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The Study Of Multi-Objective Optimization Of Supply Chain Pillars Using Bat Algorithm

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Abstract*-The supply chain pillars are the key factors that help the organization to achieve high efficiency which were and are an area of investigation for continuous improvement. The BAT Algorithm inspired by the echolocation behaviour of BATs, has emerged as a powerful metaheuristic optimization tool used across various domains including supply chain management. This article explores the application and effectiveness of the BAT Algorithm in optimizing supply chain networks, addressing complex problems of supply chain pillars such as inventory control, demand forecasting, distribution routing, and dispatch. The BAT Algorithm's ability to balance global exploration and local exploitation allows for efficient and effective solutions in dynamic and uncertain supply chain environments. This article focuses on the workings of the BAT Algorithm considering factors like frequency, loudness, and pulse rate. This paper investigates the different aspects and identifies how this aid in multi-objective optimization and help create more sustainable working supply chain networks. This research is based on secondary data covering literature articles, and case studies, where the BAT Algorithm has been successfully implemented, demonstrating significant cost reduction, improved resource allocation, and overall performance.*

Keywords*: Bat Algorithm, Green Supply Chain Management, Inventory Control, Demand Forecasting, Distribution Routing, Dispatch*

INTRODUCTION

Supply chain management (SCM) involves the management of resources, and information as they flow from the sellers of raw material to the buyers of the finished product with function(Lu and Swaminathan, 2015).where customer satisfaction, reduction of costs and optimization of operations are as its primary goals. The four key activities of supply chain management include inventory control, demand management, route distribution and dispatch management; The parameters of inventory control involve identifying the maximum and minimum stock levels that is convenient to hold as a business to avoid lack of stock and at the same time not to have excess stock(Diabat, 2014). These features lay the foundation to an efficient and effective supply chain structure(Gocić et al., n.d.) either through variability, costs, or even environmental factors. Supply chain is significantly complex, and it must be optimized to maintain efficiencies(Lu and Swaminathan, 2015). It is then possible for businesses to cut unnecessary expenses, adopt efficient use of resources, ensure timely delivery, and improve buffer against variation and changes within the market(Gocić et al., n.d.). Traditional techniques often work ineffectively due to the nature and complexity of the SCM issues are often bio-inspired algorithm(Ristic and Koprivica, 2022). These algorithms are highly adaptive, fault tolerant, and accurate in solving hard optimization problems and based on natural processes such as; evolution, swarm behaviours and echolocation(Chatterjee and Layton, 2020). One among this newly introduced group of algorithms that has evolved into a powerful tool to solve SCM optimization problem is the BAT Algorithm(Chatterjee and Layton, 2020). This can find the best outputs just for the refining in the local analysis co-operating with the global search for the solutions in any possible way cooperating with the BAT's echolocation frequency, loudness, and pulse rate Due to real-time changes of parameters, it can respond to supply chain management issues such as network design, inventory control, and route optimization(Benmamoun et al., 2024). The BAT Algorithm is a useful method to achieve efficiency and adaptability common in the contemporary supply chain systems

due to its speed, accuracy, and effectiveness for multi objective problems(Yang, 2010). The BAT Algorithm has made tremendous contribution towards optimizing SCM pillars across different industries and shows the potential to reach the transformative state.

BAT Algorithm

The BAT Algorithm is an optimization technique, based on behaviour of bats. It is a method of simulation using sound wave to identify the location of prey or obstacle by adjusting the loudness and pulse emission rate. It is a balancing of exploration and exploitation in which a high frequency is used for broader search and lower frequencies for focussing on promising areas. Loudness represents the intensity of the research and decreases as a bat gets closer to a potential solution.

Application of BAT algorithm in supply chain Management

Analogues of BAT Behaviour and Supply chain management

BAT Behaviour	Source end	Delivery end
Echolocation Simulation	Locating source	Identify the right customer
Population of BATs	Probable sources	Probable customer/ competitors
Frequency Tuning	Specification & Dimension	Customer needs and expected utility
Loudness	Decrease as targeted resources is approached	Decrease as the customer is identified
Pulse emission rate	Increase as fine tune of research	Fine tune the customer need and expectation – Customization.

