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OWNER

Prof. Dr. RAFET AKTAŞ

Ankara Yildirim Beyazit University, Business School, Ankara, Turkey

CORRESPONDENCE ADDRESS

Ankara Yıldırım Beyazıt University, Esenboğa Campus, Business School, Esenboğa/ANKARA

Ankara Yildirim Beyazit University, Esenboğa Campus, Esenboğa/Ankara

Phone: (0312) 906 16 /21 / 47 /48

E-mail:bsdo@ybu.edu.tr

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RESEARCH ARTICLE

A Comprehensive Analysis of Multi-Strategy Memetic Algorithms Incorporating Low-Level Heuristics and Acceptance Mechanisms

Mazlum Özçağdavul[a*]

[a]*Management Information Systems, Ankara Yildirim Beyazit University, Ankara, Turkey*

Abstract

Hyper-heuristics are designed to be reusable, domain-independent methods for addressing complex computational issues. While there are specialized approaches that work well for particular problems, they often require parameter tuning and cannot be transferred to other problems. Memetic Algorithms combine genetic algorithms and local search techniques. The evolutionary interaction of memes allows for the creation of intelligent complexes capable of solving computational problems. Hyper-heuristics are a high-level search technique that operates on a set of low-level heuristics that directly address the solution. They have two main components: heuristic selection and move acceptance mechanisms. The heuristic selection method determines which low-level heuristic to use, while the move acceptance mechanism decides whether to accept or reject the resulting solution. In this study, we explore a multi-meme memetic algorithm as a hyper-heuristic that integrates and manages multiple hyper-heuristics (Modified Choice Function All Moves, Reinforcement Learning with Great Deluge, and Simple Random Only Improvement) and parameters of heuristics (such as mutation rates and search depth). We conducted an empirical study testing two different variations of the proposed hyper-heuristic. The first algorithm uses the Only Improvement acceptance technique for both Reinforcement Learning and Simple Random, and All Moves for Modified Choice Function. In the second version, the Great Deluge method replaces Only Improvement for Reinforcement Learning. The second algorithm's results were the best of all competitors from the CHeSC2011 competition, achieving the fourth-best hyper-heuristic performance.

Keyword

Hyper-Heuristic, Cross-domain Heuristic Search Challenge (CHeSC 2011), Multi-meme memetic algorithm, parameter tuning.

1. INTRODUCTION

The effectiveness of heuristic approaches in addressing practical computer optimisation problems has been demonstrated. Applying them to both new problem domains and new instances of the same problem domain has many disadvantages, though. It is challenging to apply such search strategies to a wide range of

*Corresponding author.

Contact: Mazlum Özçağdavul mozcagdavul@aybu.edu.tr

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computational search problems since there is a lack of guidance about the selection of algorithms and their parameters during the search process (Özcan et al., 2010; Burke et al., 2003). Furthermore, the fact that state-of-the-art heuristics are custom problem-specific approaches that take a long time and extensive domain expertise to design adds to the difficulty of actual procedures (Burke et al., 2009; Ross, 2005)

Burke et al.'s description of metaheuristics as a framework for structuring a search algorithm to locate an ideal or nearly ideal solution for challenging combinatorial optimization problems is found in (Burke and Kendall, 2005). Despite being categorized as universal algorithms, metaheuristics require modification for every issue domain. In addition to single-point based metaheuristics, which employ a single candidate solution, multi-point based metaheuristics employ several candidate solutions to carry out the search process. Among the population-based metaheuristics are genetic programming and genetic algorithms (Burke and Kendall, 2005).

Using a variety of genetic operators, including crossover and mutation to produce new people, genetic algorithms aim to raise the objective value of candidate solutions within a population (Moscato, 1989). Afterwards, created individuals are swapped out for other population members using replacement procedures such as the Steady State Genetic Algorithm (Gendreau and Potvin, 2005). The selection of these operators may have a significant impact on the balance between intensification and diversification.

By adding an extra intensification level to the evolutionary iterations, multipoint-based evolutionary algorithms combined with single-point-based local search heuristics get better results. This is Memetic Algorithms' primary reasoning. It was Muscato who initially proposed memetic algorithms (Moscato, 1989). That being said, Dawkins was the first scientist to coin the term "meme." According to him, a meme is a bit of information that spreads and becomes managed, accepted, acclimated to, and passed to the affected individual (Dawkins, 1976). Furthermore, a genetic algorithm (GA) can be employed to identify the optimal feature selection for learning-based issues by applying a metaheuristic approach (Yılmaz et al., 2020)

There are similarities between this acclimatization process and local search. Thus, hill climbing is often used in memetic algorithms. Stated differently, memetic algorithms combine local search (hill climbers) and genetic algorithms. In order to enhance the population's objective quality, hill climbers are used in a specific lap of each course throughout the development phase. Numerous memetic algorithms have been proposed. Two primary examples of these algorithms are transgenerational memetic algorithms and steady state memetic algorithms. Memetic algorithms are typically customized for a particular problem domain (Neri and Cotta, 2012)

Aims and Objectives

It is challenging to create a custom method for every problem domain since computational problems have a large number of distinct domains. Furthermore, in order to construct a solver, each instance of a domain could call for specialized domain knowledge. The goal is to produce high-level algorithms that are independent of issue domains because of this. Numerous studies have been conducted in the literature, and it has been demonstrated that a number of algorithms including Reinforcement Learning, Choice Function, Simple Random and acceptance mechanisms including Great Deluge, Simulated Annealing, and Only Improvement can yield encouraging outcomes.

This work examines a multi-meme memetic algorithm as a hyper-heuristic that combines and regulates many heuristic selection techniques (Modified Choice Function, Reinforcement Learning, and Simple Random), as well as low-level heuristic parameters (operators), in light of these studies. The primary goal is to create an intelligent algorithm that can select the appropriate heuristic selection technique on its own and adjust the low-level heuristic's parameters for each kind of heuristic selection method.

2. Hyper-heuristics

2.1. Hyper-Heuristics overview and History

A unique, problem-independent method for resolving and optimizing computational issues is the use of hyper-heuristics. In a work published in 2001, Cowling et al. (2001), used the term "hyper-heuristic" for the first time. Hyper-heuristics are defined as general techniques that can be applied to a wide range of problems. Özcan et al. highlight in (Kendall and Mohamad, 2004) that the development of meta-heuristics stems from their application to a variety of problem domains. The neighborhood operators that transform meta-heuristics into problem-specific structures rather than broad frameworks are what make them effective. For this reason, it is inappropriate to use meta-heuristics as a framework independent of problems.

Since hyper-heuristics operate on the space of heuristics rather than the space of solutions, they are often applicable to a wide range of problem domains (Cowling et al., 2001). From a given set of heuristics, a hyper-heuristic technique can intelligently select the most appropriate low-level heuristic to utilize at any given time. Thus, rather than providing a solution for a particular issue instance at hand, we in hyper-heuristics concentrate on adaptively developing organization approaches (Özcan et al., 2010). Hyper-heuristics can be employed in place of meta-heuristics since they don't require as much knowledge and experience with the problem domain. Thus, even a programmer without any prior knowledge of the issue domain can use them (Kaelbling et al., 1996).

This research began with a study published at the start of the 1960s that expressed a concept comparable to the behavior of hyper-heuristics. Fisher and Thompson (1963) contend that a great accomplishment in production scheduling can be achieved by combining scheduling rules, as opposed to utilizing them separately. It is possible to demonstrate that the effective research in hyper-heuristics began with this paper (Fisher and Thompson, 1963).

2.2. Classification of Hyper-heuristic approaches

Two primary groups of hyper-heuristics have been distinguished by Burke et al. (2010). The first is heuristic selection, which comprises methods for picking or selecting low-level heuristics that already exist, and the second is heuristic creation, which generates heuristics from the parts of various low-level heuristics that already exist. The distinction between the constructive and perturbative search paradigms is the next step in this dimension (Burke et al., 2013)

However, there are also two major classes when considering the quantity of solutions used during the search process. These are multi-point-based search, which operates on several solutions, and single solution, which acts on a single-point-based search.

According to Özcan et al. (2013), a hyper-heuristic is a learning algorithm if it makes use of evaluation throughout the search process. They divide the feedback received during learning into two classes: online learning and offline learning, depending on where it came from. Hyperheuristics for online learning involve learning while solving problems. In offline learning, on the other hand, the system learns from a collection of training cases with the intention of generalizing to solve problems in cases that have not yet been observed.

2.3 Multi-meme Memetic Algorithms

From a conceptual standpoint, metaheuristics are utilized as a template for addressing challenging combinatorial optimization issues and aid in the creation of search algorithms. Metaheuristics cannot be categorized as universal techniques since they require knowledge particular to the issue domain. There are two different kinds of metaheuristics based on how many points they use during the search process. These metaheuristics are based on both single and multiple points. Another name for multi-point-based metaheuristics is population-based metaheuristics. Genetic algorithms are one type of potential solution used by population-based metaheuristics (Burke and Kendall, 2005). In an evolutionary cycle, genetic algorithms iteratively improve population quality using a set of genetic operators. The best one may survive, or the old person may be replaced by kids. Crossover, mutation, and local searches are among names for these operators. Local searches are employed to intensify the solution, whereas crossover and mutation heuristics are used to avoid local optima (Gendreau and. Potvin, 2005). The balance between diversification and intensity is a critical decision that impacts an individual's level of fitness.

2.3.1 Multi-meme memetic algorithm taxonomy

Memetic algorithms are divided into two categories by Ong et al. (2006): the process of adaptation, also known as the adaptation type (Hinterding et al., 1997; Eiben et al., 1999) and the adaptation level, which modifies the selection of memes in adaptive memetic algorithms. Another name for adaptation level is meme history knowledge. The taxonomy of adaptive memetic algorithm techniques in use is shown in Figure 1.

Adaptive Type		**Adaptive Level**		
		External	*Local*	*Global*
Static		Basic meta-Lamarckian learning / Simplerandom		
Adaptive	*Qualitative Adaptation*		Randomdescent / Randompermdescent	Tabu-search
	Quantitative Adaptation		Sub-Problem Decomposition/ Greedy	Straightchoice/ Rankedchoice/ Roulettechoice/ Decompchoice/ Biased Roulette Wheel
Self-Adaptive			Multi-memes/ Co-evolution MA	

Figure 1: A Classification of Memes Adaptation in Adaptive Memetic Algorithms (Ong et al., 2006)

This taxonomy divides co-evolution memetic algorithms (Smith et al., 2002; Smith, 2003) and multi-meme memetic algorithms (Krasnogor et al., 2002; (Krasnogor, 2002) into self-adaptive categories since the memes are coded as a component of the population and also go through conventional evolution. Additionally, a multi-meme memetic algorithm or a memetic algorithm is categorized based on the decision-making process based on the degree of adaption. This meme selection procedure is local if it just takes into account a portion of historical knowledge. As a result, this taxonomy places our multi-meme memetic algorithm in the local level and self-adaptive category.

2.4 Heuristic selection methodologies

Many hyper-heuristic approaches that are divided into two categories can be found in the literature. These categories can be divided into two groups: those based on constructive low-level heuristics and those based on perturbative low-level heuristics. Starting with a blank solution, the constructive low-level heuristics construct attempts to gradually develop the entire solution (Özcan et al., 2010). They have had success using them to solve combinatorial optimization issues. Bin-packing (Ross et al., 2003) timetabling (Terashima-Marin et al., 1999; Asumuni et al., 2007; Qu, et al., 2008) production scheduling (Vazquez-Rodriguez et al., 2007) and reducing stock (Terashima-Marin et al., 2005) are a few examples of these issues.

Within the second category, methods utilizing perturbative low-level heuristics attempt to identify a feasible starting solution using some straightforward mechanisms; these can be determined arbitrarily or through the application of a fundamental constructive heuristic. Subsequently, the solution is attempted to be improved by applying shift and swap perturbations (Özcan et al., 2010). In other words, they pick or choose from a group of neighborhoods that can yield better results than the initial, full answer. Perturbative hyper-heuristics are sometimes referred to as improvement hyper-heuristics by Özcan et al. (2005). Improvement hyper-heuristics like this have been effectively used to solve real-world issues including staff scheduling (Cowling et al., 2001), timetabling (Terashima-Marin et al., 2005), and (Burke et al., 2003). In most cases, perturbative hyper-heuristics are used on a single candidate solution. These hyper-heuristics aim to improve a particular answer.

Most search operations in a perturbative hyper-heuristic framework are carried out with a single candidate solution. Iteratively, these hyper-heuristics aim to enhance a given solution by averaging two successive steps: heuristic selection and move acceptance, as seen in Figure 1. Using a chosen heuristic (or heuristics), a candidate solution (St) at a specified time (t) is disturbed into a new solution (or solutions). After this stage is complete, the found solution is either rejected or accepted using a technique known as move acceptance. Until a predetermined halting requirement is satisfied, this procedure is repeated (Özcan et al., 2010). Information related to the problem cannot be transferred from the problem domain to the hyper-heuristic layers due to a domain barrier.

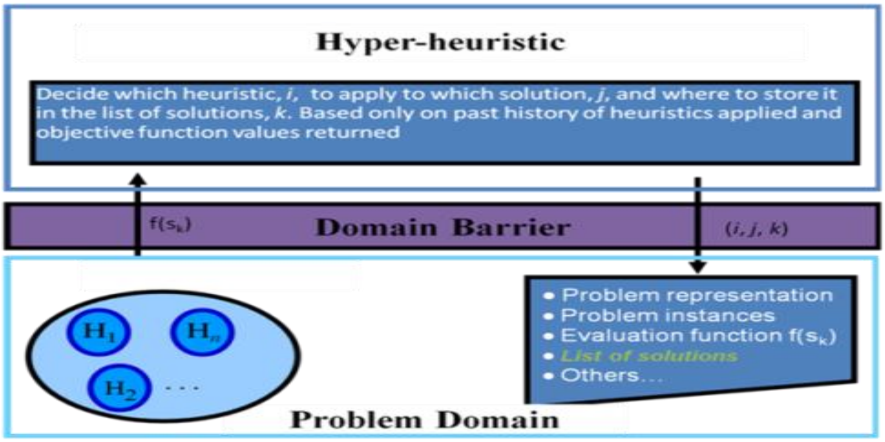

Figure 2. Hyper-heuristic Domain Barrier (Burke et al., 2009)

2.4.1 Simple Random

Simple Random uses a uniform random distribution to randomly select low-level heuristics. This heuristic selection process lacks a learning mechanism because no information is kept (Neri and Cotta, 2012)

2.4.2 Reinforcement Learning

The ability to be applied to a broad range of problem cases, some of which may come from other problem domains with unique features, is one of the primary characteristics of hyperheuristics. For hyper-heuristics to choose the best heuristic during the selection phase, machine learning processes are therefore necessary. One of the current hyper-heuristics for learning is reinforcement learning (Kaelbling, et al., 1996; Sutton and Barto, 1998). The reinforcement learning process chooses an action to raise or reduce a value in exchange for a long-term reward, working in tandem with the environment to change its state (Özcan et al., 2010). For this reason, for any low-level heuristic, a learning hyper-heuristic updates a utility value that is acquired through a predefined system of rewards and punishments.

