscopic fundament diagram mfd:43 Target set:22
Cmp	Complementarity:55/ Complementarity problem:70 **[USE Complementarity problem]** e.g., Linear complementarity problem:85; Nonlinear complementarity problem:31;

Cvp	Covering:41/ Covering problem:17 **[USE Covering problem]** e.g., Set covering problem:24/ Set covering:64 **[USE Set covering problem];**
Csp	Cutting:126/ Cutting stock problem:85/ Cutting stock:80 **[USE Cutting stock problem]**
Cpp	Cutting and packing:46 **[USE Cutting and packing problem]**
Fpp	First passage problem e.g., First passage time:15;
Ivp	Inverse problem:26
Jrp	Joint replenishment:53 **[USE Joint replacement problem]**
Ksp	Knapsack problem:156/ Knapsack:38 **[USE Knapsack problem]**
Flp	Location problem:48/ Location allocation problem:14/ Allocation problem:5 **[USE Location problem]** e.g., Location allocation:39 Continuous location:35 **[USE Continuous location problems];** Discrete location:25 **[USE Discrete location problems];** Location model:26; Hub location:94; P-median:41; Weber problem:13;
Nwp	*Networks:420* **[USE Network problems]** e.g., Backhaul:15 **[USE Backhaul problem in transport flows];** Bottleneck:40/Bottleneck model:31 **[USE Bottleneck problem in networks];** Transportation problem:76
Nvp	Newsvendor problem:95/ Newsvendor:119/Newsboy:14/ Newsboy problem:58 **[USE Newsvendor problem]** e.g., Newsvendor model:116/ newsboy model:6 Distance:24 **[USE Shortest distance];**
Orie	Orienteering problem:35
Pkp	Packing problem:30/ Packing:199 **[USE Packing problem]**
Gen	General e.g., *Stability:166;*
Pkp00	Bin packing:106/ Bin packing problem:10 **[USE Bin packing problem]** e.g., *Overlapping:17* **[USE Bin packing with overlapping objects];**
Pkp01	Container loading problem:12 e.g. Berth allocation:38
Pkp02	Set packing:7 **[USE Set packing problem]**
Rop	Routing:444 **[USE Routing problem]**
Gen	General e.g., *Time-dependent:44;* *Time windows:187;* **[USE Routing problem with time windows];** Routing choice:43
Rop00	Arc routing:75 **[USE Arc routing problem]** e.g., Capacitated arc routing problem:5; Chinese postman problem:21; Rural postman problem:32;
Rop01	Inventory routing:71/ Inventory routing problem:28 **[USE Inventory routing problem]**
Rop02	Vehicle routing:592/ Vehicle routing problem:208 **[USE Vehicle routing problem]**
Gen	General e.g., Dynamic vehicle routing:40
Rop02.a	Dial-a-ride:20/ Dial-a-ride problem:33 **[USE Dial-a-ride problem]**
Rop02.b	Heterogeneous fleet:36 **[USE Vehicle routing problem with heterogeneous fleet]**
Rop02.c	Split delivery:29 **[USE Split delivery vehicle routing problem]**
Scp	Scheduling problems:22
Gen	General e.g., *Lot sizing:514;* Lot sizing scheduling:27 Lot sizing problem:15 Dynamic lot sizing:40; Dynamic scheduling:54; Deteriorating jobs:62 **[USE Schedule deteriorating jobs];**
Scp00	Batch scheduling:58
Scp01	Bicriteria:44/Bicriteria scheduling:20
Scp02	Flowshop scheduling:144/ Flowshop scheduling problem:8 **[USE Flowshop scheduling]**

e.g.,
Lot streaming:33 **[USE Lot-streaming flowshop scheduling problem];**
Permutation flowshop:42 **[USE Permutation flowshop scheduling];**

Scp03 Jobshop scheduling:134 /Jobshop scheduling problen:8 **[USE Jobshop scheduling]**

Scp04 Machine scheduling:77

- **Gen** General
- **Scp04.a** Parallel machine scheduling:101/ Parallel machines:217 **[USE Parallel machine scheduling]**
  e.g.,
  Identical parallel machines:34;
  Unrelated parallel machines:41;
- **Scp04.b** Single machine scheduling:178/ Single machine:177 **[USE Single machine scheduling]**

Scp05 Multiprocessor scheduling:17

Scp06 Open shop scheduling:13/ Open shop:66

Scp07 Production scheduling:195

Scp08 Project scheduling:252/ *Project management and scheduling:24* **[USE Project scheduling]**
e.g.,
Resource-constrained project scheduling:59;

Scp09 Sports scheduling:39

Scp10 Vehicle scheduling:83/ Vehicle scheduling problem:4

Scp11 Workforce scheduling:28/ Personnel scheduling:34 **[USE Workforce scheduling]**
e.g.,
Nurse scheduling:23/ Nurse rostering:28 **[USE Nurse scheduling];**
Crew scheduling:56;
Workforce planning:24
Manpower planning:108
Appointment scheduling:55