The BAT algorithm is a systematic approach that can be used in supply chain management in both supply or source end and delivery end. The first level is identifying the location of the resources especially rare or scarce resources. In business, continuous supply of resources is essential and, in many cases, there will be a limit for the quantity that can be availed from one source at an economical rate and convenient way. Appropriateness, availability, quality, cost, and consistency in supply are a few factors relevant in the source or supply point. Similarly, managing the sales of the product, especially if the product has a longer life period and product is expensive like capital goods. In the source point, both exploration and exploitation are needed for identifying right suppliers. Hence, collecting information on available resources, possible substitutes, cost aspects of resources, current demand, and users of the resources etc are in the echolocation simulation. In the sales point, effective contents, and strategies to attract the attention of the potential customers is important in generating enquiries and sales.

Population of bats is a collection of potential vendors available or potential competitors in the market. Increase in the potential suppliers cause easy availability of the products at a lower cost of procurement while increase in competition compel to reduce the price and profit and increase the cost of sales. Uniqueness of the product, dynamism in improvement and updating etc give an upper hand in market.

Frequency tuning is an activity in which fine tuning the vendors based on a set of

Key points about the Bat Algorithm:

- Echolocation simulation:

The algorithm mimics how bats use sound waves to locate prey by adjusting the frequency and intensity of their echolocation pulses.

- Population of bats:

The algorithm represents a population of "artificial bats" that move through the search space, each representing a potential solution.

- Frequency tuning:

Each bat has a "frequency" parameter that controls the search area, with higher frequencies leading to wider exploration and lower frequencies focusing on specific areas.

- Loudness:

Represents the intensity of the search, decreasing as a bat gets closer to a potential solution, signifying a more focused search.

- Pulse emission rate:

Controls how often a bat emits a pulse, increasing as it approaches a potential solution to refine its search.

Applications of the Bat Algorithm:
Engineering design optimization, Machine learning parameter tuning, Data analysis, Image processing, and Scheduling problem
For example, it cut holding costs by 20% and stock-outs by 25%, especially in the pharmaceutical usage case (Seow et al., 2022)(Liu et al., 2022). Using BAT Algorithm, fuel consumption in route distribution has been reduced by 15% and reduced delivery times by 20% while increasing vehicle utilization 22% in dispatch management (Perez et al., 2021)(Osaba et al., 2019). However, it also increased demand forecasting accuracy of the 12% with the savings of millions annually in terms of reducing waste of food processing companies (Seow et al., 2022; Hector D. Perez et al., 2021)(Liu et al., 2022; Osaba et al., 2019). This raises BAT Algorithm versatility and its impact in real world applications of the SCM. Based on these successes, this research will pursue the BAT Algorithm's potential and applicability to optimize the critical SCM pillars, inventory control, demand forecasting, distribution routing and dispatch. This study attempts to determine what makes the algorithm's prime parameters (frequency, loudness, and pulse rate) enable Multi objective optimization across dynamic and uncertain supply chain environments. In addition, it evaluates the feasibility for the algorithm to lead to a sustainable operations of supply chains through the reduction of costs, optimization of resources, and improved overall performance, making a comprehensive approach for optimization of a modern supply chain
The purpose of this work is to fill the knowledge gap by examining the literature for supply chain management research. The following parts contain literature review, research problem, findings, discussion, and conclusion.
Relevance of BAT Algorithm