2.4.3 Modified Choice Function

Low-level heuristics are scored by the Choice Function based on three different variables. The strategy that depends on these scores helps choose the low-level heuristic that will be used. First, the low-level heuristic's prior performance (f1) is noted. The low-level done more recently is given more weight. Equation 1's formula is then used to calculate the value for each heuristic:

$$f_1(h_j) = \sum_n \alpha^{n-1} \frac{I_n(h_j)}{T_n(h_j)} \qquad (1)$$

Equation 1 : Choice Function f1

Where Tn(hj) is the time taken to invoke the low-level heuristic for each precedent appeal n of the low-level heuristic hj, α is a value between 0 and 1 that has a higher influence to late performance, and ln(hj) is the difference in the evaluation function.

Second, f2 value looks for any pairwise relationships between heuristics at the low-level. Equation 2's formula is used to determine f2 values when the hj low-level heuristic is used immediately following hk.

$$f_2(h_k, h_j) = \sum_n \beta^{n-1} \frac{I_n(h_k, h_j)}{T_n(h_k, h_j)} \qquad (2)$$

Equation 2: Choice Function f2

where Tn(hk, hj) is the amount of time needed to call a low-level heuristic for each precedent appeal, and In(hk, hj) is the difference in evaluation function. The low-level heuristic hj's n and β have a stronger effect on late performance when they have a value between 0 and 1.

Thirdly, a value f3 is computed that permits the selection of all low-level heuristics. The time elapsed since the low-level heuristic was selected by the Choice Function is represented by f3.

$$f_3(h_j) = \tau(h_j) \quad (3)$$

Equation 3: Choice Function f3

Following the computation of these three f, a score is assigned independently to each low-level heuristic using the Choice Function F formula, as indicated by Equation 4:

$$F(h_j) = \alpha f_1(h_j) + \beta f_2(h_k, h_j) + \delta f_3(h_j) \quad (4)$$

Equation 4: Choice Function Formula [10]

where f1 and f2 are weighted by α and β, giving an intensified heuristic search process. To provide sufficient diversification, δ weights f3. These variables in the Choice Function were chosen based on the author's prior experimentation knowledge. They also demonstrated how well Choice Function works in conjunction with the All Move acceptance technique.

The weight of f1 and f2, as well as the values of α and β, are taken into account by Drake et al. (2012), in their suggested Modified Choice Function as a single parameter that is employed for intensification. This parameter was given the name ϕ. This value will also be used, similar to the original Choice Function created by Cowling et al. (2001), to assign late performance a greater noteworthy relevance. The weight of f3, the parameter that governs the degree of diversification of the low-level heuristic, will be displayed as δ in the updated version. For each low-level heuristic hj, the Ft score in the Modified Choice Function will be determined using the formula in Equation 5:

$$F_t(h_j) = \phi_t f_1(h_j) + \phi_t f_2(h_k, h_j) + \delta_t f_3(h_j) \quad (5)$$

Equation 5: Modified Choice Function Formula [33]

3. Implementation and Methodology

3.1. HyFlex

A group at The University of Nottingham's Department of Computer Science has created an object-oriented framework known as HyFlex for testing hyper-heuristic algorithms. The purpose of this framework's design and development was to enable the CHeSC2011 Cross-domain Heuristic Challenge. Creating a standard framework for testing and comparing different cross-domain algorithms is one of the key goals of this framework. HyFlex comprises six domains. These fields include the following: traveling salesman issue, bin-packing (one-dimensional) flow shop, personnel scheduling, and maximum satisfiability, or MAX-SAT. Developers can use this framework to test their algorithms' performance directly on past challenge participants (The University of Nottingham, 2021).

3.2 Implementation

Simple Random, Reinforcement Learning, and Modified Choice Function are the three hyper-heuristic selection methods that the memes regulate. They also determine the mutation rate and depth of search for each method. Table 1 shows how memes are organized.

Table 1: Representation of Memes

	memes		Possible values
	0	Hyper-Heuristic Selection Method	{0: SR, 1: RL, 2: M CF}
SR	1	Mutation Rate	{0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8 4: 1}
	2	Depth of Search	{0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8 4: 1}
RL	3	Mutation Rate	{0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8 4: 1}
	4	Depth of Search	{0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8 4: 1}
M CF	5	Mutation Rate	{0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8 4: 1}
	6	Depth of Search	{0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8 4: 1}

A framework called HyFlex (The University of Nottingham, 2021) is employed. Although it offers nine distinct domains, only the six that were utilized at CHeSC2011 were actually used. HyFlex offers a partition between domains and algorithms. The individuals' fitness values and the kinds of low-level heuristics are the only pieces of information that can go between levels. Only the low-level heuristic's type—whether it's a mutational, crossover, or local search—is disclosed. Both mutation and ruin and recreate heuristics are included in mutational heuristics. The number of low-level heuristics of each kind varies between domains (The University of Nottingham, 2021).

3.2 Algorithms

Algorithm 1: Simple Random - OI + Reinforcement Learning – OI + Modified Choice Function AM

Create a population of populationSize with random individual

Initialise all individuals

Create a two dimmentional array *memeplex* with size of populationSize by seven

For *i*=0 to *populationSize* **do**

    // Randomly fill heuristic selection method (0: SR, 1: RL, 2: M CF)

    Fill *memeplex* for each individual with random values from heuristic selection methods

    // Randomly fill *mutation_rate* and *depth_of_search* (0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8, 4: 1)

    Fill *memeplex* for each individual with random values from heuristic selection methods

End For

While termination criterion is not met **do**

    Parent1 ← Select Parent (Population, tour-size)

    //Select a different parent than Parent1

    Parent2 ← Select Parent (Population, tour-size)

    offspring ← Apply a random a crossover operator (Parent1, Parent2)

    bestParentID ← set the parents ID who has best function value

    // Inherit best parents memes to offspring

    offspring memes ← bestParent's memes

    If *memeplex[bestParentID][0]== 0:*

        Apply ***Simple Random Only Improvement*** Heuristic Selection Method

    Else if *memeplex[bestParentID][0]== 1:*

        Apply ***Reinforcement Learning Only Improvement*** Heuristic Selection Method

    Else if *memeplex[bestParentID][0]== 2:*

        Apply ***Modified Choice Function*** Heuristic Selection Method

    end if

    Replacement: Replace the worst individual by offspring

end while

The first algorithm initializes each individual after generating a random population of size ten. After each person has been initialized, a two-dimensional array known as a memeplex is produced. The mutation rate, search depth, and hyper-heuristic that will be applied to each individual are predetermined. Next, a parent who has picked a tournament with a two-tour option is selected. After the first parent, a second parent is selected. With parent 1 and parent 2, a random crossover low-level heuristic is used, and an offspring is produced. The child inherits the memes of the parent who is the fittest. The child is randomly assigned to the meme of one parent if both parents have the same fitness score.

The Simple Random Only Improvement (SR-OI) hyper-heuristic is selected if the hyper-heuristic selection meme is zero. In case number one and number two are selected, the Modified Choice Function All Move and Reinforcement Learning Only Improvement (RL-OI) hyper-heuristic, respectively. The heuristics do not exchange any information.

If there is any improvement, the offspring in the SR-IO is subjected to a randomly chosen low-level heuristic for mutations, and if not, a randomly chosen local search is used. If there is no improvement, the low-level heuristics for local search and/or mutation are not applied to the progeny. Then the child takes the position of the worst person. Following all procedures, each meme may undergo a mutation at a rate of 0.2 innovation to achieve meme diversification. Every low-heuristic (LLH) in the RL-OI has a score, and the LLH with the highest score is selected. Once more, only enhanced solutions are approved.

Algorithm 2: Simple Random - OI + Reinforcement Learning – GD + Modified Choice Function AM

Create a population of populationSize with random individual

Initialise all individuals

Create a two dimmentional array *memeplex* with size of populationSize by seven

For *i*=0 to *populationSize* **do** // Randomly fill heuristic selection method (0: SR, 1: RL, 2: M CF)

    Fill *memeplex* for each individual with random values from heuristic selection methods

    // Randomly fill *mutation_rate* and *depth_of_search* (0: 0.2, 1: 0.4, 2: 0.6, 3: 0.8, 4: 1)

    Fill *memeplex* for each individual with random values from heuristic selection methods

End For

While termination criterion is not met **do**

    Parent1 ← Select Parent (Population, tour-size) //Select a different parent than Parent1

    Parent2 ← Select Parent (Population, tour-size)

    offspring ← Apply a random a crossover operator (Parent1, Parent2)

    bestParentID ← set the parents ID who has best function value // Inherit best parents memes to offspring

    offspring memes ← bestParent's memes

    If *memeplex[bestParentID][0]== 0:*

        Apply ***Simple Random Only Improvement*** Heuristic Selection Method

    Else if *memeplex[bestParentID][0]== 1:*

        Apply ***Reinforcement Learning Great Deluge*** Heuristic Selection Method

    Else if *memeplex[bestParentID][0]== 2:*

        Apply ***Modified Choice Function*** Heuristic Selection Method

end if

Replacement: Replace the worst individual by offspring

end while

Every setting in the second algorithm was the same as in the first, with the exception that the Great Deluge was used as the acceptance criterion for reinforcement learning. The hyper-heuristics were still not exchanging information with each other.

4. Results and Analysis

The first Cross-domain Heuristic Search Challenge (CHeSC 2011) was organized by the Automated Scheduling Optimisation & Planning Group, or ASAP, at The School of Computer Science at The University of Nottingham. The purpose of the challenge was to bring together experts from various fields, including computer science, operational research, and artificial intelligence, to evaluate their advanced methodologies. Every issue domain has a few low-level heuristics available. These particular low-level heuristics should be managed by the high-level algorithm in order to tackle various problems from various fields. Each domain has its own set of low-level heuristics, but the hyper-heuristic, the governing high-level algorithm, must be distinct. Stated differently, more than one low-level heuristic from a separate issue domain should be controlled by the same algorithm.

Additionally, ASAP offers a common software framework (HyFlex) designed in Java to handle a variety of combinatorial optimization issues in diverse fields. HyFlex offers a number of techniques for producing and assessing solutions. In addition, the hyper-heuristics can apply move operators, hill-climbers (local searches), ruin and recreate heuristics, and mutation operators to the solutions.

4.1. Formula One Scoring System

Every hyper-heuristic in the CHeSC 2011 has completed 31 runs on five distinct examples from each of the six problems. Next, each problem instance's median score was taken into account. The Formula One scoring methodology is then used to order these scores. The top hyper-heuristic receives 10 points for each instance, followed by eight for the second, six for the third, and five, four, three, two, and one points for the other hyper-heuristics. From the ninth-best score, every other score is zero (The University of Nottingham, 2021).

4.2 Results of the Algorithms

The competition's ranking mechanism assigns a number to each hyper-heuristic based on its relative performance. Three distinct algorithms have been created and examined in this study. An Intel i5 fifth generation 2.7GHZ CPU with four cores and a 3MB L3 cache was used for all tests. To be fair with the 600 seconds of competition running time, the benchmarking tool that ASAP gave offers 464 seconds for each run.

Eleven runs were scheduled for each method, across six distinct domains with five distinct examples each. The entire algorithm test took 42.53 hours with these parameters.

4.2.1 Results of the First Algorithm

The first multi-meme memetic algorithm combines low-level heuristic values for mutation rates and search parameter depth with hyper-heuristic approaches such as Simple Random Only Improvement, Reinforcement Learning Only Improvement, and Modified Choice Function All Moves. As in (Özcan et al., 2013). the population size is ten, and the initialization of each member of the population is done at random. This population also has a memeplex allocated to it, which governs the attributes of each member, including the hyper-heuristic and its parameters.

Following eleven runs, the median values are determined. The findings are then compared to the performance of prior competitors using the Formula One scoring system, which is available on the CHeSC 2011 website.

Figures 3 and 4 illustrate how the created algorithm failed to receive a single point in either Bin Packing or MAX-SAT. placed sixth with twelve points in Flow Shop, eighth with ten points in TSP, ninth with six points in VRP, and twelfth with three points in personnel scheduling. Figures 5, 6, 7, and 8 show the rankings for Flow Shop, TSP, VRP, and Personnel Scheduling, respectively.

When compared to other competitors, this algorithm's overall performance is appalling. With only thirty-one points altogether, this algorithm finished the competition in thirteenth place. This is depicted in figure 9.