Spp Set partitioning:73/ *Partitioning:35/* Set partitioning problem:14 **[USE Set partitioning problem]**

Shp *Shortest path:140*/ Shortest path problem:51 **[USE Shortest path problem]**

Ssp Stable set:13 **[USE Stable set problem]**

Tsp Traveling salesman problem:258/ Traveling salesperson problem:10/ Traveling salesman:127 **[USE Traveling salesman problem]**
e.g.,
Time windows:187 **[USE Travelling salesman problem with time windows];**

Vip Variational inequality:242 **[USE Variational inequality problem]**
e.g.,
Quasi-variational inequality:22 **[USE Quasi-variational inequality problem];**
Variational analysis:36

PR APPLICATIONS:224/ PRACTICE OF OR:172/ PROCESS OF OR:27 [USE OR/MS APPLICATION] (4 sub-levels)

Gen GENERAL
e.g.,
OR group:13;
OR in societal problem analysis:33
Community OR:59;
Professional:90 **[USE OR professional];**
Effectiveness:35 **[USE Effectiveness analysis];**
Trade-offs:40;
Practice:36
Applications:224

Cta Cost:84/ Cost analysis:46 **[USE Cost analysis]**

- **Gen** General
  e.g.,
  Cost allocation:70;
  Cost efficiency:38;
  Cost model:40
  Setup cost:35
  Minimum cost flow:30
  Effectiveness:35 **[USE Cost effectiveness];**
  Cost estimation:49
  Transaction costs:71 [USE transaction costs analysis];
- **Cta01** Cost benefit analysis:62 **[USE Cost benefit analysis]**
  e.g.,
  Returns to scale:80;
  Activity based costing (abc):48

Dmk Decision making:324/ Decision making process:43/ Decision:54 **[USE Decision making]**

- **Gen** General
  e.g.,
  Time preference:19 **[USE Decision making under time preference];**
  Decision making under uncertainty*: 25; Uncertainty:412* **[USE Decision making under uncertainty];**
  Minimax regret: 16/ *Minimax: 43* **[USE Minimax regret];**
  Bias:26/ decision bias:11
- **Dmk00** *Cost benefit analysis:62* **[USE Cost benefit analysis in decision making]**
- **Dmk01** Decision analysis:577
  e.g.,
  Decision trees:60/ trees:46 **[USE Decision trees];**
  Influence diagrams:22;
- **Dmk02** Decision rules:27

	Dmk03	Decision support:163 e.g., *Cognitive mapping:47;* Scenario analysis:34;		
	Dmk04	Decision support systems (dss):651		
			Gen	General
			Dmk04.a	*Information systems:177*
			Dmk04.b	Geographical information systems(GIS):30
			Dmk04.c	Knowledge-based systems:50
	Dmk05	Group decision making:107		
			Gen	General e.g., Collaboration:110; Consensus:26; Facilitation:20; Group decisions:62; Group decision support system (gdss): 32; Group decisions and negotiations:64; Group technology:184; Teams:34
			Dmk05.a	Conflict:31 e.g., Conflict analysis:20;
Eco		Economics:173		
	Gen	General e.g., *Search theory:42* **[USE Search theory in microeconomics];** *Spillovers:20* **[USE Spillover effect];**		
	Eco00	Allocative efficiency:31		
	Eco01	*Auctions/bidding:37*		
			Gen	General e.g., *Asymmetric information/information asymmetry:219;* *Incentive compatibility:25*
			Eco01.a	*Auctions:94*
			Eco01.b	*Bidding:59*
	Eco02	Behavioral Econometrics:39		
	Eco03	Econometrics:46 /Econometric analysis:25		
	Eco04	Economic design:46		
	Eco05	Equilibrium:91 **[USE Economic equilibrum]** e.g., Equilibrium problem:60 User equilibrium:69 Stochastic user equilibrium:36 Network equilibrium:35		
	Eco06	Experimental economics:68		
	Eco07	*Information goods:17*		
			Gen	General
			Eco07.a	Value of information:66
	Eco08	Learning effect:91		
			Gen	General
			Eco08.a	Learning curve:69
	Eco09	Location theory:35		
Emr		Emergency response:33		
	Gen	General e.g., *Disruption management:67;* *Disruption:62;*		
	Emr01	Evacuation:24		
Ent		Entrepreneurship:61 e.g., *Leadership:22*		
Enm		Environment:187/ Environmental management:71 **[USE Environmental management]**		
	Gen	General e.g., Natural resources:26; OR in natural resources:39; OR in environmental climate change:35; Protection:12 **[USE Environmental protection];** Carbon dioxide emissions/Co2 emmissions:74;		
	Enm00	*Environmental performance:40*		
	Enm01	Environmental studies:35		
	Enm02	Recycling:50		
	Enm03	Climate change:22		
	Enm04	*Forest Management:19*		
	Enm05	Waste management:21		
	Enm0	Corporate social responsibility:56 e.g., Social welfare:44;		
Fpd		Facility planning and design:81		