LITERATURE REVIEW

Supply Chain Management (SCM) is an essential business strategy that makes the way information and goods can move from suppliers to customers easier(Lu and Swaminathan, 2015).SCM has evolved through time towards integration, efficiency, resilience, and sustainability, however, this has not been enough to overcome the complexities of SCM with many stakeholders' involvement, fluctuating demands, and diverse regulations (Yahya Zebari et al., 2020)(Yahya Zebari et al., 2020). According to (Zhang et al. 2020), inefficiencies such as sub optimal inventory control, erroneous forecasts of demand and inappropriate routing, lead to increased expenses, stockouts, and reduced customer satisfaction(Chatterjee and Layton, 2020). According to (Gocic et al. n.d.the) studies explain, adoption of technology is required to improve the performance whilst decreasing the risks, increase the sustainability and increase the resilience. As operational levers for supply chain management (SCM) to improve in this current market uncertainty, collaborative tactics, predictive analytics, and sustainable practices are needed. In this paper we focus on the supply chain management and the four pillars(Kiran, 2019). And these four essential components that make to Inefficiencies, excessive resources utilization, and long-distance freight transportation tend to have greater environmental impact especially on carbon emissions(Chatterjee and Layton, 2020).In demand forecasting, according to (Bahmani et al. 2021) Without accurate demand forecasting, supply chain management cannot successfully match the supply for given demands of customers(Bahmani et al., 2021). Most modern supply chains present such unstructured unpredictability and rapid changes that are beyond the capabilities of conventional forecasting techniques such as regression models and time series analysis and conventional optimization techniques like Genetic Algorithms (GA) and Particle Swarm Optimization (PSO) that still do not achieve the best possible result in each case(Bahmani et al., 2021). We have demonstrated that the BAT Algorithm (BA) can be used to address these issues because its inspiration comes from Bats' echolocation skills. Due to its ability to flexibly adjust when the market changes, BA possesses a strong ability to produce extremely accurate forecasts by balancing local fine tuning and global exploration of the solution space. The BAT Algorithm's adaptive properties, like frequency modification and pulse rate modulation, make it a very versatile tool and works especially well in erratic markets where conventional approaches frequently perform poorly. In inventory control, (Lu et al. 2015) convey that preserving ideal stock levels, cutting expenditures, and providing product availability in supply chain management are critical tasks of effective inventory control(Lu and Swaminathan, 2015). But (Jain et al. 2023) implies the irrespective of the

complexities such as fluctuating demand, varied lead time, and diverse decision-making processes the conventional systems like Just-In-Time (JIT) and Economic Order Quantity (EOQ) struggle to deal with them(Jain et al., 2023). Production EPQ type models essentially only focus on reducing inventory and production costs, but are not suitable for addressing important problems, like sporadic manufacturing flaws and the attendant rework costs, which can severely impact profitability. According to (Sadeghi et al. 2014) Based on the echolocation behaviour of BATs, the BAT Algorithm (BA) has emerged as a novel solution to these problems, capable of operating at a kind of resource balancing of local exploitation and global exploration that eventually leads to refine those high potential solution(Sadeghi et al., 2014). To search around the whole solution space efficiently and the algorithm can accept dynamically supplement to the changing supply constraint and demand pattern characteristics via feature of frequency modulation and pulse modification, is particularly appropriate for the environment suffering from volatility and unpredictability. As the BA is included into more complex models, it becomes more and more effective. For example, (Diabate 2014) examined that a dual objective Vendor-Managed Inventory (VMI) model, by combining Random assignment Problem (RAP) with Traveling Salesman Problem (TSP), addresses the multi-level supply chain complexity. Being versatile in solving NP-hard problems, BA, especially with the Hybrid BAT Algorithm (HBA) is also a good candidate(Diabat, 2014). Moreover, meta heuristic algorithm research demonstrates that parameter adjustment is paramount for meta heuristics optimization and shows that Taguchi technique provides a tremendous gain in the BA performance and potential of optimization(Sadeghi et al., 2014). In route distribution, (Ibrahim Adedeji Adeniran et al. 2024) advocated the route distribution optimization is one of the important parts of the supply chain management with the ability to minimize the transportation cost, shorten the delivery time and lower the environmental effect(Ibrahim Adedeji Adeniran et al., 2024). Large scale logistics networks are very complex however, and real traffic patterns and constraints both fluctuate over time and change frequently with a variety of publications focusing on traditional optimization techniques such as linear programming, heuristic approaches, and metaheuristics such as Genetic Algorithm (GA) and Ant Colony Optimization (ACO)(Fister et al., 2014). n (Dwi et al. 2020) projected, while widely utilized, these techniques notoriously fall short at scale and in adapting to real time situations. When client requests cannot be met with private vehicles that have limited capacity on offer, extra vehicles are rented, which is expensive and increases logistics. Changing travel distance for minimizing on maps is further complicated by designing routes so that the vehicles never surpass capacity constraints(Dwi et al., 2020). The BAT Algorithm (BA) has successfully turned around these problems inspired by BATs echolocation system. (delali et al. n.d) BA is good at solving routing problems because to some extent it can find a balance between exploiting (further developing best solutions) and exploring (a lot of options within solution space)(Delali6 et al., n.d.). (Kussman et al. 2020) analysed Its dynamic features, such as frequency modulation and pulse adjustments, allow the mode to adjust to real time variables of traffic conditions, delivery constraints, and truck capacity limits(Kussman et al., 2020). Integrity due to its adaptability makes BA especially useful for routing situations such as multi-dept and multi vehicle systems. Let us look further; BA can handle situations in which rental cars can finish their routes with the final customer, whereas private vehicles must come back to the depot after deliveries have been completed. This capability addresses operating variation in these vehicle types and is scalable and effective at solving route distribution problems(Dwi et al., 2020). With last mile logistics, vehicle capacity and schedule collision being obstacles in dispatch process optimization, delivery of goods in a timely and effective manner is vital to supply chain management(Ibrahim Adedeji Adeniran et al., 2024). However, the intricacy of dynamic, real-time events typically outpace conventional optimization techniques (rule-based heuristics or linear programming). The BAT Algorithm (BA) is inspired by the echolocation of BATs, and is a practical solution for these problems. In the dispatch of the supply chain, (Li 2013) given the ability to dynamically react to changes in real time while being able to balance local refining and global search to optimize dispatch processes was a strong point of BA(Li, 2013). Simulating (Delali6 et al. n.d.) approaching the frequency modulation and pulse modifications used by BATs for navigation, it reacts to changes in delivery demand, vehicle availability and routing limit(Zhang and Li, 2020). (Li et al. 2022) research has shown that BA improves vehicle usage, decreases delays and reduces trip distances, leading to more efficient dispatch schedules. Furthermore, BA may be used in combination with other optimization methods (e.g. multi objective

