**Harnessing the Slime Mould Algorithm: Optimizing Supply Chain Logistics**

A close-up of a tree bark

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**Course: SCH-MGMT 663**

**ANAND GUPTA**

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**What is a Cognitive Supply Chain?**

Technological breakthroughs such as the Internet of Things (IoT) and Artificial Intelligence (AI) are changing the way we live and work, and traditional supply chains are no exception. Traditional supply chains, which rely on human operations, struggle to keep up with the demands of the modern market. The complexity and pace of modern commerce quickly overwhelm the procedures utilized 10 years ago for inventory balancing and forecasting.

Digital technologies allow for the gathering, storage, processing, and sharing of massive volumes of data, increasing efficiency at every stage of the supply chain. Automation of processes enables supply chain managers to cut costs, enhance throughput, and give firms with the information they need to respond in real time to quickly changing market conditions (SPRINT LOGISTICS, 2019)

The integration of cognitive analytics and metaheuristic algorithms has significantly transformed supply chain logistics. A cognitive supply chain consists of four critical steps: prediction, planning, control, and sharing. These stages use cognitive analytics to forecast demand, allocate resources, manage operations, and communicate essential information throughout the supply chain network.

The term “**Metaheuristics**,” which was first coined by Glover in 1986, comprises two words *meta* and *heuristic*. The term is derived from the Greek verb (heuriskein), whose meaning is ‘to find.’ A metaheuristic algorithm is a search procedure designed to find a good solution to an optimization problem that is complex and difficult to solve to optimality. It is imperative to find a near-optimal solution based on imperfect or incomplete information in this real-world scenario of limited resources, such as computational power and time. The emergence of metaheuristics for solving such optimization problems is one of the most notable achievements of the last two decades in operations research (Metaheuristics in Optimization: Algorithmic Perspective, 2020).

Metaheuristic algorithms hold an elevated position among academic researchers in various fields, such as science and engineering, for solving optimization problems and providing the most optimal solutions. One such innovative algorithm is the **‘Slime Mould Algorithm (SMA),’** which is inspired by the foraging behavior of the **‘*Physarum Polycephalum’***commonly known as‘Slime Mould.’ The SMA has several new features with a unique mathematical model that uses adaptive weights to simulate the biological wave, providing an optimal pathway for connecting food sources with high exploration and exploitation ability. Since its development, SMA has been widely researched and applied in various scientific fields, showing enormous potential in solving complex optimization problems.

This report investigates this metaheuristic algorithm, Slime Mould Algorithm (SMA) from different optimization aspects. The SMA algorithm was inspired by the fluctuating behavior of slime mould in nature. It has several new features with a unique mathematical model that uses adaptive weights to simulate the biological wave. It provides an optimal pathway for connecting food sources with high exploration and exploitation ability.

As of 2020, many types of research based on SMA have been published in various scientific databases, including IEEE, Elsevier, Springer, Wiley, Tandfonline, MDPI, etc. According to the findings, it can be claimed that SMA has been repeatedly used in solving optimization problems. As a result, this paper will be beneficial for engineers, professionals, and academic scientists.

**METHODS / ANALYSIS**

**Algorithm Overview**

**Selection of Algorithm**

The Slime Mould Algorithm (SMA) is based on the foraging behavior of the slime mould Physarum Polycephalum. This creature is notable for its ability to locate the shortest way to food by dynamically modifying its vein network. In supply chain logistics, SMA is utilized for tasks including vehicle routing, resource allocation, and network design. The algorithm’s biological inspiration enables it to handle complicated optimization problems using decentralized, adaptable, and self-organizing behaviors.

**Specific Use**

The SMA is especially useful for vehicle route planning, as it assists in establishing the most efficient paths for delivery trucks, ensuring the shortest trip distance and time while fulfilling various restrictions including vehicle capacity and delivery windows.

**How The Algorithm Works**

**Formulaic Summary**

The SMA mimics the slime mould's capacity to discover efficient paths to resources. The algorithm consists of several critical steps:

**Initialization:** A population of slime mould agents is randomly distributed over the problem space. These agents indicate viable solutions to the optimization problem.

**Fitness Evaluation:** Each agency assesses its fitness using distinct criteria, such as limiting trip distance or cost. This examination helps to discover which paths are more efficient.

**Position Update:** Agents update their positions using a combination of attraction to ideal pathways and repulsion from suboptimal ones. This process includes:

* **Chemotaxis:** Movement towards higher concentrations of a virtual pheromone, simulating the slime mould's attraction to food sources.
* **Avoidance:** Movement away from areas with lower pheromone concentrations or obstacles.