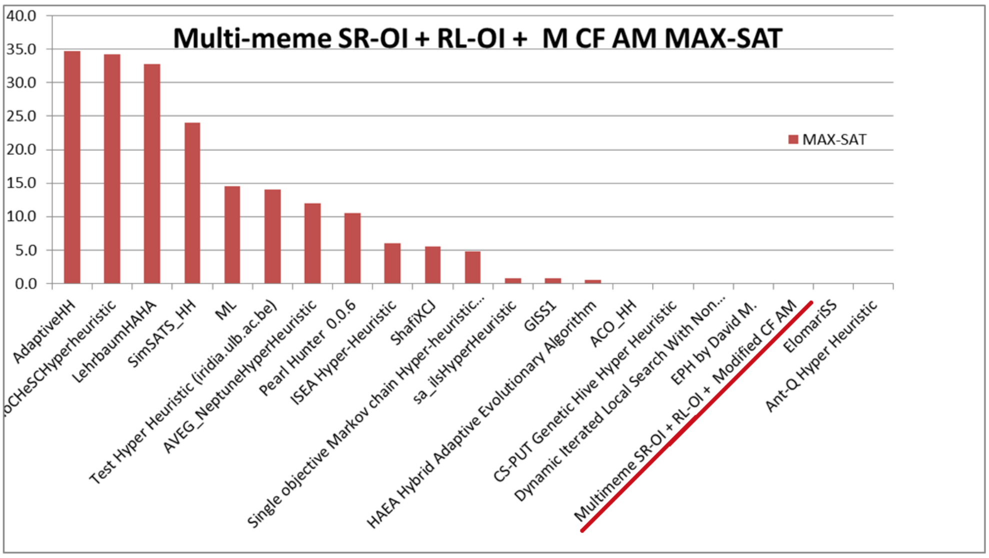

Figure 3: Multi-meme SR OI RL OI M CF AM MAX-SAT Results

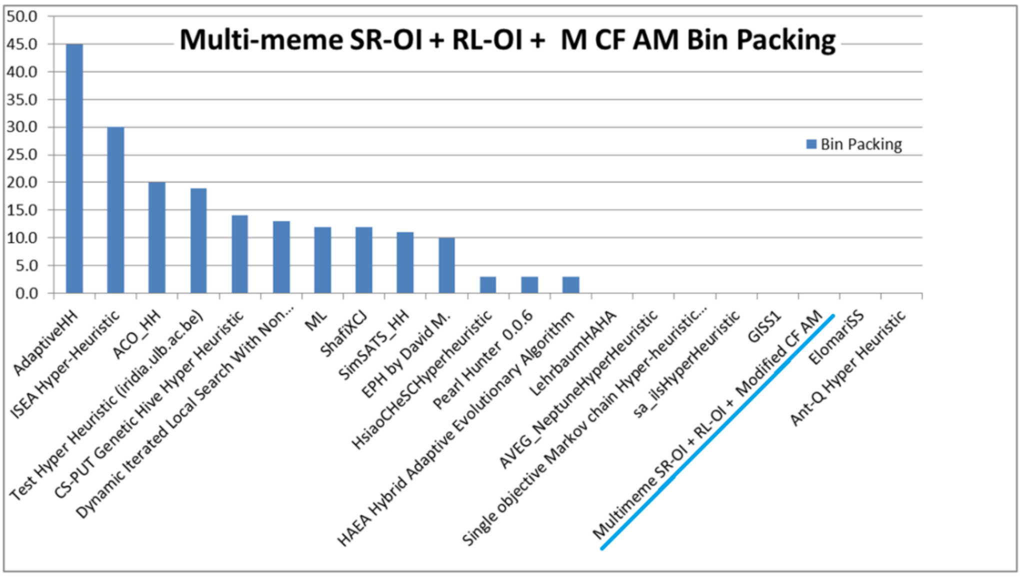

Figure 4: Multi-meme SR OI RL OI M CF AM Bin Packing Results

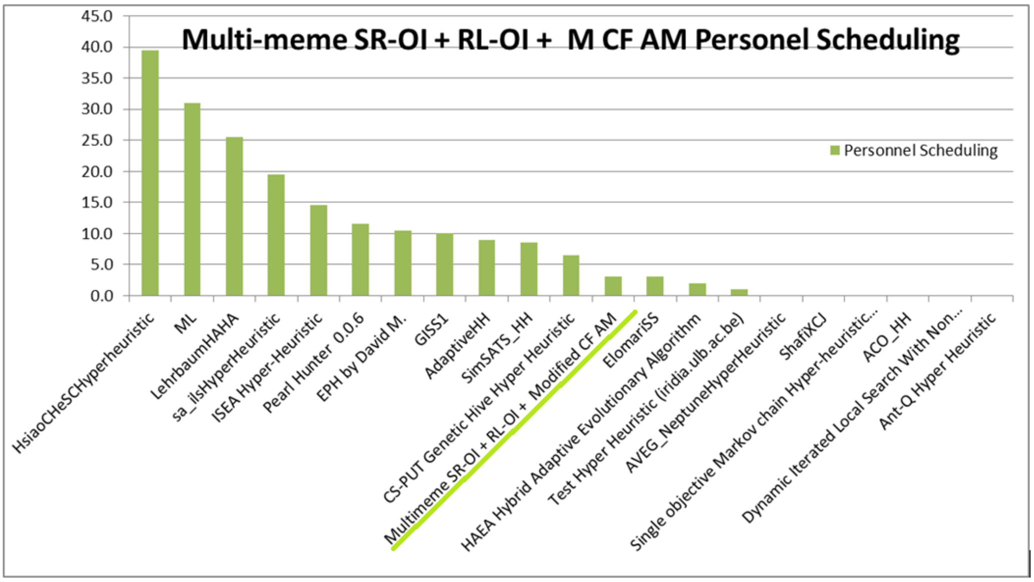

Figure 5: Multi-meme SR OI RL OI M CF AM Personnel Scheduling Results

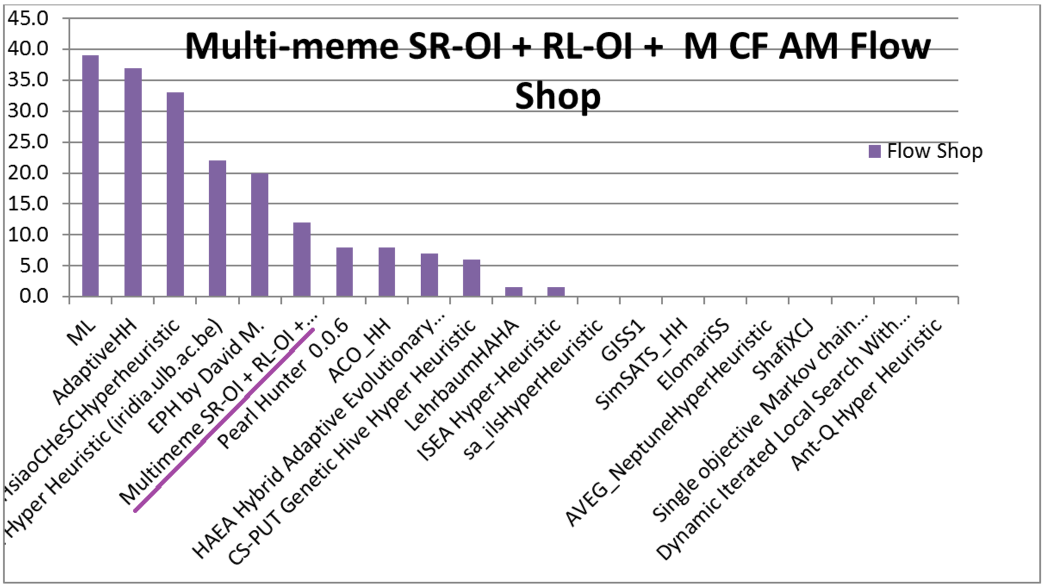

Figure 6: Multi-meme SR OI RL OI M CF AM Flow Shop Results

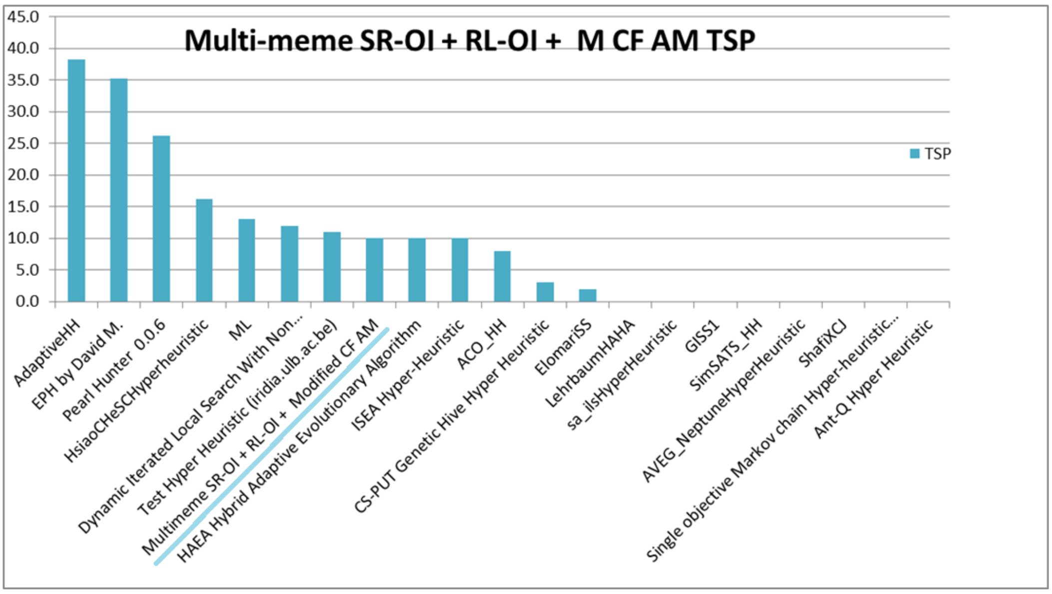

Figure 7: Multi-meme SR OI RL OI M CF AM TSP Results

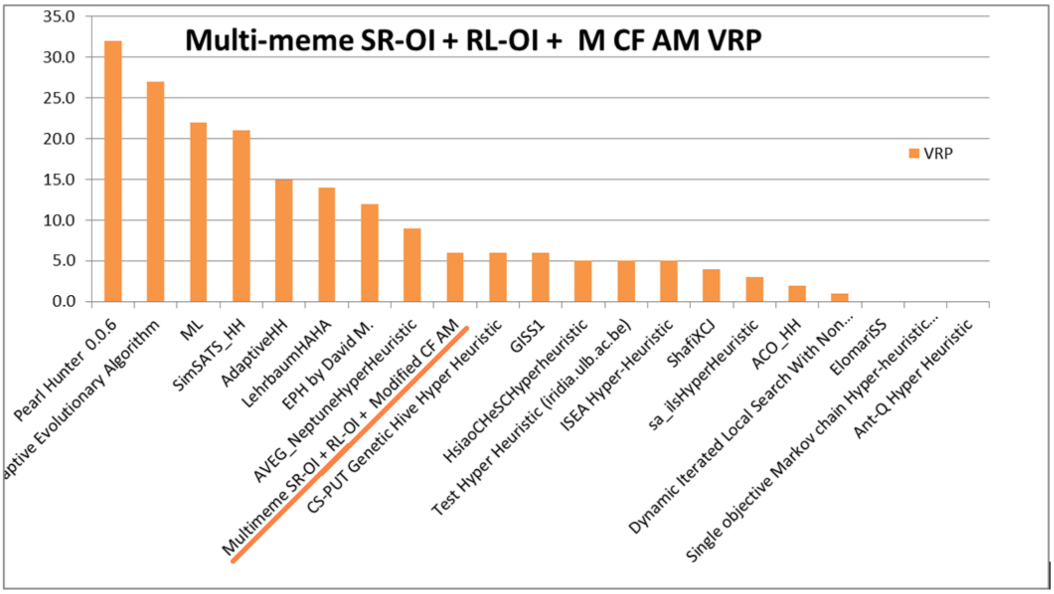

Figure 8: Multi-meme SR OI RL OI M CF AM VRP Results

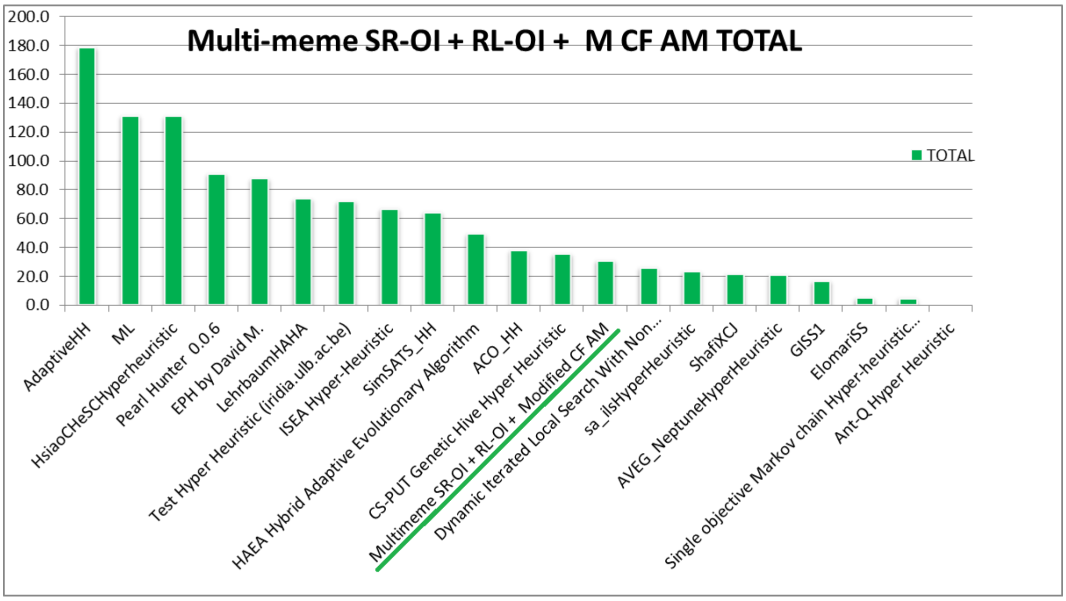

Figure 9: Multi-meme SR OI RL OI M CF AM Overall Results

Co-evolution of memes was managed using the basic inheritance mechanism in the first algorithm. Reward Learning Only Improvement was the hyper-heuristic that was most frequently selected. The least chosen hyper-heuristic was the Simple Random Only improvement one. The mutation rate and search depth that the mechanism has mostly chosen are 0.2 and 0.4, respectively.

Table 2 : Detailed scores for Hyper-Heuristic 1 (Algorithm 1) with compare to other competitors

	Multimeme SR-OI + RL-OI + MCF With NO information Sharing between Heuristics							
Rank	**Heuristic Name**	**MAX-SAT**	**Bin Packing**	**Personnel Scheduling**	**Flow Shop**	**TSP**	**VRP**	**TOTAL**
1	AdaptiveHH	34.8	45.0	9.0	37.0	38.3	15.0	179.0
2	ML	14.5	12.0	31.0	39.0	13.0	22.0	131.5
3	HsiaoCHeSCHyperheuristic	34.3	3.0	39.5	33.0	16.3	5.0	131.0
4	Pearl Hunter 0.0.6	10.5	3.0	11.5	8.0	26.3	32.0	**91.3**
5	EPH by David M.	0.0	10.0	10.5	20.0	35.3	12.0	**87.8**
6	LehrbaumHAHA	32.8	0.0	25.5	1.5	0.0	14.0	**73.8**
7	Test Hyper Heuristic (iridia.ulb.ac.be)	14.0	19.0	1.0	22.0	11.0	5.0	**72.0**
8	ISEA Hyper-Heuristic	6.0	30.0	14.5	1.5	10.0	5.0	**67.0**
9	SimSATS_HH	24.0	11.0	8.5	0.0	0.0	21.0	**64.5**
10	HAEA Hybrid Adaptive Evolutionary Algorithm	0.5	3.0	2.0	7.0	10.0	27.0	**49.5**
11	ACO_HH	0.0	20.0	0.0	8.0	8.0	2.0	**38.0**
12	CS-PUT Genetic Hive Hyper Heuristic	0.0	14.0	6.5	6.0	3.0	6.0	**35.5**
13	**Multimeme SR-OI + RL-OI + Modified CF AM**	**0.0**	**0.0**	**3.0**	**12.0**	**10.0**	**6.0**	**31.0**
14	Dynamic Iterated Local Search With Non Improvement Bias	0.0	13.0	0.0	0.0	12.0	1.0	**26.0**
15	sa_ilsHyperHeuristic	0.8	0.0	19.5	0.0	0.0	3.0	**23.3**
16	ShafiXCJ	5.5	12.0	0.0	0.0	0.0	4.0	**21.5**
17	AVEG_NeptuneHyperHeuristic	12.0	0.0	0.0	0.0	0.0	9.0	**21.0**
	Colours representation : First Second Third							

4.2.2 The Results of the Second Algorithm

With the exception of the Reinforcement Learning acceptance criterion, every setting in the second algorithm was unchanged. The Great Deluge mechanism is employed rather than settling for only an improved solution. The hyper-heuristics were still not exchanging information with each other. Memes have been passed down through the application of the Simple Inheritance Mechanism. Put another way, the child has inherited the memes of the parent who is the fittest.

Numerous researchers have demonstrated the effectiveness of the Great Deluge acceptance mechanism in the literature (Özcan et al., 2010). This investigation demonstrated the effectiveness of this technique once more. The updated algorithm became the best hyper-heuristic in this field with a score of 37.5 in MAX-SAT. Not only has it improved, but it has also received scores of 10, 14, 5, 20, and 16 in bin packing, PS, TSP, and VRP, in that order. But in Flow Shop, the score dropped to six.

The improved algorithm now has an overall score of 104.1, and the hyper-heuristic has moved up to fourth place. The results are shown in Table 3.

The percentage of hyper-heuristic selection was similarly impacted by this modification. While Reinforcement Learning received the highest selection rate (45.33%) in the first hyper-heuristic, it received a higher percentage (51.44%) in the second hyper-heuristic.