Gen	General e.g., Competitive location:25;
Fpd01	Facilities:34 e.g., Obnoxious facility:13;
Fpd02	Facility planning:30
Fpd03	Facility design:23
Fpd04	Facility layout:96
Fpd05	Facility location:335 e.g., Location:520; Location-allocation:39;
Fim	*Finance:418* **[USE Financial management]**
Gen	General e.g., Financial performance:40; Signaling:51 **[USE Financial signal processing];** *Liquidity:20;* Stochastic volatility:18; Volatility:22; Financial institutions:30;
Fim00	*Auditing:31* **[USE Financial audit]**
Fim01	Budget/budgeting:25 e.g., Capital budgeting:55; Capital structure:23; Venture capital:23 Net present value:83; Competitive ratio: 55
Fim02	Investment analysis:116/ Investment:127 **[USE Investment analysis]**
Gen	General e.g., *Uncertainty:412* **[USE Investment under uncertainty];**
Fim02.a	*Asset pricing:43* e.g., *Arbitrage23;* Asset allocation:40;
Fim02.b	Derivative:6 e.g., Options:43; *Option pricing:79;* Real options:211; Option contract:38;
Fim02.c	Equity:65
Fim02.d	*Exchange rate:16*
Fim02.e	Franchising:21
Fim02.f	Mutual funds:31
Fim02.g	Portfolio:23
Gen	General e.g., Mean-variance analysis:30; *Diversification:47* **[USE Portfolio diversification];**
Fim02.g.00	Portfolio analysis:18
Fim02.g.01	Portfolio choice:32
Fim02.g.02	Portfolio management:30
Fim02.g.03	Portfolio optimization:156 e.g., Efficient frontier:54; Efficient set:25;
Fim02.g.04	Portfolio selection:120
Fim02.h	Securities:17
Fim03	*Liquidity:20*
Fim04	Mergers and acquisitions:30/ Mergers:25 **[Use Mergers and acquisitions]**
Fim05	*Regulation:61* **[USE Financial regulation]**
Fim06	Risk management:330
Gen	General e.g., Ambiguity:42; Ambiguity aversion:14; Risk:260; Risk analysis:176;
Fim06.a	Bankruptcy:35
Fim06.b	Risk measures: 60 e.g., Coherent risk measures:37
Fim06.c	Compensation:36
Fim06.d	Value at risk:79 e.g., Conditional value-at-risk:128
Fim06.e	Credit risk:57 e.g., Credit scoring:77;

		Fim06.f	Downside risk:18
		Fim06.g	Hedging:34
		Fim06.h	*Insurance:34*
		Fim06.i	*Liquidity:20* **[USE Liquidity risk]**
		Fim06.j	*Moral hazard:43*
		Fim06.k	Risk aversion:173 e.g., Loss aversion:70;
		Fim06.l	Risk pooling:33/ *Pooling:33* **[USE Risk pooling]**
		Fim06.m	Risk preference:33
		Fim06.n	*Weights:31* **[USE Risk weights]**
	Fim07	Corporate Finance:29	

Fos	*Forecasting:520*		
	Gen	General e.g., Combining forecasts:30; *Prediction:54;*	
	Fos01	Diffusions:45 **[USE Forecasting of diffusion]**	
	Fos02	Expert judgment:15/ Judgment:44 **[USE Expert judgement]**	

Hcm	*Healthcare: 264/ Health:36/ Healthcare management:39* **[USE Healthcare management]**		
	Gen	General	
	Hcm00	Accidents:12	
	Hcm01	Epidemiology:22 e.g., hiv/aids:16	
	Hcm02	Screening:32 **[USE Health screening]**	

Inm	Inventory management:426		
	Gen	General e.g., *Multi-item:48* **[USE Multi-item inventory systems];**	
	Inm00	Inventory:1543	
		Gen	General e.g., Safety stock:79; Conwip (CONstant work in process):40; Wip (Work in process):23;
		Inm00.a	Perishable inventory:39 e.g., Deteriorating items:77; Deterioration:126; Perishable product:57; Perishable:43;
	Inm01	Inventory control:479	
	Inm02	Inventory systems:45	
	Inm03	Inventory/production:83/ Production/inventory systems:33 **[USE Production/inventory systems]**	
	Inm04	Material requirements planning (MRP):123 Master production scheduling:35 Material handling: 78 Radio frequency identification Rfid:126	
	Inm05	Rationing:47/ Inventory rationing:29 **[USE Inventory rationing]**	
	Inm06	*Replenishment:35* **[USE Inventory replenishment]** Assortment planning:40	
	Inm07	Vendor-managed inventory:88 e.g., Vendor selection:31	