**Convergence:** The method iteratively changes the agent placements until they reach an optimal or near-optimal solution. This convergence is determined by a predetermined criterion, such as a maximum number of iterations or an improvement threshold.

**Solution Extraction:** The optimal solution discovered by the agents is extracted and assessed against the optimization objectives.

The SMA's decentralized design enables it to respond to dynamic changes in the environment, making it ideal for real-time logistics applications.

**Data inputs**

To work properly, the SMA needs many critical data inputs:

**Depot and customer locations:** Geographic coordinates or addresses used to identify nodes in the logistics network. This information is critical for mapping out the supply chain.

**Distance or trip time:** Metrics reflecting the cost of traveling between locations, frequently based on maps or transportation data. These indicators are used to assess the effectiveness of various routes.

**Vehicle capacities:** The maximum weight that a vehicle can transport, which is important for route design. This ensures that the algorithm produces feasible solutions that do not exceed the vehicle's constraints.

**Customer demand:** The quantity of goods each customer requires, which must be matched with vehicle capacities. This data helps the algorithm allocate resources effectively.

**Delivery time windows:** Specific time periods during which deliveries must be made, adding a temporal constraint to the optimization problem. This ensures that solutions adhere to customer schedules (National Library of Medicine, 2023).

**Results**

**Slime Mould Algorithm**

A diagram of a method

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Figure 1: Methods of SMA

The SMA is a population-based meta-heuristic algorithm recently introduced by Li et al. The SMA takes on the shape of the acellular Slime Mould Physarum polycephalum while actively searching for a source of nutrition. What follows, 𝑃ℎ𝑦𝑠𝑎𝑟𝑢𝑚 𝑝𝑜𝑙𝑦𝑐𝑒𝑝ℎ𝑎𝑙𝑢𝑚 will be referred to as "Slime Mould". It is a complex amoeboid structure of interconnected tubes that carry cytoplasm throughout the organism. Slime Mould can do this because of its unusual anatomy, which allows it to construct complex networks of veins between its many food sources, allowing it to feed on all of them at once. After locating a food supply, Slime Moulds’ biochemical oscillator sends contraction waves across the venous system, resulting in tubular veins flowing with the cytoplasm. The velocity of cytoplasmic streaming is related to the vein's wall thickness. Therefore, as the rate of cytoplasmic streaming increases, the vein thickens; when it decreases, the vein thins. The Slime Mould relies on positive and negative input to find its way to food sources. Detailed explanations of the suggested mathematical model and procedure will be provided in this section. (A survey of recently developed metaheuristics and their comparative analysis, 2023).

**Approaching Food**

The Slime Mould Algorithm (SMA) is inspired by the way the slime mould organism approaches food by following its odor. This behavior is modeled using mathematical formulas. Here is a simplified explanation of how these formulas work.

A diagram of a diagram of a sun

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Figure 2: Approaching Food

A diagram of a sound wave

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Figure 3: Variations vs Iterations

**Equation 1: Movement Towards Food**

**𝑋⃗(𝑡+1) = 𝑋⃗𝑏(𝑡) + v⃗b × (𝑊⃗× 𝑋⃗𝐴(𝑡) − 𝑋⃗𝐵(𝑡)) when 𝑟<𝑝**

**v⃗c × 𝑋⃗(𝑡) when 𝑟≥𝑝**

This equation describes how the slime mould moves towards food:

* X⃗(t+1) is the new position of the slime mould.
* 𝑋⃗𝑏(𝑡) is the position with the highest odor concentration (best solution found so far).
* v⃗b​ is a parameter that can vary between -1 and 1.
* v⃗c decreases linearly from 1 to 0 over time.
* W⃗ is the weight of the slime mould.
* X⃗A(t) and X⃗B(t) are two randomly chosen positions from the slime mould population.
* X⃗(t) is the current position of the slime mould.
* ‘r’ is a random value, and ‘p’ is a probability calculated as follows:

**Equation 2: Probability p**

**p = tanh ∣ S(i)−DF ∣**

This equation calculates the probability p:

* DF is the best fitness value found so far.
* S(i) is the fitness value of the current position X.
* ‘i’ ranges over the entire population of slime mould positions.

**Equation 3: Parameter v⃗b**

**v⃗b = [−a⋅a]**

**Equation 4: Parameter a**

**a = arctanh (−(t/max\_t) +1)**

These equations define the parameter v⃗b​:

* t\_max is the maximum number of iterations.
* ‘t’ is the current iteration.