Table 3: Detailed scores for Hyper-Heuristic 2 (Algorithm 2) with compare to other competitors

	Multi-meme SR-OI + RL-GD + Modified CF With NO Information Sharing between Heuristics							
Rank	**Multimeme SR-OI + RL-GD + Improved CF**	**MAX-SAT**	**Bin Packing**	**Personnel Scheduling**	**Flow Shop**	**TSP**	**VRP**	**Total**
1	AdaptiveHH	**29.9**	**43.0**	9.0	**36.0**	**36.3**	14.0	**168.2**
2	HsiaoCHeSCHyperheuristic	**29.9**	3.0	**37.5**	**33.0**	16.3	5.0	**124.7**
3	ML	10.5	10.0	**29.5**	**39.0**	12.0	20.0	**121.0**
4	**Multimeme SR-OI + RL-GD + Modified CF**	**37.6**	**10.0**	**14.5**	**6.0**	**20.0**	**16.0**	**104.1**
5	Pearl Hunter 0.0.6	7.5	3.0	11.5	8.0	**25.3**	**30.0**	**85.3**
6	EPH by David M.	0.0	9.0	9.5	20.0	**33.3**	12.0	**83.8**
7	Test Hyper Heuristic (iridia.ulb.ac.be)	11.5	19.0	1.0	22.0	11.0	5.0	**69.5**
8	LehrbaumHAHA	26.9	0.0	**24.0**	2.8	0.0	14.0	**67.8**
9	ISEA Hyper-Heuristic	3.5	**29.0**	14.5	3.5	9.0	4.0	**63.5**
10	SimSATS_HH	19.9	11.0	7.5	0.0	0.0	**21.0**	**59.4**

11	HAEA Hybrid Adaptive Evolutionary Algorithm	0.0	2.0	2.0	9.3	10.0	**26.0**	**49.3**
12	ACO_HH	0.0	**20.0**	0.0	8.3	7.0	1.0	**36.3**
13	CS-PUT Genetic Hive Hyper Heuristic	0.0	13.0	6.5	7.0	2.0	6.0	**34.5**
14	Dynamic Iterated Local Search With Non Improvement Bias	0.0	12.0	0.0	0.0	11.0	0.0	**23.0**
15	AVEG_NeptuneHyperHeuristic	10.5	0.0	0.0	0.0	0.0	9.0	**19.5**
16	sa_ilsHyperHeuristic	0.3	0.0	16.0	0.0	0.0	3.0	**19.3**
17	ShafiXCJ	3.5	11.0	0.0	0.0	0.0	4.0	**18.5**
	Colours representation :		**First**	**Second**	**Third**			

5. Conclusion

Automated techniques that can be used to a wide range of problem situations from various areas are provided by hyper-heuristics. Using instances of various instances of different domains from HyFlex, this study examined three separate hyper-heuristics that incorporate three different acceptance mechanisms while manipulating the mutation rate and depth of search parameters of various low-level heuristics. Two distinct hyper-heuristic combinations were examined. Thirty distinct cases originating from six distinct domains were employed. A multi-meme memetic strategy was employed to regulate the attributes of each individual, including the depth of search, mutation rate, and hyper-heuristic selection procedure. A mutation with a probability of 0.2 is applied to every meme in order to boost diversification. These two algorithms' outputs were carefully examined and contrasted with the outcomes of previous CHeSC2011 participants.

The results have shown that, second algorithm outperformed not only the first implemented algorithm, but also lots of competitors of CHeSC2011.

6. Further Studies

It was not possible to evaluate various combinations of heuristic selection techniques and acceptance mechanisms because the testing of the suggested algorithms required over 200 hours. Memes were employed in this study to choose hyper-heuristic selection techniques, with the parameters being restricted to search depth and mutation rate.

Different memes can be used to regulate the acceptance mechanisms and heuristic selection techniques in future research. This will broaden the range of mechanisms that can be used to various problem scenarios. Put differently, this will enable the hyper-heuristic to combine the Simple Random heuristic selection approach with several acceptance methods, such as All Moves, Only and Equally Improvement, Great Deluge, Simulated

Annealing, and so on. As a result, several acceptance mechanisms may be quickly implemented for every heuristic selection technique.

References

A. E. Eiben, R. Hinterding, and Z. Michalewicz, "Parameter control in evolutionary algorithm," IEEE Trans. Evol. Comput., vol. 3, pp. 124–141, Jul. 1999.

Asmuni, H., Burke, E. K., Garibaldi, J. M., & McCollum, B. (2007). A novel fuzzy approach to evaluate the quality of examination timetabling. In Proceedings of the 6th International Conference on the Practice and Theory of Automated Timetabling (PATAT'06), LNCS, 3867, (pp. 327-346), Springer.

Burke EK, Hyde M, Kendall G, Ochoa G, Özcan E and Woodward J (2009), Exploring hyper-heuristic methodologies with genetic programming. In: Mumford C and Jain L (eds). Computational Intelligence: Collaboration, Fusion and Emergence, Intelligent Systems Reference Library. Springer: New York, pp 177–201.

Burke, E., Kendall, G., & Soubeiga, E. (2003b), A tabu-search hyper-heuristic for timetabling and rostering. Journal of Heuristics, 9, 451-470, Kluwer Academic Publishers

Cowling, P., Kendall, G., & Soubeiga, E. (2001a). A hyperheuristic approach to scheduling a sales summit. In Proceedings of the 3rd International Conference on Practice and Theory of Automated Timetabling (PATAT'00), (pp. 176-190), Springer-Verlag.

E. Burke and G. Kendall, Search methodologies: introductory tutorials in optimization and decision support techniques. Springer Science+ Business Media, 2005.

E. Burke and G. Kendall, Search methodologies: introductory tutorials in optimization and decision support techniques. Springer Science+ Business Media, 2005.

E. K. Burke, M. Gendreau, M. Hyde, G. Kendall, G. Ochoa, E. ¨Ozcan, and R. Qu, "Hyper-heuristics: A survey of the state of the art," Journal of the Operational Research Society, 2013.

E. K. Burke, M. Hyde, G. Kendall, G. Ochoa, E. Ozcan, and J. R. ¨ Woodward, "A classification of hyper-heuristic approaches," in Handbook of Metaheuristics, ser. International Series in Operations Research & Management Science, M. Gendreau and J.-Y. Potvin, Eds. Springer US, 2010, vol. 146, pp. 449–468.

E. Özcan, M. Misir , G. Ochoa, E. K. Burke, A Reinforcement Learning - Great-Deluge Hyper-heuristic for Examination Timetabling, International Journal of Applied Metaheuristic Computing, 1(1), pp. 39-59, 2010.

E. Ozcan, S. Asta, and C. Altıntas, "Memetic algorithms for cross domain heuristic search," in Proceedings of the 13th Annual Workshop on Computational Intelligence (UKCI 2013), Y. Jin and S. A. Thomas, Eds. Surrey, UK: IEEE Press, 2013, pp. 175–182.

F. Neri and C. Cotta, "Memetic algorithms and memeting computing optimization: A literature review," Swarm and Evolutionary Computation, vol. 2, pp. 1–14, 2012.

Fisher H, Thompson GL (1963) Probabilistic learning combination of local job-shop scheduling rules. In: Muth JF, Thompson GL (eds) Industrial Scheduling, Prentice-Hall, Inc, New Jersey, pp 225-251.

J. E. Smith et al., "Co-evolution of memetic algorithms: Initial investigations," in Parallel Problem Solving From Nature—PPSN VII, G. Guervos et al., Eds. Berlin, Germany: Springer, 2002, vol. 2439, Lecture Notes in Computer Science, pp. 537–548.

J. E. Smith, "Co-evolving memetic algorithms: A learning approach to robust scalable optimization," in IEEE Congress on Evolutionary Computation. Piscataway, NJ: IEEE Press, 2003, vol. 1, pp. 498–505.

John H. Drake, Ender Özcan and Edmund K. Burke An Improved Choice Function Heuristic Selection for Cross Domain Heuristic Search The 12th International Conference on Parallel Problem Solving From Nature (PPSN 2012), Lecture Notes in Computer Science, Volume 7492, pp. 307-316, 2012.

Kaelbling, L. P., Littman, M., & Moore, A. (1996), Reinforcement learning: a survey. Journal of Artificial Intelligence Research, 4, (pp. 237-285).

Kendall G and Mohamad M (2004a), Channel assignment in cellular communication using a great deluge hyper-heuristic. In: Proceedings of the 2004 IEEE International Conference on Network (ICON2004). IEEE: Singapore, pp 769–773.

M. Gendreau and J.-Y. Potvin, "Metaheuristics in combinatorial optimization," Annals of Operations Research, vol. 140, no. 1, pp. 189–213, 2005.

M. Gendreau and J.-Y. Potvin, "Metaheuristics in combinatorial optimization," Annals of Operations Research, vol. 140, no. 1, pp. 189–213, 2005.

N. Krasnogor, "Studies on the Theory and Design Space of Memetic Algorithms," Ph.D., Faculty of Comput., Math., and Eng., Univ. of the West of England, Bristol, U.K., 2002.

N. Krasnogor, B. Blackburne, J. D. Hirst, and E. K. N. Burke, "Multimeme algorithms for the structure prediction and structure comparison of proteins," in Parallel Problem Solving From Nature, 2002, Lecture Notes in Computer Science.

Ozcan, E., Bilgin, B., Korkmaz, E.: Hill Climbers and Mutational Heuristics in Hyperheuristics. In: PPSN IX. pp. 202–211, 2010.

P. Moscato, “On evolution, search, optimization, genetic algorithms and martial arts: Towards memetic algorithms,” Caltech concurrent computation program, C3P Report, vol. 826, p. 1989, 1989.

Qu, R., Burke, E. K., & McCollum, B. (2008a). Adaptive automated construction of hybrid heuristics for exam timetabling and graph colouring problems. European Journal of Operational Research, 198(2), 392-404.

R. Dawkins, The Selfish Gene. New York City: Oxford University Press, 1976.

R. Hinterding, Z. Michalewicz, and A. E. Eiben, “Adaptation in Evolutionary Computation: A Survey,” in IEEE International Conference on Evolutionary Computation. Piscataway, NJ: IEEE Press, Apr. 1997, pp. 65–69.

Ross P (2005). Hyper-heuristics. In: Burke EK and Kendall G, Search Methodologies: Introductory Tutorials in Optimization and Decision Support Techniques. chap 17, Springer: Berlin, pp 529–556.

Ross, P., Hart, E., Marin-Blazquez, J., & Schulenberg, S. (2003). Learning a procedure that can solve hard bin-packing problems: a new GA-based approach to hyperheuristics. Proceedings of Genetic and Evolutionary Computation Conference (GECCO'2003), (pp. 1295-1306).

Sutton, R. S., & Barto, A. G. (1998). Reinforcement learning: an introduction. The MIT Press.

Terashima-Marin, H., Moran-Saavedra, A., & Ross, P. (2005). Forming hyper-heuristics with GAs when solving 2D-regular cutting stock problems. In Proceedings of the 2005 IEEE Congress on Evolutionary Computation, 2, (pp. 1104-1110), IEEE Press.

Terashima-Marin, H., Ross, P., & Valenzuela-Rendon, M. (1999). Evolution of constraint satisfaction strategies in examination timetabling. In Proceedings of the Genetic and Evolutionary Computation Conference (GECCO'99), (pp 635-642).

The University of Nottingham CHeSC2011 website. Retrieved April ,21, 2021 from: http://www.asap.cs.nott.ac.uk/external/chesc2011/hyflex_description.html

Vazquez-Rodriguez, J.A., Petrovic, S. & Salhi, A. (2007). A combined meta-heuristic with hyper-heuristic approach to the scheduling of the hybrid flow shop with sequence dependent setup times and uniform machines. In P. Baptiste, G. Kendall, A. Munier-Kordon & F. Sourd (Ed.), the 3rd Multi-disciplinary International Scheduling Conference: Theory and Applications (MISTA’07), (pp. 506-513), Paris, France.

Yew-Soon Ong, Meng-Hiot Lim, Ning Zhu, and Kok-Wai Wong, “Classification of Adaptive Memetic Algorithms: A Comparative Study” IEEE Transactions on Systems, Man, and Cybernetics—Part B: Cybernetics, vol. 36, pp. 141-152 No. 1, February 2006

Yilmaz, A. A., Guzel, M. S., Bostanci, E., & Askerzade, I. (2020). A novel action recognition framework based on deep-learning and genetic algorithms. *IEEE Access*, *8*, 100631-100644.

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RESEARCH ARTICLE

Exploring Production Management Trends through a Bibliometric Analysis in the Era of Green Transformation

Bünyamin Daldıran[a*]

[a]*Production Management and Marketing, Erciyes University, Kayseri, Turkey*

Abstract

A comprehensive bibliometric analysis is used in this study to investigate the emerging trends in production management concerning green transformation. A massive literature review was conducted using the Web of Science and various bibliometric indicators, namely SWOT analysis, co-citation of cited authors, bibliographic coupling of authors, citation of authors, co-occurrence of author keywords, co-authorship of countries and co-authorship of authors. The analysis employed VOS viewer software which is a bibliometric network mapping tool.

Such findings shed light on significant areas and research clusters within production management field particularly regarding sustainability and eco-friendly orientation. Co-citation and bibliographic coupling analyses disclose that seminal works by critical authors contributed to the dialogue on green transformation in production management. Besides, the examination of the author's keywords revealed the prevailing themes as well as current topics being researched passionately today through scholarly papers. The collaborative networks among researchers were shown by a country-wise distribution across continents indicating that research activities are not restricted to particular countries. The process of SWOT analysis gave a framework to evaluate the strengths, weaknesses, opportunities and threats related to the inclusion of sustainability in production management.

This research provides insights into how organizations are changing their production management systems in response to environmental sustainability concerns. In addition, it is helpful for both researchers and practitioners who want to ensure that their production management strategies align with green transformation goals. Future research directions are suggested to address identified gaps and to investigate further the dynamic interplay between production management and sustainable development.

Keyword

Production Management, Green Transformation, Sustainable Production, Eco-friendly Technologies, Environmental Management

*Corresponding author.

Contact: Bünyamin Daldıran bunyamindaldiran@erciyes.edu.tr

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1. INTRODUCTION

Production management is paramount in modern business, with a strong emphasis on minimizing costs and enhancing product quality through the efficient and effective utilization of resources. (Stevenson, 2015). This area involves planning, organizing, directing, and controlling the production processes for both goods and services. (Heizer & Render, 2014). Intercalarily, production management has continuously evolved since the Industrial Revolution, emerging as an indispensable component of contemporary business strategies. With the rise of globalization, digitalization, and heightened competition, it has become imperative for companies to cultivate effective production management practices. (Slack, Chambers, & Johnston, 2010). Within this framework, production management not only enhances the efficiency of production processes but also aids businesses in attaining competitive advantages and fostering sustainable growth.

Currently, the effective implementation of production management practices significantly influences a business's long-term competitive strength and market position. Efficient production management also enhances customer satisfaction and increases market share. By continuously improving production processes and adopting innovative practices, businesses can adapt to changing market conditions, achieving operational excellence and strategic flexibility.

1.1 Green Transformation and Sustainability

Hart (1997) states that increasing environmental concerns and the push for sustainability have led to significant changes in production management practices. Linton, Klassen, and Jayaraman (2007) use the term “green transformation” to describe the shift from traditional production systems to environmentally friendly and sustainable ones. Green transformation avails the guidelines of sustainable manufacturing and minimizes its adverse influence on the environment. Such tips may involve taking up renewable sources of energy, use of eco-friendly raw materials as well as minimizing waste or recycling.