frameworks or simulation models) to address more complex dispatch requirements (e.g. satisfying customers' preferences and deadlines)(Li et al., 2022). (Gocić et al. n.d) in his research the BA can extend the application to the situation where emergency management is needed as in the example of firefighting operations, maximum distribution of the resources can be obtained. The main goal is lowering expenses and guaranteeing quick reaction times, while prioritizing vital assets during a major fire. This is also a strategy to reduce environmental impacts of fire trucks CO2 emissions through the inclusion of CO2 emissions from fire trucks in the optimization model(Gocić et al., n.d.). (Qi et al. 2021) implementing an effective resource deployment plan is developed based on the mathematical model of a Green-PCVRP (Prize Collecting Vehicle Routing Problem) considering of variables such as vehicle capacity, asset value, etc., and considering the resource allocation problem under the complexity of moving armored equipment between several targets and supply sites(Qi and Cai, 2021). This method ensures an efficient allocation of resources, improves the performance, increases coordination, and decreases errors in such complicated logistical situations. Fig 1. Shows the BA that involving the supply chain pillars the loudness, frequency, pulse rate are used for demand forecasting, inventory control, route distribution as and dispatch. Beyond this, this study also intends to examine and evaluate significant literature on the multimethod application of the BAT Algorithm to supply chain management (SCM). To classify and synthesize these papers rigorously to identify gaps, important issues, and avenues for further research it is worth doing research to this field. Probably one of the most important steps to identify new research avenues and contribute to the advancement of the field, is doing a literature review. It is broad basis for reviewing and testing conceptual elements critically and, thus, for formulating new theoretical explanations.

Figure 1. Application of BAT Algorithm in Supply Chain Management

Table. 1 Supply chain pillars using bat echolocation behaviour

	Frequency	Loudness	Pulse Rate
Inventory Control	Balances order and reorder frequency	Dynamically adjusts to stock levels	Optimizes restocking pulse rates
Demand Forecasting	Analyses seasonal trends and fluctuations	Adapts to market demand changes	Refines predictions with iterative updates
Route Distribution	Evaluates travel frequencies for vehicles	Modulates vehicle load distribution	Adjusts routing strategies in real-time
Dispatch	Calculates dispatch intervals	Adjusts resource allocation dynamically	Ensures timely delivery and response

RESEARCH QUESTIONS

Based on the review of literatures specified in this article the unexplored areas of study

RQ 1: What are the challenges faced by the BAT Algorithm in solving the Vendor-Managed Inventory (VMI), and Resource Allocation Problem (RAP), to achieve effectively operating complex, dynamic and large-scale networks in modern supply chains?