**Equation 5: Weight W⃗**

**𝑊⃗ (𝑆𝑚𝑒𝑙𝑙 𝐼𝑛𝑑𝑒𝑥(𝑖)) = 1+𝑟·𝑙𝑜𝑔({(𝑏𝐹−𝑆(𝑖))/(𝑏𝐹−𝜔𝐹)} + 1) 𝑐𝑜𝑛𝑑𝑖𝑡𝑖𝑜𝑛**

**1−𝑟·𝑙𝑜𝑔({(𝑏𝐹−𝑆(𝑖))/(𝑏𝐹−𝜔𝐹)} + 1) 𝑜𝑡ℎ𝑒𝑟𝑠**

This equation calculates the weight W⃗:

* Index(i) is the rank of the fitness value S(i).
* ‘F’ is the worst fitness value in the current iteration.
* ‘bF’ is the best fitness value in the current iteration.
* ‘r’ is a random value between 0 and 1.

**Equation 6: Sorting Fitness Values**

**Smell Index = Sort(S)**

This equation sorts the fitness values in ascending order.

**Wrap Food**

The Slime Mould Algorithm (SMA) models the way a slime mould's venous tissue contracts when it is seeking food. When the slime mould consumes more food, its bio-oscillator generates a stronger wave, causing the cytoplasm to move faster and making the veins more prominent. This behavior is captured by the positive and negative feedback loops between the slime mould's vein diameter and the food content it is exploring, as described by Equation 5.

In Equation 5, the variable ‘r’ represents the unpredictability of the venous contraction mechanism. The logarithmic function is used to slow the rate of change in the contraction frequency, ensuring that the frequency does not fluctuate drastically. The algorithm simulates the slime mould's behavior by adjusting its foraging strategies based on the quality of the food it encounters.

When there is an abundance of food in the vicinity, the weight of the area increases, indicating a higher significance. Conversely, when food is scarce, the significance of the region decreases, prompting the slime mould to shift its focus to other areas. This adaptive behavior allows the slime mould to efficiently explore and exploit food resources.

The process for determining the slime mould's fitness values, which measure the effectiveness of its foraging strategies, is illustrated in Figure.

A diagram of a diagram

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Figure 4: Wrapping Food

**Equation 7: Updated Position of Slime Mould**

Based on the theory presented earlier, the formula for the mathematical approach used to update the position of slime mould is specified as Equation 7.

**𝑋∗ = 𝑟𝑎𝑛𝑑. (𝑈𝐵−𝐿𝐵) +𝐿𝐵 when 𝑟𝑎𝑛𝑑 < 𝑧**

**𝑋⃗𝑏(𝑡) + v⃗b × (𝑊⃗× 𝑋⃗𝐴(𝑡) − 𝑋⃗𝐵(𝑡)) when 𝑟<𝑝**

**v⃗c × 𝑋⃗(𝑡) when 𝑟≥𝑝**

The bottom and upper bounds of the search range are represented by the symbols LB and UB in Eq. 7, respectively. In addition, rand and r stand for the value chosen randomly from the range [0,1]. During the phase of the experiment devoted to modifying the parameters, we will have a conversation about the significance of the value z.

**Oscillation**

The value of v⃗b oscillates in a random manner between [−a,a] and gradually approaches zero with more iterations. The value of v⃗c oscillates among [-1, 1] and converges to zero eventually (National Library of Medicine, 2023).

**How It Works**

A diagram of a program

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Figure 5: Working Principle of SMA

1. **Initialization**: The algorithm starts by randomly placing multiple agents (representing slime moulds) in the problem space.
2. **Fitness Evaluation**: Each agent evaluates its position based on how close it is to the optimal solution (food source), determined by a fitness function.
3. **Position Update**: Agents adjust their positions based on the detected odor (fitness value) using the above formulas. They move towards better solutions while exploring the solution space in all directions.
4. **Convergence**: The process continues until the algorithm converges on the best solution or reaches the maximum number of iterations.

**Visualization**

**A diagram of food and food

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Figure 6: Visualization of the Whole Process

* As the agents move, they create a pattern that resembles the slime mould's search for food in a three-dimensional space.
* The use of the \arctanh\arctanh function allows the agents to explore the solution space in various directions, improving the chances of finding the optimal solution.

By using these equations, the SMA effectively simulates the natural behavior of slime moulds, making it a powerful tool for solving complex optimization problems in supply chain logistics (National Library of Medicine, 2023).