Knm	Knowledge management:122/ knowledge:22 **[USE Knowledge management]**		
	Gen	General	
	Knm00	Information:69 **[USE information management]**	
		Gen	General
		Knm00.a	*Asymmetric information/information asymmetry:216* e.g., *Adverse selection:24;* *Moral hazard:43;*
	Knm01	Knowledge acquisition:23	
	Knm02	Knowledge sharing:23	
	Knm03	*Knowledge transfer:35*	
	Knm04	*Learning:232*	
		Gen	General
		Knm04.a	*Learning curve:69*
		Knm04.b	Learning effect:91
	Knm05	*Spillovers:20* **[USE Knowledge spillover]**	

Mgt	Management:132

	Gen	General
	Mgt00	Consulting/Consultancy:21
	Mgt01	*Decentralization:29* **[USE Management decentralization]**
	Mgt02	*Disruption management:67* e.g., Disruption:62; Disaster Management:36 e.g., Disaster:23;
	Mgt03	*Planning:194* **[USE Planning in management]** e.g., *Collaborative planning:15;* *Multi-period:38*
Mnt	Maintenance:366	
	Gen	General
	Mnt00	Condition based maintenance:38/Condition monitoring:28
	Mnt01	Equipment replacement:16
	Mnt02	*Geometric process:15* **[USE Geometric process maintenance]**
	Mnt03	Maintenance scheduling:35
	Mnt04	Preventive maintenance:134
Mkg	Marketing:369	
	Gen	General e.g., OR in marketing:37 Promotion:45; Consumer behavior:41 */Behavior:51/* Buyer behavior:18/ Constomer behavior:29 **[USE Consumer behavior];**
	Mkg00	Advertising:94 e.g., Cooperative advertising:25; Reputation:29;
	Mkg01	Customer relationship management:33 e.g., Customer satisfaction:65; Strategic customers:37 Customers:33
	Mkg02	Market/marketing channel:14
	Mkg03	Marketing strategy:22
	Mkg04	Marketing/operations interface:57
Mkt	Markets:20	
	Gen	General e.g., Electricity markets:43; Electronic markets:26;
	Mkt00	Competition:335 **[USE Market competition]**
	Mkt01	Competitive advantage:48
		Gen — General
		Mkt01.a — Competitive analysis:64
		Mkt01.b — Resource-based view:47
		MKt01.c — Time-based competition:16
	Mkt02	Market efficiency:31
	Mkt03	Market entry:15
	Mkt04	Market power:23
	Mkt05	Oligopoly:29
	Mkt06	*Price competition:41*
	Mkt07	Market structure:26 e.g., Segmentation:35/ Market segmentation:56 **[USE Market segmentation]**
Ned	*Networks:420/ Network design:336* **[USE Network design]**	
	Gen	General e.g., Communication networks:29; Social networks:81; Telecommunication networks:33; Wireless sensor network:43
	Ned00	Congestion:116 **[USE Network congestion]**
	Ned01	Network externalities:31
	Ned02	Network programming:38 **[USE Network flow programming]**
	Ned03	Network reliability:38
	Ned04	*Quality of service:99* **[USE Network QoS]**
	Ned05	*Synchronization:47* **[USE Network synchronization]**
	Ned06	Traffic:58 **[USE Network traffic]**/Traffic flow:45
Opm	Operations management:190	
	Gen	General e.g., Global operations:18; Operations:57;

Opm00	*Behavior:51*/ Behavioral operations:104/ Behavioral operations management:50 **[USE Behavioral operations]/** Behavioral OR:		
Opm01	Capacity management:56		
	Gen	General e.g., Capacity:124;	
	Opm01.a	*Allocation:99/* Capacity allocation:82 **[USE Capacity allocation]** Allocation efficiency:31	
	Opm01.b	Finite capacity:20	
	Opm01.c	*Capacity constraints:68* *Availability constraints:21* Capacity reservation:15	
	Opm01.d	Capacity expansion:73	
	Opm01.e	Capacity investment:32	
	Opm01.f	Capacity planning:168	
	Opm01.g	Economies of scale:39	
Opm02	Operations strategy:163		
Opm03	Resource Managenet:22 /Resources:29 **[USE Resource management]**		
	Gen	General	
	Opm03.a	Resource allocation:310/ *Allocation:99* **[USE Resource allocation]** e.g., *Fairness:65* **[USE Fairness in resource allocation]** Resource constraints: 75 *Resource constraint project scheduling:59* *Constraints:31* *Chance constraints: 31* *Chance constraint program: 48* *Constraints satisfaction: 34* *Available constraints:33* *Constraint propagation:31*	
	Opm03.b	***Pooling:33*** **[USE Resource pooling]**	
	Opm03.c	**Enterprise resource planning (ERP): 79**	
Opm04	Service management:14/ Service operations management:21 **[USE Service operations management]**		
	Gen	General e.g., Service operations:175; Service systems:38; Production and service systems:35;	
	Opm04.a	Service level:100 **[USE Service Level Agreement]**	
	Opm04.b	*Service quality:61/ Quality of service:36* **[USE Service quality]**	