Some benefits of ecology and what may happen in terms of business competitiveness are identified as the results of green transformation. After that, there has been a trend where businesses are striving to incorporate green manufacturing practices (Fu et al., 2018). Furthermore, governments or international organizations have environmental policies and incentives that can aid in the process (Fu et al., 2018). A case in point is the European Union’s Green Deal which encourages all companies operating within its member states to go green.

1.2 Objectives and Research Questions

This research aims to examine recent trends in production management and impact of greening on this sphere. Using bibliometric analysis, the research will assess scientific literature relevant to production management and green transformation with respect to key trends, gaps in knowledge, and future areas for investigation. The study seeks to answer the following key questions:

- What are the main trends in the field of production management?
- What are the effects of green transformation on production management?
- How are sustainable production management strategies developing?
- Which topics require further research in this area?

In answering these questions, the study will conduct a detailed analysis of the existing literature, proposing new research areas based on the findings. Thus, the study will contribute to the knowledge base in the fields of production management and green transformation.

2. Literature Review

2.1 Strategic Importance of Production Management

The effective implementation of production management is crucial for organizations to gain competitive advantages. Competitive advantage refers to a company's ability to outperform its rivals, through cost leadership, differentiation, or focus strategies (Porter, 1985).

Effective production management helps businesses reduce production costs, gaining a competitive price advantage (Heizer & Render, 2014). For example, Wal-Mart has emerged as a cost leader in the retail sector through its low-cost production and supply chain management strategies (Fishman, 2006). Focusing on innovation and quality in production processes helps businesses achieve differentiation in their products and services. This strategy aims to gain a competitive advantage by offering unique and high-quality products to customers (Porter, 1985). Apple successfully applies this strategy through innovative product designs and a superior quality approach (Kahney, 2008). Specializing in a specific market segment or product helps businesses gain a competitive advantage. This strategy aims to offer tailored solutions to a narrow target audience and become a leader in that area (Porter, 1985).

2.2 Sustainable Growth and Production Management

Sustainable growth refers to a business's ability to ensure long-term performance and environmental, social, and economic sustainability. Production management plays a critical role in achieving this goal. Sustainable growth pertains to an organization's capacity to ensure enduring performance while balancing environmental, social, and economic sustainability. Production management is pivotal in attaining sustainable growth by implementing practices that align profitability with environmental stewardship and social responsibility. These practices involve optimizing resource utilization, minimizing waste, and incorporating eco-friendly technologies, fostering business success and societal welfare (Hart, 1997). Sustainable production practices involve resource efficiency, waste management, and environmentally friendly technologies (Hart, 1997).

2.2.1 Resource Efficiency: One of the main pillars of sustainable production is the judicious utilization of natural resources to minimize waste and environmental impact (Hart, 1997). Improved resource efficiency not only lowers costs but also reduces the ecological footprint of production activities (Hart, 1997). General Electric's Ecomagination program for example is one such attempt at improving resource productivity while ensuring environmental sustainability. This campaign has led to inventions aimed at cutting down energy consumption and emissions that are beneficial both to the environment and also to the economic performance of the company (GE, 2005).

Strategies for effective resource efficiency include:

2.2.1.a Energy Efficiency: Introduction of energy-saving technologies/practices in production processes to reduce energy use and associated cost.

2.2.1.b Water Conservation: Application of water efficient technologies/practices that will enable reduction of water use and wastewater generation.

2.2.1.c Material Optimization: Reducing material loss through better design, well adapted processes and using recycled or renewable materials.

2.2.2 Waste Management: Reducing waste and implementing recycling practices are fundamental components of sustainable production strategies. These practices not only provide environmental protection but also help businesses reduce costs (Elkington, 1997). A prime example is Interface, a global leader in modular flooring, which has made significant advances in waste reduction through its Mission Zero initiative. This initiative aims to eliminate any negative environmental impact by 2020, primarily by integrating recycled materials into its carpet tiles. Consequently, Interface has successfully reduced waste, conserved natural resources, and set a benchmark for sustainability within the industry (Anderson, 1998).

Effective waste management practices encompass:

2.2.2.a Waste Minimization: Optimizing production methods that will result in reduced waste generation.

2.2.2.b Reusing and Recycling: Establishing recycling programs and innovative methods for reutilization of materials within the manufacturing process.

2.2.2.c Ecofriendly Packaging: Using biodegradable or reusable packaging materials to reduce waste.

2.2.3 Technologies for the Environment: For sustainable production, it is crucial to consider eco-friendly technologies such as renewable energy sources and environmental impact minimizing manufacturing processes (Hart, 1997). Tesla, for instance, has transformed the auto industry by producing electric cars that produce significantly less greenhouse gas emissions compared to traditional internal combustion engine motor vehicles. In addition, Tesla demonstrates its commitment to sustainability through incorporating renewable energy and efficient resource use in their manufacturing processes (Tesla, 2020).

Some environmentally friendly technologies are as follows:

2.2.3 a Renewable energy; It is the use of solar, wind or hydroelectric power sources to minimize dependence on fossil fuels and lower carbon emissions.

2.2.3 b Green manufacturing; These are the production methods that reduce pollution levels, conserve energy resources as well as minimize waste products.

2.2.3 c Energy storage; Advanced battery technologies that help in more efficient energy use and sustainability at the same time.

A comprehensive approach should be taken toward inclusive sustainable production management growth involving resource efficiency, waste management and eco-friendly techniques. The firms which seek to adopt such approaches will enjoy long term profitability while promoting environmental sustainability and social well-being at the same time. This has been evidenced by leading companies like General Electric, Interface, and Tesla whose success stories have shown how they apply these strategies thus achieving sustainable development and becoming benchmarks in this field.

2.3 Analyzing Concepts Through SWOT

A SWOT analysis of green transformation and sustainable production management is an invaluable tool for understanding today's state as well as future potential developments in this area. A SWOT analysis contributes to strategic planning process by assessing firm's internal and external environments. This section will cover on how to use SWOT analysis in relation to production management and green transformation along with supporting it with relevant literature.

A SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) is a strategic planning tool that helps businesses identify their strengths and weaknesses as well as opportunities and threats they might face (Gürel & Tat, 2017). In the fields of production management and green conversion this analysis will facilitate strategic decision-making.

2.3.1 Strengths

Resource efficiency and cost savings, brand reputation and customer loyalty and competitive advantage are the strengths powered by sustainable production practices. They can enhance the use of natural resources, leading to huge cost savings (Hart, 1997). For instance, General Electric's Ecomagination shows how enhancing resource efficiency may be able to support environmental sustainability (GE, 2005). By using eco-friendly production methods a brand develops a good name and builds loyalty with its customers (Elkington, 1997).Sustainability strategies give companies a competitive edge in terms of differentiation within the market (Porter, 1985)

2.3.2 Weaknesses

Green transformation and sustainable production management features several weaknesses for enterprises including high initial costs, challenges in technology adaptation and lack of training and expertise. Transitioning into sustainable production technologies often involves significant initial investments. Also, the adoption of new technologies alongside their integration into existing systems is a process that may take longer than expected or prove costly. Moreover, often businesses do not have specific knowledge and skills needed for sustainable production practices.

2.3.3 Opportunities

Increasing environmental awareness and consumer demand, government incentives and international agreements and invention of new technologies and digital revolution are benefits provided. The growing number of consumers who are environmentally conscious has resulted in a heightened demand for green and sustainable commodities, hence opening up new markets for businesses. Moreover, incentivization by governments in various forms or the existence of international accords promote sustainability, thus creating new markets for enterprises. The rise of industry 4.0 and digital revolution resulted in advanced technology which can improve the effectiveness and efficiency of sustainable manufacturing processes (Kusiak, 2018).

2.3.4 Threats

Fast changing environmental regulations, increased rivalry and economic uncertainties are among the possible threats. Mutability harshness linked to environmental policies discourages firm's compliance resulting in high operating costs. Intensifying rivalry among firms adopting green production may result in market shares wars (Porter, 1985). Also, changing global economic conditions represents one hindrance to investment on sustainability projects such as those which could jeopardize the health of the business community (Elkington, 1997).

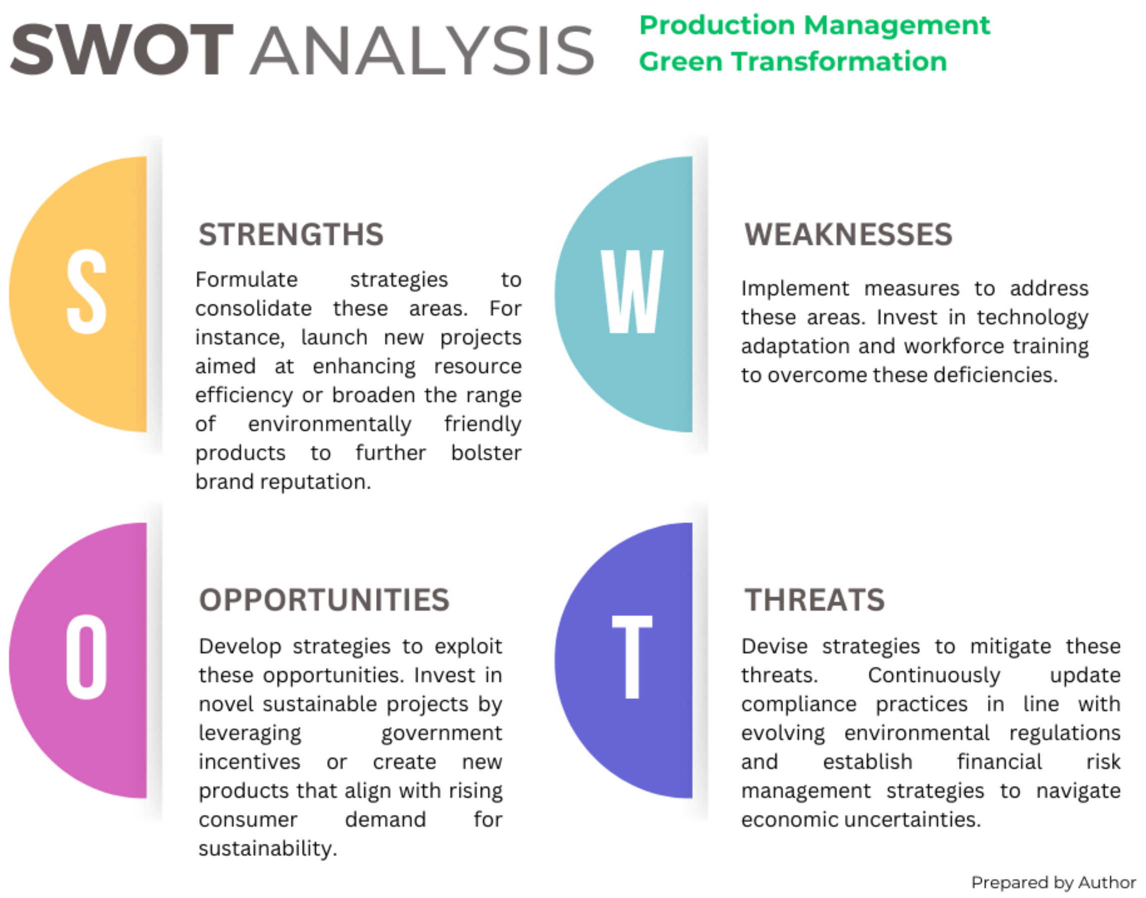

Figure1 Swot Analysis

2.3.5 Discoveries from SWOT Analysis

The perceptions, which have been obtained through the SWOT analysis, can significantly assist companies in the strategic planning and implementation of their green transformation as well as sustainable growth efforts.

Consequently, for a business to formulate its green transformation and sustain development strategy, it needs to consider the invaluable role played by SWOT analysis (Teece, D.J., 2018). This procedure facilitates strategic planning by identifying organizational strengths, weaknesses, opportunities, and threats that contribute to long-term success. Therefore, an extensive examination of SWOT analysis within the literature review will amplify the current knowledge about this study.

3.METHODOLOGY

Bibliometric analysis is a method that shows the overall map or pattern of literature by summarizing quantitative data on papers published in such journals. It helps identify what are the main trends in a specific area of research today; who has made significant contributions, and what topics are likely to be researched further on (Ding et al., 2014). The bibliometric analysis provides valuable information to researchers in decision-making processes and helps to close gaps identified in literature (Moed, 2005).

Therefore, it is vital to conduct a bibliometric analysis of research trends and developments in production management trends and green transformation. It is essential therefore, that the interlacing and relationships between these two fields be identified for coming up with sustainable production strategies, which today are more than ever needed in green transformation of production management (Tseng et al., 2019). Bibliometric Analysis is a roadmap for future research revealing how much more attention these fields get towards certain subjects or how many stand out papers and authors have been produced from this methodological point of view (Fahimnia, Sarkis & Davarzani, 2015). This is a way to understand the implications of green transformation strategies for production management better and develop effective policies to support sustainability goals.

A comprehensive study was performed on May 26th, 2024 using the Web of Science database focusing primarily on energy use in production systems. The search strategy used AND/OR Boolean operators to refine results. Below are the specific queries:

1. #1: TI = (Production Management) OR TI = (Operations Management) OR TI = (Manufacturing Management) – 16,388 results.
2. #2: TI = (Green Transformation) OR TI = (Green Manufacturing) OR TI = (Sustainable Production) OR TI = (Eco-friendly Technologies) – 10,929 results.
3. #3: TI = (Environmental Management) OR TI = (Industrial Sustainability) OR TI = (Circular Economy) OR TI = (Renewable Energy) OR TI = (Resource Efficiency) – 52,008 results.
4. #4: #1 AND #2 – 585 results.
5. #5: #1 AND #4 – 518 results.
6. Final Query: #3 OR #5 – 1,064 results.

These specific Boolean operators were chosen to balance comprehensiveness and relevance, aiming to capture a wide array of literature pertinent to production management and green transformation. However, this approach may still result in some degree of bias or exclusion of pertinent literature, particularly if critical studies use different terminology or are classified under different subject areas not captured by the chosen terms.

4.FINDINGS

This study identified 1,063 works, with the earliest published in 1981 and the most recent in 2024. The analysis encompassed 763 articles, 181 proceedings papers, 74 review articles, 46 editorial materials, 43 book chapters, 22 early access articles, 21 meeting abstracts, 6 book reviews, 5 books, 2 corrections, 1 data paper, and 1 reprint, spanning a range of disciplines. The collected data were meticulously examined based on author, citation, journal, country, institution, keyword, and abstract analyses. The studies indexed in the Web of Science were considered, and a VOS viewer was employed for the analysis. The Center for Science and Technology Studies (CWTS) at Leiden University in the Netherlands is the organization that created VOSviewer. From bibliographic data based on data files retrieved from WoS, Scopus, Dimension, PubMed, and RIS format, it is capable of extracting bibliographic networks. A Java-based program called VOSviewer can be used to create maps from network data and then view and analyze those maps(Moral-Muñoz et al.,2020).