RQ 2: How can the BAT Algorithm be improved to have better scalability and flexibility in solving optimization problems of multi-regional supply chains under dynamic and uncertain situations?

Analysis

Objective 1:

Vendor Managed Inventory is widely used in distribution of fast-moving consuming goods (FMCG) by the manufacturers. In vendor Managed Inventory, the vendors regularly monitor the consumption of the product and replenished the consumed product range to maintain the set inventory level.

Table. 1 summarizes articles that implement the frequency, loudness, pulse rate into the supply chain pillars

Application of BAT in VMI

Key points about the Bat Algorithm:

Echolocation simulation:	BAT in determining Routes	BAT in Identifying selling pints
The algorithm mimics how bats use sound waves to locate prey by adjusting the frequency and intensity of their echolocation pulses.	How many routes can evolve and determination of number of shops in each route Number of outlets covered = n*r n=maximum possible number of routes and r is the number shops per route	The quantity sold= k= = p*q n= number of routes and r is the number shops per route p= number of products and q is the quantity per product Assume that the vendor is supplying in bundles of q units of each product and there are p products for that vendor.
Population of bats:	Competition Among vendors	Substitution effect
The algorithm represents a population of "artificial bats" that move through the search space, each representing a potential solution.	FMCG market is a competitive market and hence the number of suppliers of same kind of products are high. All these vendors communicate with the independent vendors. If m is the number of competitors vendors of the same product in the region, average visit of vendors in each route = m*n*r m can be independent labels in each product assuming that each vendor deals with a single label per product	The quantity available for sales =m* n*r*k The number units sold will be based on the influence of retailers in pushing label of each product
Frequency tuning:	Frequency of visiting	Frequency of replenishment
Each bat has a "frequency" parameter that controls the search area, with	It is the frequency of the supply in each route. It	The frequency of each product depends on its rate

higher frequencies leading to wider exploration and lower frequencies focusing on specific areas.	depends on inventory velocity of the product. If the vendor is planning to maintain minimum average stock of t% and average rate sales s% Then number of visits will be f= $\frac{1-t}{1-s}$ For example, if the vendor keeps 20% minimum stock and rate of sales is 20% Them f= 1 per week If week is the replenishing period. Assume that each vendor replenishes at least once in a week, it will meet the planned replenishment requirements	of sale. Fast moving products will be replenished regularly.
Loudness:	Population density	Quantity consumed
Represents the intensity of the search, decreasing as a bat gets closer to a potential solution, signifying a more focused search.	The focus will be on quantity of sale. The routes will form linking maximum number shops that can sell maximum in the shortest route. As the capacity is fixed, the pareto principle is used, select 20% of the shops that can give 80% order value. As the value decreases, number of shops must increase proportionally.	80% of the value generated from 20% of the products, the importance will be given to that product. As the value per product decreases, then more products that can contribute more have to be introduced and maintained.
Pulse emission rate:	Identify the higher sales shop distinctive	Higher value generating products to be maximised
Controls how often a bat emits a pulse, increasing as it approaches a potential solution to refine its search.	The more the higher selling retail shops, the more the sale, but the capacity is a constrain	Importance can be given to those products with higher sales, but other products can be ignored

The challenge in Vendor Inventory Management is in understanding the competitor strategy and convince the agents. Also, the agents may not disclose the price or benefits.

BAT in Resource allocation

There are primely five resources, Labour, capacity, fund, and material, Time.