Ors	Organizational studies:93/ Organization:11 **[USE Organizational studies]**			
	Gen	General e.g., Small and medium enterprises (SME):85 Industrial organization:21 Virtual enterprises:39		
	Ors00	Culture:23 **[USE Organizational culture]**		
	Ors01	Ethics:33 **[USE Organizational ethics]**		
	Ors02	Human resources:42/ Human resources management:33		
		Gen	General	
		Ors02.a	Manpower planning:108 e.g., OR in manpower planning:14 Human factor:35	
		Ors02.b	Personnel:28	
			Gen	General
			Ors02.b.00	Cross-training:49
			Ors02.b.01	Motivation/motive:26 *Leadership:22*
			Ors02.b.02	Opportunism/opportunity:25
			Ors02.b.03	Redundancy:29
		Ors02.c	Staffing:48	
	Ors03	Organizational learning: 78 /Learning:232 **[USE Organizational learning]**		
	Ors05	Organizational design:34		
	Ors06	Organizational performance:31		

Pem	Performance measurement:279/ Performance:229/ Performance management:13 **[USE Performance measurement]**		
	Gen	General e.g., Firm performance:65; Operational/operating performance:47; Organizational performance:31;	
	Pem00	Balanced scorecard:29	
	Pem01	Benchmarking::110 **[USE Performance benchmarking]**	
	Pem02	Efficiency:470 **[USE Performance efficiency]**	
		Gen	General e..g Cross-efficiency:19

		Pem02.a	Efficiency analysis:26
		Pem02.b	Efficiency evaluation:16
		Pem02.c	Efficiency measurement:42/ Measurement: 39
		Pem02.d	Efficient solutions:61
		Pem02.e	Technical efficiency:60
	Pem03		Performance analysis:105
	Pem04		Performance evaluation:157/ Evaluation:66 **[USE Performance evaluation]**
	Pem05		Performance guarantee:11
	Pem06		Productivity:200 **[USE Productivity and Performance]**
		Gen	General
		Pem06.a	Malmquist index: 24 /malmquist productivity index:28
		Pem06.b	Productivity and competitiveness:27
Poa			Policy analysis:29/ Policies:36 **[USE Policy analysis]**
	Gen		General
	Poa00		*Optimal policy:83*
	Poa01		Public policy:49
	Poa02		*Regulation:61*
	Poa03		Adaptation::38
Pri			Price/pricing:919
	Pri00		*Asset pricing:43*
		Pri00.a	*Arbitrage:23*
	Pri01		Directional distance function:74 e.g., Distance function:29;
	Pri02		Dynamic pricing:187
	Pri03		*Exchange rate:16*
	Pri04		*Incentive compatibility:25*
	Pri05		*Incentives:131* **[USE Incentive pricing]**
	Pri06		Inflation:37
	Pri07		*Option pricing:79*
	Pri08		*Price competition:41*
	Pri09		Price discrimination:46
	Pri10		Profit/ Profitability:75
	Pri11		Price of anarchy:37
	Pri12		Revenue management:361
		Gen	General e.g. Revenue share:38 Revenue share contract:43
		Pri11.a	Yield management:51
		Pri11.b	Profit maximization:30
	Pri13		Transfer pricing:33
	Pri14		Congestion pricing:42
Prd			Product development:138
	Gen		General e.g., Durable goods:25;
	Prd00		Component commonality:23
	Prd01		Design:83/ Product design:112 **[USE Product design]**
	Prd02		*Engineering:25* **[USE Product engineering]**
		Gen	General
		Prd02.a	Concurrent engineering:61
		Prd02.b	Engineering design:19 e.g., Robust design:38
	Prd03		Mass customization:109
	Prd04		Modularity:55 **[USE Modular design]**
	Prd05		New product development:125 e.g., New products:31; Multiproduct:50;
	Prd06		Product life cycle:47
	Prd07		Standardization:25 **[USE Product standardization]**
Prp			Product policy:22/Production management:62
	Gen		General e.g., Availability:61 **[USE Product availability];** Order release:41;
	Prp00		*Backorders:26*
		Gen	General
		Prp00.a	Backlogging:29 **[USE Order backlog]**
		Prp00.b	Partial backlogging:37 **[USE Partial order backlog]**
		Prp00.c	Partial backordering:41
	Prp01		Bundling:37 **[USE Product bundling]/** Bundling method:49