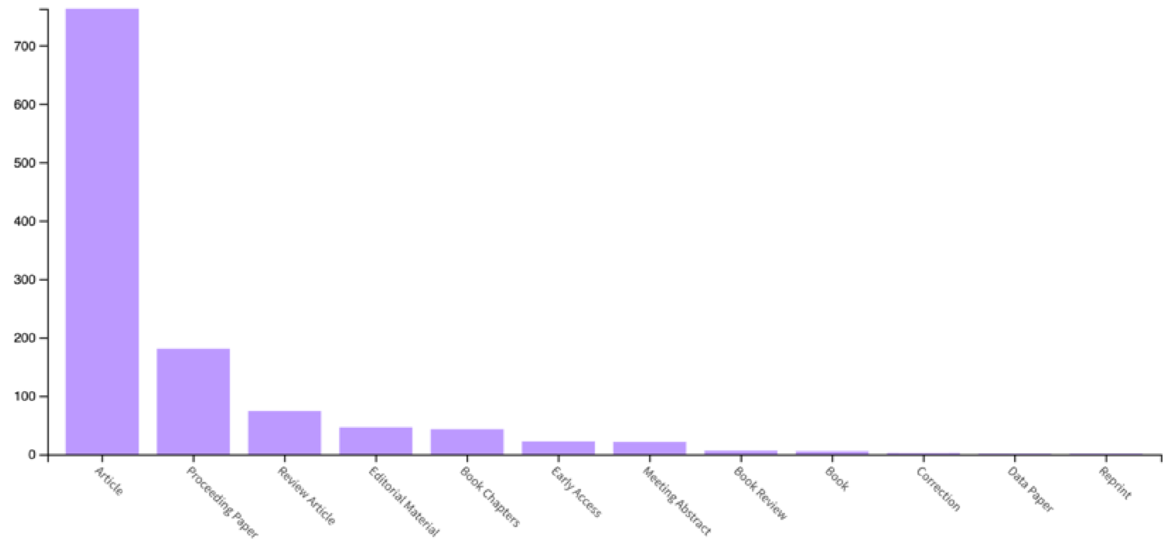

Figure 2 Publications by document type (Retrieved from Web of Science)

The findings from the Web of Science database were initially examined through the lens of the analytical frameworks provided by the Web of Science's own citation network. The results corroborated the expectation that the studies would be predominantly concentrated within scientific disciplines, with the top three areas being "Environmental Sciences", "Green Sustainable Science Technology", and "Engineering Environmental". Notably, the graph below reveals a significant concentration of research in the fields of "Operations Research

Management Science", "Business", and "Management". This outcome underscores the importance of systematic literature review methodology, reiterated by these findings.

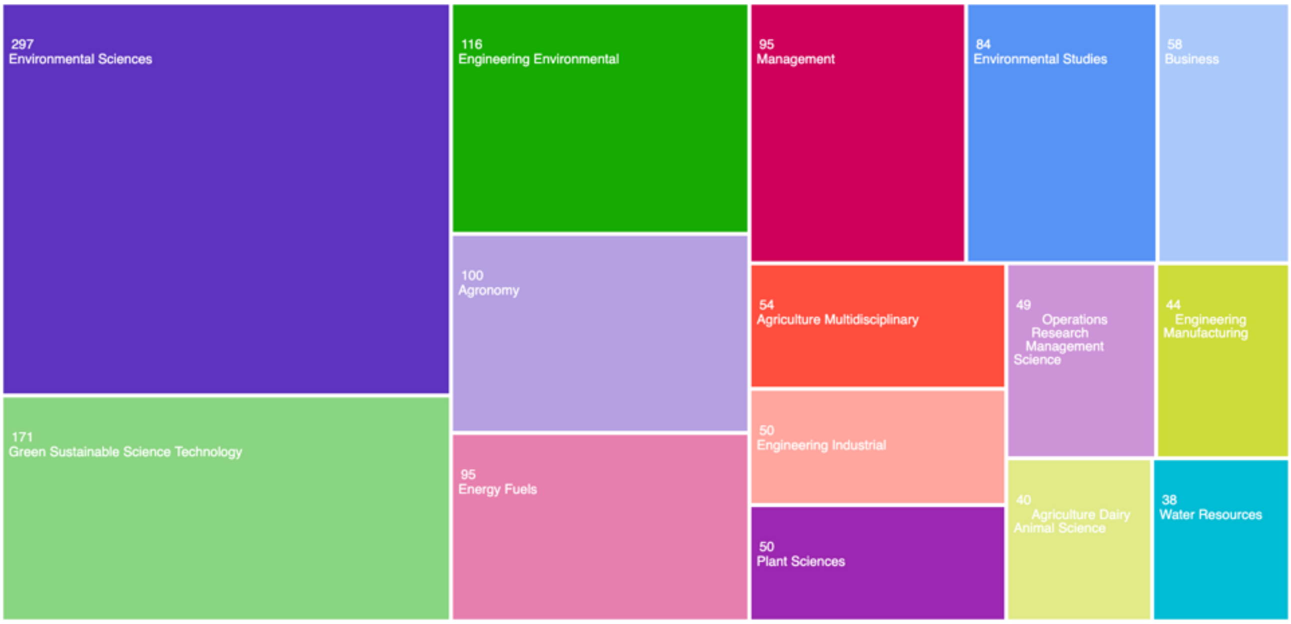

Figure 3 Publications categorized by topic (Retrieved from Web of Science)

The first study addressing the research question was conducted in 1980. The authors of the article titled "Environmental-Planning And Management Of Offshore Hydrocarbon Operations- The Development Of Environmental Guidelines" are Gilbert, J.T.E., and Harrison, P. A historical review reveals a clear trend of increasing publications on the subject from the first article to the present day. As can be seen from the graph, particularly due to the awareness brought about by the Covid-19 pandemic, the topic of green transformation and production has frequently been brought to the forefront (Zhu and Wang, 2022). According to the data, the publication graph shows a cumulative increase in the number of publications, especially in the last 10 years.

In a changing and evolving world, the effective and efficient use of resources and the integration of green transformation and production processes have become highly essential (Zhu and Wang, 2022).

After evaluating the analytical insights provided by the Web of Science database, all publications meeting the necessary eligibility criteria were downloaded for analysis using the VOSviewer application. The threshold for determining the minimum number of connections between authors was set at two to make sure that the network would remain inclusive while maintaining analytical integrity. However, it is worth noting that using a one connection threshold would have been subjective because it could lead to noise and false connections in analysis. Consequently, network analysis would only include articles with at least two citations in order to strengthen its robustness and credibility.

Also at least two citations were necessary for the citation threshold used for selected studies. This means that less frequently cited works were excluded because they may distort the results. Moreover, if we included them, they may impair the objectivity of our findings by introducing misleading relationships among low quality works. Therefore, considering both comprehensiveness and relevance in doing this research, a balance had to be struck through adopting such a stance.

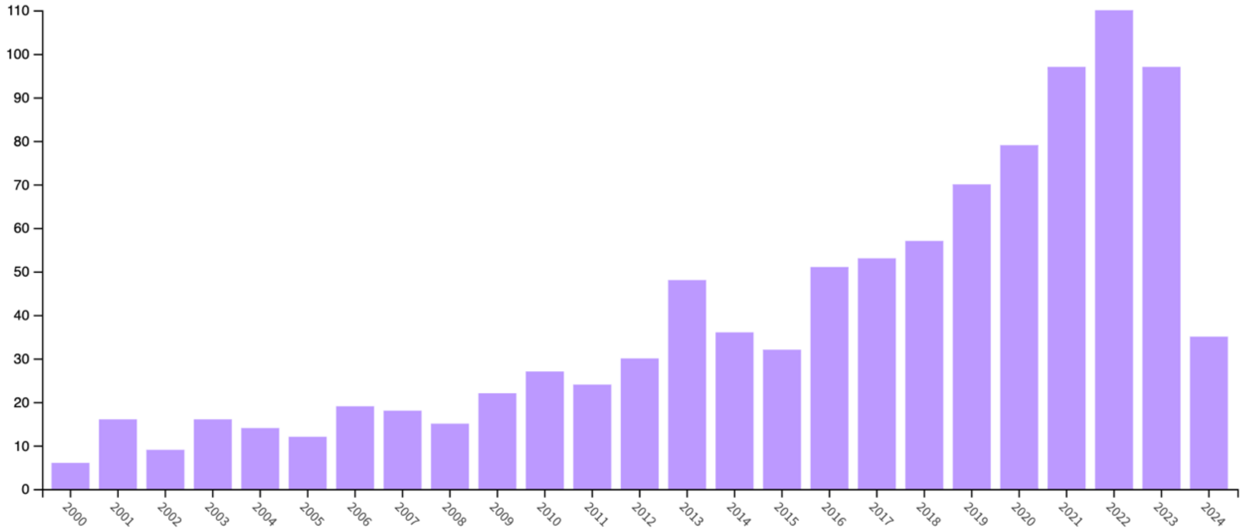

Figure 4 Publication numbers by years (Retrieved from Web of Science)

Under such key headings as publication trends, authorship analysis, co-authorship networks, citation analysis and bibliographic coupling of documents, carefully considered threshold criteria played a critical role in the outcomes of the bibliometric analyses. These included:

Publication Trends: A longitudinal analysis that would bring forth emerging trends and shifts in research focus over time.

Authorship Analysis: A study that would analyze prolific authors and their contributions to shed more light on critical contributors in the field.

Co-authorship Networks: It is important to understand the structure and dynamics of scholarly collaboration by mapping collaborative relationships among authors and institutions.

Keyword Co-occurrence: Identification of keywords prevalence as well as thematic clusters that points out dominant research themes and areas of interest.

Citation Analysis: Findings from evaluating frequently cited articles; these are seminal works that have shaped the field to date.

Bibliographic Coupling of Documents: This includes an assessment of journals publishing most articles on the topic with impact factors or relevance to identify leading journals in this area.

The deliberate selection of these thresholds ensured that the bibliometric analyses were comprehensive and methodologically sound, providing a nuanced understanding of the research landscape and highlighting significant trends, influential authors, and critical publications within the field.

4.1 Co-authorship of authors

By choosing these thresholds deliberately, the research ensured that the bibliometric analyses were exhaustive and methodologically rigorous to provide a subtle comprehension of the research terrain and identify essential fashion elements of influence such as influential authors and key publications.

Co-authorship Network:

Figure 5 presents a co-authorship network visualized by the VOS viewer using bibliometric data from the Web of Science database Co-authorship analysis aims at understanding collaborative relationships among researchers in this field.

Patterns of Clusters & Collaboration:

The network is divided into clusters, each with different colors indicating authors collaborating frequently. For example, the red cluster represents the most prominent cluster; it contains several authors such as Zhang Fen, Wang Xiaozhong and Chen Xinping. The Existence of this cluster indicates a dense collaboration network meaning these researchers often engage in works together hence making valuable contributions towards literature available within their area of study.

There is another major collaborative group represented by green cluster which includes Cui Zhenling among others. This connectivity has strongly implied close ties on co-authorships within this cluster that could lead to shared themes of research or joint projects.

There are smaller clusters such as the blue one including Wu Jiechen and Gong Haiqing, and the yellow cluster with Oenema Oene and Li Tingyu, which indicate a greater degree of isolated collaboration. These suggest that these groups although co-authored to some extents are more peripheral in the overall network.

Key Authors and Influence:

Node size reflects how many publications an individual has authored and the centrality of his or her position

within this network. Larger circles, like those representing Chen Xinping and Liu Dunyi, signify higher number of outputs published by them and their research impact others. These authors act as central nodes holding their clusters together implying that they have pivotal roles in guiding research collaboration and the dissemination of information.

Inter-Cluster Connections:

When different nodes are connected, it means there is co-authorship between them. The thickness of the lines indicates the strength of the connections. For example, thick lines indicate frequent extensive collaboration between Zhang Fen and other authors in the red cluster. Thin lines between these clusters show occasional or less intense collaborations thus showing potential areas for stronger interdisciplinary linkages.

Implications for Research Development:

Collaborative research is critical in the progression of this field as seen from this co-authorship network. Moreover, clusters that have been well-defined indicate fields of specialization where there are groups of researchers working on a specific sub-topic. These connections between clusters are less dense and provide opportunities for the cross-fertilization of ideas leading to innovative breakthroughs.

It is essential to know these collaboration patterns because they help identify central researchers, potential collaborators, and emerging research trends. It also helps identify influential research groups and understand knowledge dissemination dynamics within the field.

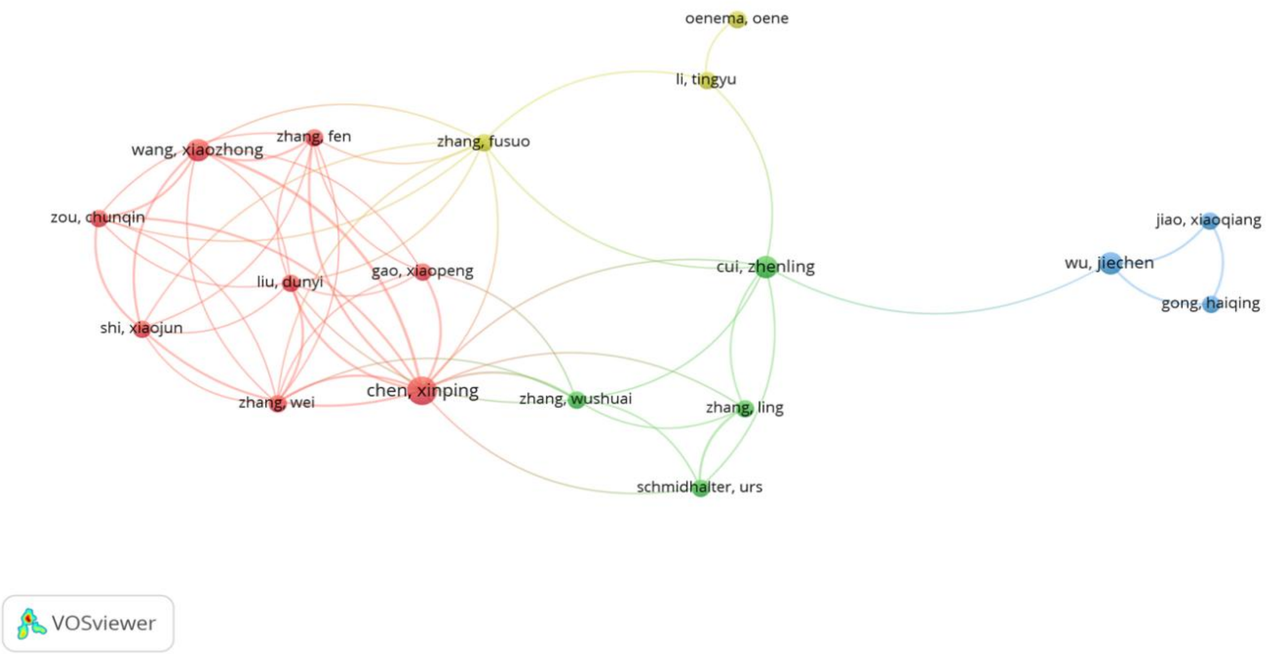

Figure 5 Co-authorship of authors

4.2 Co-authorship of countries

The visualization of a co-authorship network illustrates how countries relate to each other regarding scientific research. For example, through VOSviewer, publications show the graph of countries and the strength of collaborations.