	Labour	Capacity	Fund	Material	Time
Echolocation simulation:					
The algorithm mimics how bats use sound waves to locate prey by adjusting the frequency and intensity of their echolocation pulses.	Skill shortage is the challenge faced in all industry and searching the right skill using social media and traditional methods. Right skill, attitude, and Knowledge. BAT algorithm helps to identify the right talent	Capacity constraint will be a challenge when demand exceeds available capacity and it will be a loss of sale and revenue. It is a need to search for opportunities for capacity expansion. It can be use of extra capacity available in other firms or assembling parts procured from other producers	Searching for fund so that cost of fund is less	Searching for material that can be used as a substitute to reduce cost and increase quality	Reduce cycle time through automation and increase productivity. Reduce receivables period and enhance trading cycle
Population of bats:					
The algorithm represents a population of "artificial bats" that move through the search space, each representing a potential solution.	Identify the best talent in the market through continuous research on performance of other performances and key performers	Identify the latest machinery and technology to restructure the process to enhance capacity	Identify the cost reduction strategies possible and modify the process	Identify the possible materials that can be used to improve products	Modernise the process and plant to meet future expectations
Frequency tuning:					
Each bat has a "frequency" parameter that controls the search area, with higher frequencies leading to wider exploration and lower frequencies focusing on specific areas.	Periodic evaluation of organizational and employee performance and frequency in performance audits improve overall performance	Frequency in capacity planning, capacity utilization audit and facility restructuring are important in optimizing the capacity utilization	Capital utilization has to be monitored continuously to avoid accumulation on performance assets	Adopting Lean and agility in material management	Enhance performance by reducing non-productive tasks and repetitions
Loudness:					

Represents the intensity of the search, decreasing as a bat gets closer to a potential solution, signifying a more focused search.	Optimise the employee productivity by focussing on key performance areas	Use capacity for unique and core part of process in producing product and outsource non-core activities	Allocate fund for research, innovation and product development to sharpen competitiveness	Outsource components or material that need more time for processing and increase cost	Calculate the value of productivity in monetary terms to reduce non productive times
Pulse emission rate:					
Controls how often a bat emits a pulse, increasing as it approaches a potential solution to refine its search.	Evaluate employee contribution, innovations and reward them with appropriate incentives	Evaluate peak capacity utility and transform excess capacity with outsourcing or increasing production	Identify the peak fund needed time and requirements	Identify the EOQ (economic Order quantity foe shorter period	Flexibility in timing to absorb higher job require,ents

FINDINGS, SUGGESTIONS, AND IMPLICATION

The findings show that there is an advantage in using BAT for distribution network. In the vendor Managed Inventory, the BAT concept can be used to generate routes, and increase number of shops in each route that the sale will be maximum and cost will be minimum.
In the case of resource utilization, The BAT protocol is useful in optimizing the resource utilization and reduce cost.

CONCLUSION

By applying the BA, the significant supply chain issues have been resolved optimally, including inventory management, demand planning, distribution channels, and dispatch. It is therefore suitable for supply chain systems due to aspects of its functionality that enables it to balance between localism and globalization. This characteristic about the BA means that multi-objective optimization is possible within the system, which is better because it entails more sustainable and functional solutions; following characteristics are optimized; frequency, loudness, pulse rate. The various works of literature and case studies have shown how application of BA the supply industries have enhanced the performance of the supply chain, and resource utilization has enhanced the supply chain performance and gear down the expenses to the bare minimum.

FUTURE RESEARCH SCOPE

This study provides the basis for future advances in the use of BA to supply chain management. The enhancement of the resilience, sustainability, and efficiency. For complex, extended, and multiple objective SCM problems, the exploration and exploitation of BA can be improved by integrating it with other metaheuristic algorithms. Three application areas in which the integration of BA with AI and machine learning models can improve real-time decision making are adaptive planning, risk assessment, and demand forecasting. Thus, BA may well be a significant driver of sustainable supply chain management since it actively works to shrink carbon footprints and optimise resource intake. The usage in risk management, closed supply chain system, and real-time optimization also enhances the robustness of supply chain. In addition, the use of Blockchain technology with BA enhances it and improves on its transparency, while the scalability may support a broad supply chain network. Better supply chain coordination and effectiveness leading to decentralized, autonomy SCM shall be realized when BA is integrated with multi-agent systems. BA is claimed to play a strategic role as a key driver to flexible, resilient, and sustainable supply management.

Conflict Of Interest

All authors declare that they have no conflict of Interest.

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