General

Prp02	Core:75 **[USE Core product]**
Prp03	Lead time:127 e.g., Random lead time:20 Stochastic lead time:35
Prp04	Overbooking:31
Prp05	Product differentiation:36
Prp06	Product variety:60
Prp07	Replacement:74 **[USE Product replacement]**
Gen	General
Prp07.a	Replacement policy:24/ Returns policy:43
Prp08	Shortages:66 **[USE Product shortages]**
Prp09	Substitution:44 e.g., Product substitution:31; Product recovery:35;
Prp10	Warranty:54 **[USE Product warranty]**
Pro	**Production:745**
Gen	General e.g., Construction:22;
Pro00	Manufacturing systems:141
Gen	General e.g., Manufacturing strategy:127; Reconfiguration of manufacturing systemsy:37; Sustainable manufacturing:51;
Pro00.a	Automated manufacturing systems:18
Gen	General e.g. Automated guided vehicle (agv):42 Electric vehicles:69
Pro00.a.00	Robotic cells:53
Pro00.b	Cellular manufacturing:121/
Gen	General e.g., Group technology:84; Cell format:39;
Pro00.c	Lean manufacturing:97
Gen	General e.g., Lean production:62 Agile manufacturing:49 Agile:37 *Just-in-time :201* Lean:41 Kanban:41
Pro00.d	Manufacturing flexibility:53
Gen	General e.g., Flexibility:211;
Pro00.c.00	Flexible manufacturing systems:199/ Flexible manufacturing:44 **[USE Flexible manufacturing systems]**
Pro00.e	Remanufacturing:304
Pro01	*Process control:52/* Production control:91 **[USE Production control]**
Gen	General e.g., Workload control:59
Pro02	Process design:37
Pro02.a	Layout:26 **[USE Process layout]**
Gen	General
Pro02.a.00	Flowshop: 390; Hybrid flowshop: 62
Pro02.a.01	Jobshop:66
Pro02.a.02	Openshop:187
Pro02.b	Process improvement:59
Pro03	Production line:63/ Assembly line:66 **[USE Production line]**
Gen	General e.g., Assembly systems:77; Assembly:50; Disassembly:43; Kanban:41
Pro03.a	Assembly line balancing:134/ Line balancing:70 **[USE Assembly line balancing]** e.g., Load baklancing:37;
Pro03.b	Buffer allocation:28 **[USE Buffer allocation in production line]**
Pro03.c	Mixed-model assembly lines:67
Pro03.d	Production line design:36
Pro03.e	Setup costs:35
Pro03.f	Setup times:111
Gen	General e.g., Setups:40;

- **Pro03.f.00** — Sequence-dependent setup:52/Sequence-dependent setup times:104

- **Pro04** — Production planning:452
  - **Gen** — General
    - e.g., Process planning:55;
  - **Pro04.a** — Assemble-to-order:39
  - **Pro04.b** — Base-stock policy:48
  - **Pro04.c** — Make-to-order:84
  - **Pro04.d** — *Make-to-stock queue:20* **[USE Make-to-stock]**
- **Pro05** — Production system: 49 **[USE Production systems]**
  - **Gen** — General
    - e.g., Random yield:100;
  - **Pro05.a** — *Batching:105* **[USE Batch production]**
  - **Pro05.b** — *Just-in-time :201*
  - **Pro05.c** — *Multi-item:48* **[USE Multi-item production systems]**

Prm — Project management:336/ *Project management and scheduling:24* [USE Project management]

- **Gen** — General
  - e.g., Project:54; Project selection:35;
- **Prm00** — *CPM:9*
- **Prm01** — *Pert:37*
- **Prm02** — *Resource-constrained project scheduling:59*

Qum — Quality management:188

- **Gen** — General
  - e.g., Quality:225; Quality improvement:52; Product quality:52;
- **Qum01** — Quality control:95
  - **Gen** — General
  - **Qum01.a** — Inspection:100
  - **Qum01.b** — Statistical process control:338/ *Process control:52* **[USE Statistical process control]**
    - **Gen** — General
      - e.g., Taguchi method:40
    - **Qum01.b.00** — Control charts:161
      - e.g., Multivariate control charts:35
    - **Qum01.b.01** — Process capability indices:24
- **Qum02** — *Service quality:61/ Quality of service:36* **[USE Service quality]**
- **Qum03** — Total quality management(TQM):83
  - **Gen** — General
    - e.g., Undesirable output:44; Continuous improvement:41
  - **Qum03.a** — Six sigma:49
  - **Qum03.b** — Quality function deployment (qfd):80

Rel — Reliability:432

- **Gen** — General
- **Rel00** — Software reliability:16
- **Rel01** — System reliability:34
  - **Gen** — General
  - **Rel01.a** — Coherent system:27
  - **Rel01.b** — K-out-of-n system:19
  - **Rel01.c** — Parallel system:20
  - **Rel01.d** — Series systems:14

Rep — Repair:55

- **Gen** — General
  - e.g., Breakdowns:16;
- **Rep00** — Imperfect repair:15
- **Rep01** — Minimal repair:44
- **Rep02** — Repairable systems:19
- **Rep03** — Rework:45
- **Rep04** — Spare parts:98