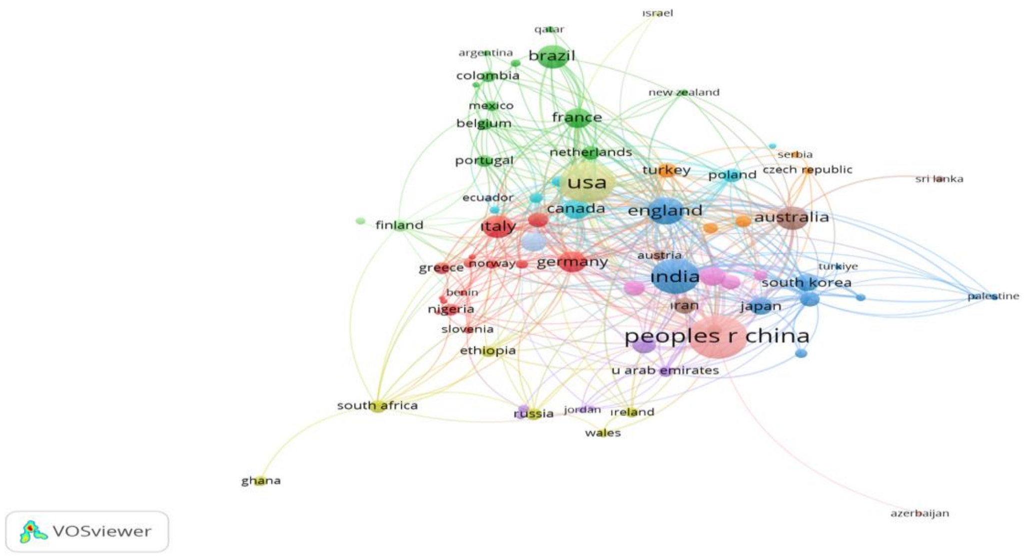

Figure 6: Co- authorship of countries

Clusters and Collaboration Patterns:

Different colors represent various clusters into which the network has been divided. These clusters denote countries that regularly work together with one another. Among others, green represents the most significant cluster that entails major centers for studies like Canada USA France Netherlands among others. The dense concentration in this cluster shows a strong network of international collaboration primarily involving Western countries, indicating a high level of research integration.

This red cluster, containing Italy, Germany and Greece, presents the second major European collaborative network. Such interconnectivity highlights strong regionalisms within EU research communities.

The blue cluster which contains central nodes in China, Japan and South Korea signifies East Asian collaborative networks' extensive nature. The central node of China and its large size indicate the country's substantial influence and contribution to global research. This suggests a highly cooperative regional research environment.

Key Countries and Influence:

Node sizes reflect the amount of published works per country as well as their centrality in the network. Big nodes such as China, USA and India imply higher publication output hence being hubs for international scientific cooperations where they are located centrally within diverse regions.

Inter-Cluster Connections:

Lines linking these nodes are co-authorship links between nations with thicker lines representing stronger relationships. For instance, the strong connections between the USA and several European countries suggest frequent and substantial joint research projects. Similarly, the robust ties between China and its neighboring countries reflect intensive regional collaboration.

The presence of lines between different clusters indicates interdisciplinary and cross-regional research collaborations. For example, connections between the USA and countries in the blue cluster (East Asia) and red cluster (Europe) suggest active involvement in diverse international research partnerships.

Implications for Research Development:

The significance of this co-authorship network lies in its description of international cooperation in scientific research. Well-defined clusters indicate regions with strong intra-regional research collaboration networks while inter-cluster links show the global nature of modern scientific undertakings.

By understanding these patterns, it is possible to identify the main actors involved in international scientific collaborations, potential partners for future joint efforts, and global trends that are apparent from these partnerships. Also, it shows how knowledge migrates across borders and reveals where research activities take place geographically.

4.3 Co-occurance of author keywords

The main themes, emerging trends, and research directions within a specific field of study can be easily identified by observing the occurrence of author keywords. By counting how often different words appear together in academic papers, we can learn about the structure and focus areas of the research landscape.

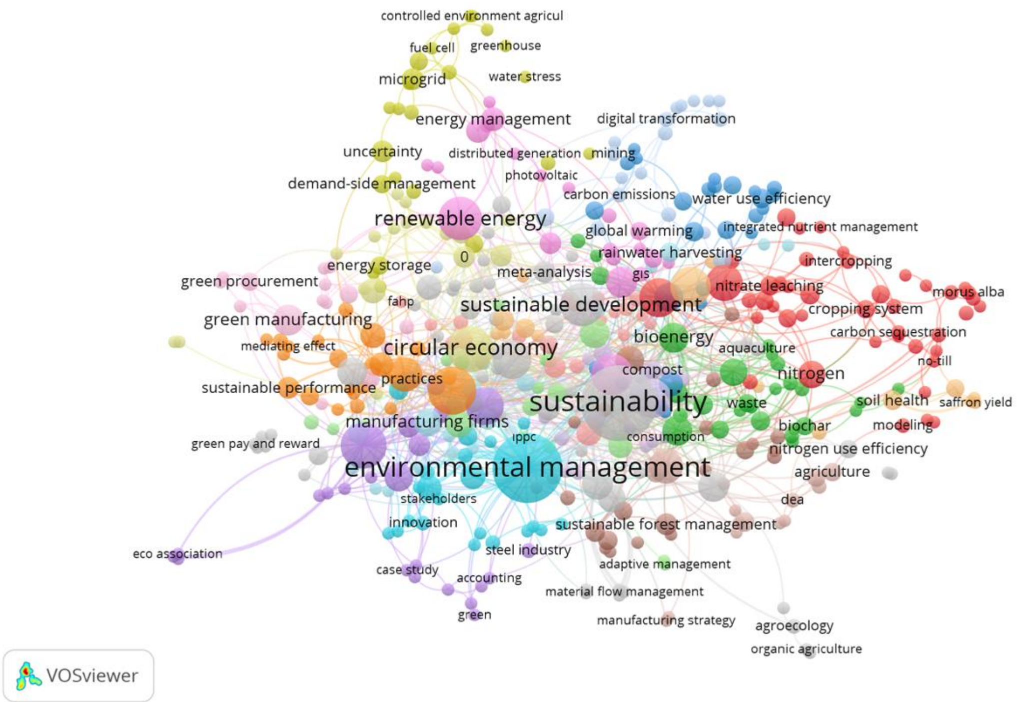

Figure 7 Co-occurrence of author keywords

Core Themes and Major Clusters:

It is visible from this network that there are several distinct clusters that represent thematic groups of related research topics. For example, a set including “sustainable development”, “green economy” and “environmental management” can form a cluster indicating an emphasis on sustainability as well as environmental issues. These are clusters where researchers have turned their attention to more collaboration.

Emerging Trends:

Furthermore, by illustrating how some keywords have gained popularity over time, it is possible to identify emerging trends using co-occurrence network. For instance, an increased number of occurrences of such words like “COVID-19,” “pandemic response,” and “public health” in recent studies implies that researchers are becoming more interested in comprehending and addressing the impacts brought about by COVID-19 pandemic. This shows that priorities for research vary according to global events.

Interdisciplinary Connections:

Within the network, the keywords tell interdisciplinary connections between different clusters. In addition, any consistent combination of keywords with terms from different disciplines suggests inter-disciplinary research tendencies. For instance, if “Artificial Intelligence” frequently appeared together with “healthcare” and “data analytics”, it would mean that AI techniques are now being directed to healthcare data and thus implying a fusion of technological discoveries and medical developments.

Influential Keywords:

In this network, the size of nodes is directly proportional to the frequency of keyword occurrences. Large nodes represent central terms in a particular area of inquiry as evidenced by numerous publications. They are keywords that quickly capture what a field comprises so they help researchers identify significant areas for investigation.

Research Gaps:

Another benefit that may be derived from looking at the network is uncovering areas that have not been researched yet or where there appears to be a lack of connection between groups. These gaps should be brought forward in order to guide future research activities and effectively allocate resources.

Co-occurrence analysis based on author keywords is helpful for intellectual mapping within fields of study. Understanding of main themes, emergent trends and interdisciplinary connections in literature facilitated. This analysis helps to identify important keywords as well as possible research gaps for guiding future research planning and collaborations.

4.4 Citation of authors

The visualization in hand is a bibliometric analysis of author citations using VOSviewer. It displays citation patterns and relationships among different researchers in a particular field. It helps an individual understand how academic influence is structured, the formation of networks of collaboration in addition to intellectual developments within an area.

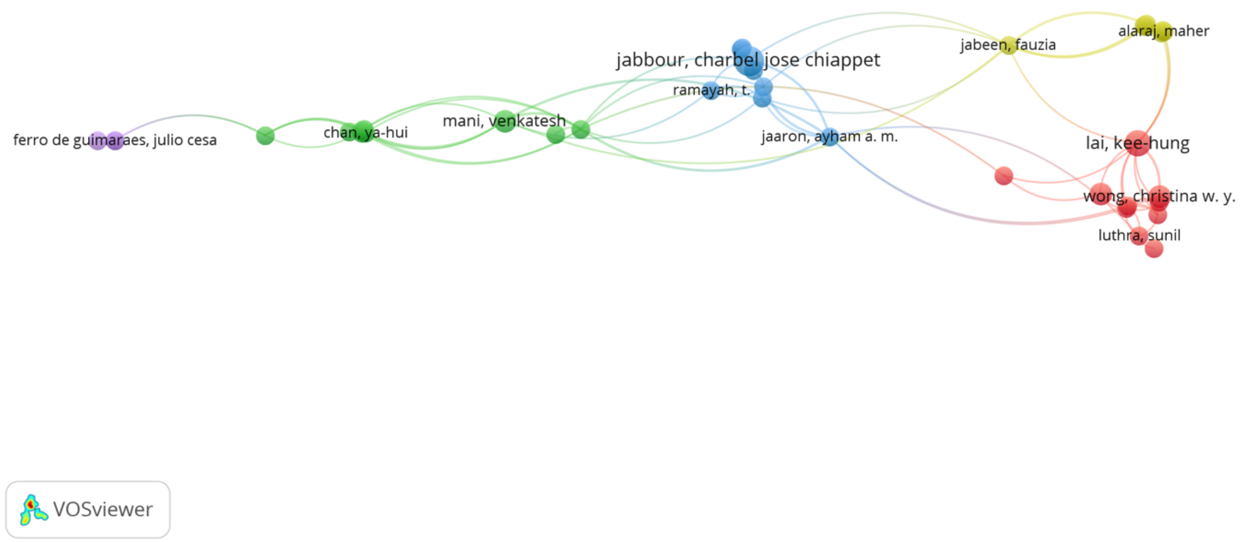

Figure 8 Citation of authors

Visualization Interpretation

This network visualization encompasses node-and-link diagrams that represent authors' works through their references. Citations made by authors are depicted by large-sized nodes, while small ones denote low citations counts. Thus, larger nodes represent authors with lots of citations they have received for their work. On the other hand, the thicknesses of each link between two nodes indicate how often an article has been cited.

Clusters and Key Authors

The visualization exposes distinct clusters indicated by different colors; these imply groups of authors who always cite each other thereby suggesting close collaboration or thematic similarity.

• Green Cluster: The group contains Mani, Venkatesh, and Chan Ya-Hui who may be the core people in this group. This inter-connection is indicative of a shared research theme or strong collaboration within this cluster.

• Blue Cluster: For instance, Jabbour, Charbel Jose Chiappetta and Ramayah, T stand out as important players in this cluster. These authors suggest that there is much influence and cross citation among themselves thus demonstrating their contribution to the field.

• Red Cluster: Lai, Kee-Hung and Wong Christina W. Y.—some of the dominant writers in this cluster—show another area of significant focus through internal citations.

• Other Clusters: Little clusters like purple (Ferro de Guimaraes Julio Cesar) or yellow (Alaraj Maher) represent more focused or upcoming research areas.

The academic field can be comprehensively studied with VOSviewer-based bibliometric analysis for a comprehensive understanding of citation patterns across different fields. Understanding key authors and clusters helps researchers understand how information flows between people and develops over time.

Additionally, it highlights areas where future collaborations can be done and points out works that have profoundly influenced other researchers.

This is a powerful tool for mapping the intellectual landscape of a field. It visually portrays the most influential authors and their networks, and gives some insights into how research themes have evolved and where future work can look into.

4.5 Bibliographic coupling of authors

This visualization represents the bibliometric analysis of author bibliographic coupling realized by VOSviewer. Bibliographic coupling refers to when two authors reference the same third document; this shows that they may be researching similar things. This method makes it possible to identify how ideas are connected within a given discipline or field.

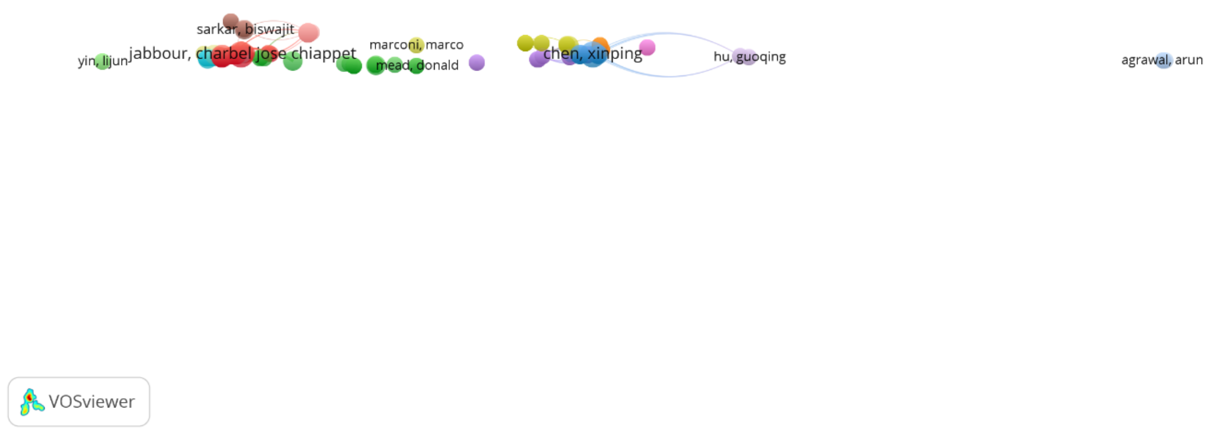

Figure 9 Bibliographic coupling of authors

Visualization Interpretation

The network visualization displays the bibliographic coupling relationships among authors, represented by nodes and links. Each node represents an author, with the node's size indicating the number of coupled documents. Larger nodes signify authors with more extensive bibliographic coupling. The links between nodes represent the strength of the coupling relationship, with thicker links indicating stronger coupling.

Clusters and Key Authors

The visualization reveals distinct clusters, each represented by different colors, indicating groups of authors with significant bibliographic coupling, suggesting thematic or topical similarity.

- Red Cluster: Central to this cluster is Jabbour, Charbel Jose Chiappetta, who appears to be highly interconnected with authors like Sarkar, Biswajit. This dense grouping suggests a strong focus on a particular research theme or high levels of collaboration.
- Green Cluster: Featuring authors such as Yin, Lijun, this cluster shows another significant research focus

- area. The interconnectedness within this cluster indicates a commonality in the referenced literature.
- Yellow and Blue Clusters: Authors like Chen, Xinping are central to these clusters, suggesting their research references are frequently shared with those of other clustered authors, highlighting thematic overlap.
- Nonetheless, some authors like Arun Agrawal are more isolated owing to the narrower specialization or lack of commonality in the referred literature compared to others.