Rde — *Research and development (R&D):65*

- **Gen** — General
  - e.g.,

		OR in R&D:19
	Rde00	Innovation:217
	Rde01	*Knowledge transfer:35*
	Rde02	Patents:32
Rsa	Robustness and sensitivity analysis:55	
	Gen	General e.g., Output analysis:18; *Worst case analysis:145*
	Rsa00	Calibration:40 **[USE Sensitivity analysis and calibration]**
	Rsa01	Robustness:200/ Robustness analysis:30 **[USE Robustness analysis]**
	Rsa02	Sensitivity:39/ *Sensitivity analysis:274* **[USE Sensitivity analysis]**
	Rsa03	Vulnerability:24
	Rsa04	*Stability:166* **[USE Sensitivity and stability analysis]**
Sch	Scheduling:2832	
	Gen	General e.g, *Multi-item:48* **[USE Multi-item scheduling];** Rescheduling:56
	Sch00	Scheduling methods
	Gen	General e.g., Rostering:26; Sorting:30; Timetabling:198;
	Sch00.a	Cyclic scheduling:80
	Sch00.b	Deterministic scheduling:19
	Sch00.c	On-line scheduling:37
	Sch00.d	Preemptive scheduling:22
	Sch00.e	Stochastic scheduling:83
	Sch01	Scheduling theory:73
	Sch02	Sequencing:245/ Scheduling/sequencing:8 **[USE Sequencing]**
	Gen	General e.g., Controllable processing times:58; Preemption:41; *Priority:55;* Priority rules:37; Release dates:57; Release times:24; *Dispatching rules:64/ Dispatching:42* **[USE Dispatching rules];** Due dates:56; Due date assignment:78; Total completion time:68; Total weighted completion time:30;
	Sch02.a	*Batching:105/* Batch processing:29 **[USE Batch sequencing]**
	Sch02.b	Earliness-tardiness /earliness and tardiness:71 e.g, Earliness:34; Tardiness:85; Total tardiness:57; *Worst case analysis::145* Batch processing machine:38
	Sch02.c	Makespan:355
	Sch02.d	Maximum lateness:42
Str	Strategy:154	
	Gen	General e.g., Business strategy:23 Business process reengineering:35 *Leadership:22;*
	Str00	Alliance:20 e.g., Coalition:18;
	Str01	Competitive strategy:73
	Str02	*Optimal strategy:21*
	Str03	*Planning:194/* Strategic planning:135 **[USE Strategic planning]** e.g., OR in strategic planning:16
	Str04	Postponement:52 **[USE Postponement strategy]**
Scm	Supply chain management:1762/ Supply management:49 **[USE Supply chain management]**	
	Gen	General e.g., Supply chains:885 *Synchronization:47* **[USE Supply chain synchronization];** Supply uncertainty:41 Supply chain disruption:37 Supply disruption:47

		Supply chain risk management:78 Green supply chain management (gscm):42 Green supply chain:37 Sustainable supply chain:3 Resilience:62
Scm00	Buyer-supplier relationships:62	
	Gen	General e.g., *Diversification:47* **[USE Supply chain diversification];** Interaction:39 **[USE Buyer-supplier interaction];** Information sharing:192 Supply chain dynamics:37
	Scm00.a	*Asymmetric information/information asymmetry:219* e.g., *Adverse selection:24;* *Moral hazard:43;*
	Scm00.b	Supplier selection:204 Supplier development:35
Scm01	Closed-loop supply chains:175	
Scm02	Coordination:210/ Supply chain coordination:239/ Channel coordination:76 **[USE Supply chain coordination]** e.g., Coordination mechanisms:31; *Cross-docking:58*	
	Decentralization:29 [USE Supply chain decentralization]	
Scm03	Demand management:21	
	Gen	General e.g., Advance demand information:28; Demand:33 Stock-dependent demand:26
	Scm03.a	Bullwhip effect:142
	Scm03.b	Demand forecasting:74
	Scm03.c	Demand uncertainty:177/Uncertainty demand:41
	Scm03.d	Deterministic demand:12
	Scm03.e	*Disruption management:67*
	Scm03.f	Intermittent demand:47
	Scm03.g	Stochastic demand:166
	Scm03.h	Time-varying demand:26 *Time-dependent:44*
Scm04	Distribution systems:40	
	Gen	General
	Scm04.a	*Dispatching rules:16/ Dispatching:14* **[USE Dispatching rules]**
	Scm04.b	Distribution channels: 47/ Channels of distribution:26 **[USE Distribution channels]** e.g., *Decentralization:29* **[USE Distribution channel decentralization];** Dual channel:50;
	Scm04.c	Transit/transitivity:18
	Scm04.d	Transshipment:79 e.g., Lateral transshipment:34;
	Scm04.e	Warehousing:90 e.g., Order picking:93; Pickup and delivery:91; *Cross-docking:58* *Liner shipping:42*
Scm05	Logistics:559	
	Gen	General e.g., *Third party logistics (3pl):47* City logistics:43
	Scm05.a	Humanitarian logistics:104
	Scm05.b	Reverse logistics:226
Scm06	Multi-echelon systems:28/ Multi-echelon inventory systems:31 e,g, Multi-echelon/ Multiechelon:68	
Scm07	Procurement:123	
	Gen	General
	Scm07.a	*Auctions:94/ Bidding:59/ Auctions/bidding:37/* Procurement auction:21 **[USE Procurement auctions/bidding]** e.g., *Combinatorial auctions:31;* Reverse auction:18; *Incomplete information:77;* Partial information:20
	Scm07.b	Contracting/contracts:135 e.g., Contract design:50; *Incentives:89/*Incentive contracts:38; Negotiation:70; Bargaining:63; Order acceptance:15 Trade credit:90; Subcontract:39;
	Scm07.c	Supply chain contracts: 65 /supply contracts:68