An intricate insight into the intellectual structure of a given research field is provided by VOS viewer bibliographic coupling analysis. The identification of key authors and clusters enables both an understanding of how research themes evolve and the development of areas of collaboration. On the other hand, clustering authors on the basis of shared references brings out interconnections among research topics enabling researchers to identify important findings that could influence future studies and even possible co-authors.

The visualization of bibliographic coupling network is an essential tool for mapping out the intellectual landscape in a field. This method determines the most interconnected authors and their networks thus allowing one to see how their research themes change over time, and suggesting new areas for probable collaboration in future research.

4.6 Bibliographic Coupling of Documents

This part presents a bibliometric analysis using VOS viewer, namely bibliographic coupling. Bibliographic coupling occurs when two documents cite another third document implying that these documents may be similar in terms of their research topic. This type of examination helps one trace thematic relations and theoretical frameworks in a field of study.

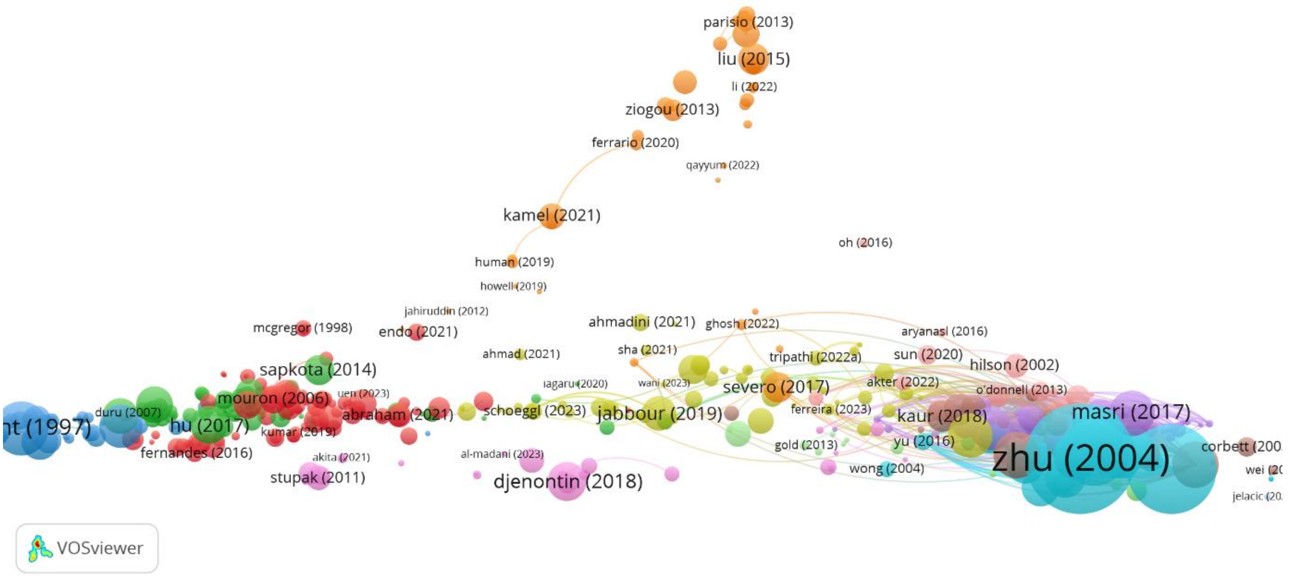

Figure 10 Bibliographic Coupling of Documents

Visualization Interpretation

A diagram like this is known as a network visualization and it demonstrates the connections between documents using bibliographic coupling. Every node represents a document; its size shows the number of other references linked to it. The big ones indicate that more works are tied to them by citations i.e., such nodes display extensive bibliographic couplings. On the other hand, more comprehensive lines imply stronger relationships.

Clusters and Key Documents

The visual representation shows separate clusters colored differently with heavy bibliographical coupling among them indicating topic or theme similarity.

- Blue Cluster: This cluster has strong thematic focus with extensive bibliographic coupling because of Zhu (2004) and Masri (2017). The high concentration of documents indicates a mature research area where notable works have been produced.
- Orange Cluster: Including documents like Parisio (2013) and Liu (2015), this cluster indicates another central research theme with strong internal bibliographic coupling.
- Green and Yellow Clusters: Featuring documents like Severo (2017) and Ahmadini (2021), these clusters highlight additional thematic areas with substantial internal connections.
- Red Cluster: Centered around documents like Sapkota (2014) and McGregor (1998), this cluster indicates another vital research focus.

Bibliographic coupling analysis through VOS viewer can help understand the intellectual landscape within any research domain. By identifying key documents and clusters, it offers insights into how research themes evolve and what future studies may be addressed. The manner in which documents cluster based on shared references provides a concrete example of how interconnected research topics guide scholars to locate influential works and spot emerging trends.

The visualization via bibliographic coupling network is a robust intellectual field mapping tool, which shows the most interconnected papers and their networks, helps to understand the development of research themes over time, and suggests possible lines for further study and collaboration.

4.7 Co-citation of cites authors

This given presentation shows a co-citation network analysis of cited authors using a VOS viewer. Such an analysis assists in understanding the intellectual structure and influential authors within a given research domain.

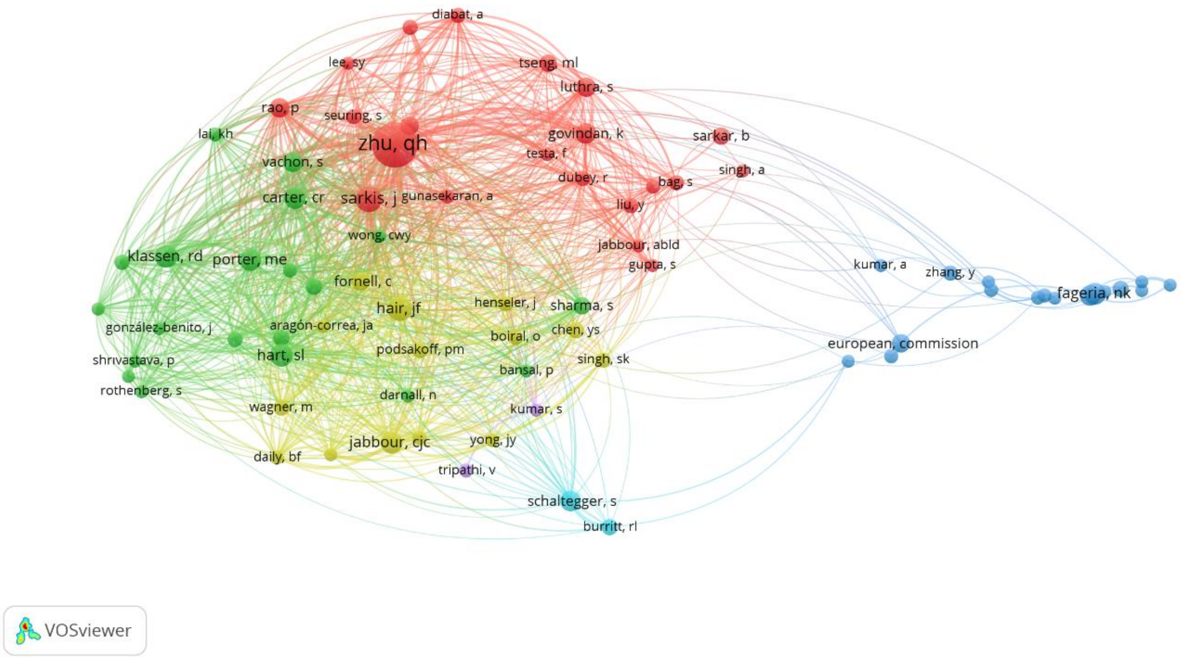

Figure 11 Co-citation of cites authors

Key Observations:

1. Cluster Identification:

Red Cluster: The red cluster includes authors like Seuring S, Sarkis J, and Gunasekaran A that tend to revolve around Zhu QH. Green logistics is focused on by this cluster; hence it represents basic researchers concerned with sustainable supply chain management.

Green Cluster: Klassen RD, Porter ME, Carter CR among others make up this green cluster that concentrates on environmental management and corporate sustainability practices.

Yellow Cluster: Hair JF, Podsakoff PM, and Darnall N are among the authors in the yellow cluster which reveals methodological contributions and sustainability reporting emphasis.

Blue Cluster: The European Commission and Fageria NK are part of the blue cluster which has a smaller size but seems to be focused on policies and regulations concerning sustainability.

2.Centrality and Influence:

Zhu QH: Zhu QH stands at the midpoint of the red cluster making him/her most influential author with significant contribution to this field of study.

High Interconnectivity: It is evident that there is high interconnectivity between authors in green and red clusters; this means that they often cite each other's work indicating an established research community.

Peripheral Authors: In relation to research, those who focus on writing about topics within this domain are considered peripheral by comparison with their counterparts in the blue cluster.

3.Research Themes:

The dense connections within and between the red and green clusters indicate robust research themes around sustainable supply chain management and environmental performance.

The yellow cluster's connections highlight the importance of methodological rigor and interdisciplinary approaches in sustainability research.

The blue cluster's connections to other clusters reflect the integration of policy and regulatory frameworks in sustainability discourse.

Implications for Future Research:

Cross-Cluster Collaboration: It would foster innovative research combining methodological rigor, practical sustainability practices, and policy implications if authors from different clusters were encouraged to collaborate.

Emerging Trends: One could monitor the changes in the blue cluster for insights into emerging trends and regulatory impacts on sustainability research.

5.LIMITATIONS

The data used in this study was exclusively obtained from Web of Science database thereby excluding other significant repositories like Scopus, TR Dizin, and YÖK National Thesis Center. By narrowing the research scope, such a limitation might eliminate those relevant studies that are not available in indexed journals. Exclusively relying on Web of Science may lead to selection bias as it does not contain all academic literature in different databases.

In addition, VOS viewer software was used for the analysis which is powerful but still it has its limitations in visualizing and interpreting complex bibliometric data. Despite being effective algorithms and clustering techniques employed by VOS viewer may simplify or fail to capture fine-grained relationships among the data.

Also, search queries have been composed subjectively to what terms should be included and how they should be combined. This may result in some topics being overrepresented or underrepresented in the search results, which could influence the main results of the bibliometric analysis.

6. CONCLUSION

A bibliometric analysis of the trends of production management in the time of green transformation can provide relevant indications on how sustainability is refashioning the field. The results underscore more sustainable practices in production management as consumption concerns, regulations, and consumer preferences move in the same direction. The adoption of renewable energy sources, waste prevention strategies, and environmentally friendly technologies transformation involves all work towards reducing the negative impact production processes have on the environment.

The study cocludes that the green transformation also provides significant competitive benefits for companies and is not solely beneficial from an environmental standpoint. Sustainable practices can only be

achieved on a case-by-case basis; one of the main reasons is because at the end of the tunnel the process becomes one of saving elements/using resources, in which companies increase their control and therefore, reduce direct and indirect costs, becoming more competitive. In addition, sustainable production management practices are starting to be seen as an essential aspect of corporate social responsibility that adds to brand strength and customer loyalty.

In addition to helping organizations have a better understand of the translation pathways, the study also conducts an agenda for specific research areas such as productive pressures in the application of digital technologies, economy dimensions of green transformation and standards for sustainability metrics. These areas present valuable opportunities for further investigation to deepen the understanding of how production management can evolve to meet the demands of a sustainable future.

Finally, this bibliometric analysis provides a comprehensive overview of the current trends and future directions in production management in green transformation. It underscores the importance of integrating sustainability into production practices and highlights the potential benefits for businesses and society. The findings of this study will help guide future research and inform the development of policies and strategies aimed at promoting sustainable production management. By continuing to explore and implement innovative sustainable practices, businesses can contribute to a more sustainable and prosperous future.

REFERENCES

Anderson, R. C. (1998). *Mid-Course Correction: Toward a Sustainable Enterprise: The Interface Model*. The Peregrinzilla Press.

Ding, Y., Rousseau, R., & Wolfram, D. (2014). *Measuring Scholarly Impact: Methods and Practice*. Springer.

Elkington, J. (1997). *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*. Capstone Publishing.

Fahimnia, B., Sarkis, J., & Davarzani, H. (2015). Green supply chain management: A review and bibliometric analysis. *International Journal of Production Economics*, 162, 101-114. https://doi.org/10.1016/j.ijpe.2015.01.003

Fishman, C. (2006). *The Wal-Mart Effect: How the World's Most Powerful Company Really Works--and How It's Transforming the American Economy*. Penguin.

Fu, J., Xiao, G., Guo, L., & Wu, C. (2018). Measuring the dynamic efficiency of regional industrial green transformation in China. *Sustainability, 10*(3), 628. https://doi.org/10.3390/su10030628

GE. (2005). Ecomagination. General Electric.

Gürel, E., & Tat, M. (2017). SWOT Analysis: A Theoretical Review. The Journal of International Social Research, 10(51), 994-1006.

Hart, S. L. (1997). Beyond greening: Strategies for a sustainable world. *Harvard Business Review, 75*(1), 66-76.

Hart, S. L. (1997). Beyond Greening: Strategies for a Sustainable World. Harvard Business Review, 75(1), 66-76.

Heizer, J., & Render, B. (2014). *Operations Management: Sustainability and Supply Chain Management*. Pearson.

Kahney, L. (2008). *Inside Steve's Brain*. Portfolio.

Kusiak, A. (2018). Smart manufacturing. International Journal of Production Research, 56(1-2), 508-517.

Linton, J. D., Klassen, R., & Jayaraman, V. (2007). Sustainable supply chains: An introduction. *Journal of Operations Management*, 25(6), 1075-1082. https://doi.org/10.1016/j.jom.2007.01.012

Moral-Muñoz, J. A., Herrera-Viedma, E., Santisteban-Espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up-to-date review. Profesional de la Información, 29(1), 1-20. https://doi.org/10.3145/epi.2020.ene.03

Moed, H. F. (2005). Citation Analysis in Research Evaluation. Springer.

Porter, M. E. (1985). Competitive Advantage: Creating and Sustaining Superior Performance. Free Press.

Slack, N., Chambers, S., & Johnston, R. (2010). *Operations Management* (6th ed.). Financial Times/Prentice Hall.

Stevenson, W. J. (2015). *Operations Management*. McGraw-Hill Education.

Teece, D. J. (2018). SWOT Analysis. In M. Augier & D. J. Teece (Eds.), The Palgrave Encyclopedia of Strategic Management. Palgrave Macmillan. https://doi.org/10.1057/978-1-137-00772-8_285

Tesla. (2020). Impact Report. Tesla Inc.

Tseng, M. L., Chiu, A. S. F., Tan, R. R., & Siriban-Manalang, A. B. (2019). Sustainable consumption and production for Asia: sustainability through green design and practice. *Journal of Cleaner Production*, 197, 1232-1240. https://doi.org/10.1016/j.jclepro.2019.06.226

Zhu, J. H., & Wang, S. S. (2022). Evaluation and Influencing Factor Analysis of Sustainable Green Transformation Efficiency of Resource-Based Cities in Western China in the Post-COVID-19 Era. Frontiers in Public Health, 10, 832904.