		Scm07.d	Purchasing:155
Scm08	Reverse supply chain: 30		
Scm09	Sourcing:50		
		Gen	General
		Scm09.a	Dual sourcing:71;
		Scm09.b	Offshoring:36;
		Scm09.c	Outsourcing:228
Scm10	Supply chain design:117/ Supply chain network design:46/ Supply network:39		
Scm11	Integration:101/ Supply chain integration: 51		
		Gen	General
		Scm11.a	Interaction:39 **[USE Supplier interaction]**
		Scm11.b	Vertical integration:32

Sde Sustainable development:34

Gen	General e.g., Sustainable operatios:41;
Sde00	Sustainability:255

Sym Systems:91 **[USE Systems modelling]**

Gen	General
Sym00	Complex systems:19 e.g., Complex adaptive systems:15; Complexity theory:72; Chaos:26 **[USE Chaos theory]**; *Multi-agent systems:104;*
Sym01	Distributed systems:40 **[USE Distributed systems modelling]** e.g., *Petri nets:37*
Sym02	Dynamical systems:47/ Dynamic:67 **[USE Dynamic systems modelling]** e.g., *Feedback:25* **[USE dynamic system feedback]**;

Tem Technology management:57

Gen	General e.g., *Technology:67* **[USE Technology Management]**; Technology change:22
Tem00	IT policy and management:23 e.g. *Information systems:177*

IN INDUSTRIES:94

Gen	GENERAL e.g, *Services: 107* *Technology:67;* Industry 4.0:37;
Acc	Accounting:50
Agi	Agriculture:80 e.g., OR in agriculture:32;
Aud	*Auditing:31* **[USE Audit]**
Aui	Automotive industry:116 e.g., Automotive:45;
Cmm	Communications:86 e.g., OR in telecommunications:33; Telecommunications:129;
Inf	Information technology:131 e.g., Computers:79; Internet:75; Software:49; Cloud computing:39;
Def	Defence/ Defense:19 **[USE Defense]** e.g., *Defence studies:31* Military:114; OR in military:16; OR in defense:11;
Edu	Education:125 e.g., OR in education:49 **[USE OR education]**; Higher education:29; Education systems:15

Ecm	E-commerce: 128/ Electronic commerce:65 **[USE E-commerce]**		
Eng	*Engineering:25*		
Fin	Finance:418 **[USE Financial services]**		
		Gen	General e.g., Financial institutions:30;
		Fin00	Bank/banking:160 e.g., OR in banking:34;
		Fin01	*Insurance:34* **[use Insurance industry]**
Fst	Forestry:34		
Hse	Health services:164/ *Healthcare:264/ Health:36* **[USE Health services]** e.g., OR in health services:138; Healthcare operations:41;		
		Gen	General
		Hse00	Hospitals:105
		Hse01	Emergency medical service:30
Mnf	Manufacturing:409/ Manufacturing industry: 47		
		Gen	General
		Mnf00	Semiconductor manufacturing:106/ semiconductor industry:15
Poi	Process industry:45		
Pse	Public service:20		
		Gen	General e.g., Public sector:31;
		Pse00	Government:83 e.g., OR in government:27;
		Pse01	Homeland security:22
		Pse02	Police:12
Res	Recreation and sports:16		
		Gen	General e.g., Recreation:16; Sports:82; OR in sports:30 Tournaments:37;
		Res00	Cricket:19
		Res01	Football:16
Ret	Retailing:202 e.g. Retail Operations:55 Online retail:38		
Rdv	*Research and development (R&D):65/ OR in R&D:19* **[USE Research and development]**		
Ser	Service/services:107		
		Gen	General
		Ser00	Call centers:85
Tra	Transport/tranportation:662		
		Gen	General e.g., *Liner shipping:42* *Third party logistics (3pl):47*
		Tra00	Air transport:63 e.g., Airlines:50;
		Tra01	Container terminal:106
		Tra02	Freight transportation:47
		Tra03	Rail transport:37 e.g., Railways:38;
		Tra04	Road transport:26
		Tra05	Sea transport:19 Maritime transport:59
		Tra06	Public transport:71
Uti	Utilities:48		
		Gen	General
		Uti00	Electricity:49
		Uti01	Energy:102 e.g., OR in energy:130; Renewable energy:37; Energy efficiency:47;
		Uti02	Power:30

CO COUNTRY:27 **(1 sub-level)**

Gen	GENERAL e.g.,

		China:76; India: 19; Australia: 10; Greece: 9; Spain: 8; Brazil: 8; Sweden:5; Finalnd:5; Germany:5; UK: 4;
	Dco	Developing countries:65