**Value to Supply Chain Logistics**

Implementing the SMA in supply chain logistics can lead to significant benefits, including reduced transportation costs, improved routing efficiency, and enhanced adaptability to changes. By dynamically adapting to changes in the network, the SMA can optimize routes in real-time, ensuring that deliveries are made in the most efficient manner possible.

**Cost Reduction:** The SMA's ability to find the shortest and most efficient paths reduces overall transportation costs. This is particularly important for logistics companies looking to minimize expenses and maximize profitability.

**Efficiency Improvement:** The algorithm's iterative process ensures that routes are continuously optimized, leading to improved delivery times and resource utilization. This results in faster deliveries and better customer satisfaction.

**Adaptability:** The SMA's decentralized nature allows it to adapt to real-time changes, such as traffic conditions, vehicle breakdowns, and varying customer demands. This adaptability is crucial for maintaining efficiency in dynamic and uncertain environments.

**Scalability:** The SMA can handle large-scale problems with numerous variables, making it suitable for complex logistics networks involving multiple depots, vehicles, and customer locations.

**Robustness:** The algorithm's decentralized approach makes it robust to disruptions and uncertainties, such as sudden demand changes or route blockages. This robustness ensures that the supply chain remains resilient under various conditions.

**Sustainability:** By optimizing routes and reducing travel distances, the SMA contributes to lower fuel consumption and greenhouse gas emissions. This supports environmental sustainability initiatives and helps companies meet regulatory requirements.

**Case Studies/ Examples**

**Case Study 1: Tokyo Rail Network**

Talented and dedicated engineers spent countless hours designing Japan’s rail system to be one of the world’s most efficient. Could have just asked a slime mold.

When presented with oat flakes arranged in the pattern of Japanese cities around Tokyo, brainless, single-celled slime molds construct networks of nutrient-channeling tubes that are strikingly like the layout of the Japanese rail system, researchers from Japan and England report Jan. 22 in *Science*. A new model based on the simple rules of the slime mold’s behavior may lead to the design of more efficient, adaptable networks, the team contends (Wired, 2022).

**Case Study 2: Optimizing Urban Transport Networks**

Researchers have applied the Slime Mould Algorithm (SMA) to model and optimize urban transport networks, drawing inspiration from the slime mould's ability to efficiently connect food sources. In a notable study, scientists used *Physarum polycephalum*, a type of slime mould, to model the Tokyo rail system. By placing food sources (represented by oatmeal flakes) on a Petri dish, the slime mould grew and established connections that mimicked the city's rail network. This experiment demonstrated the slime mould's capability to identify the most efficient routes between points, which has significant implications for optimizing supply chain logistics in urban environments (Tero et al., 2010).

Further studies have extended this approach to mapping global trade routes and national motorway networks. For instance, researchers compared the efficiency of 14 countries' motorway systems using slime mould. The findings revealed that countries like Belgium, Canada, and China had transport networks most like the slime mould's model, indicating high efficiency. In contrast, the US and Africa were found to have less efficient networks (Adamatzky & Jones, 2014). This application of SMA in transport planning highlights its potential to identify optimal routes, reduce congestion, and improve overall efficiency in supply chain logistics.

**Case Study 3: Dynamic Traffic Management**

The dynamic nature of the Slime Mould Algorithm allows it to adapt to changing conditions, making it a valuable tool for managing real-time disruptions in supply chains. In practical applications, researchers have simulated road crashes and flooding by introducing salt to specific points on the slime mould's network model. Salt is toxic to the slime mould, causing it to retract and reroute around the affected areas. This behavior strengthens alternative routes and provides insights into potential traffic planning contingencies (Adamatzky & Jones, 2014).

Such dynamic modeling can be crucial for supply chain managers who need to respond to unexpected disruptions. By using SMA, they can simulate various scenarios and develop robust strategies to maintain the flow of goods even in adverse conditions. This capability ensures continuity in supply chains, reduces downtime, and enhances resilience against disruptions.

**Case Study 4: Predictive Adaptation to Regular Events**

One of the most intriguing aspects of the slime mould's behavior is its ability to anticipate changes in its environment. In a study conducted by researchers at Hokkaido University, slime moulds were subjected to low temperatures and dry air every 30 minutes. Even after the adverse conditions were removed, the slime moulds continued to slow their growth rate in anticipation of the next stimulus (Saigusa et al., 2008). This predictive adaptation can be leveraged in supply chain logistics to model and prepare for regularly occurring events, such as rush hours or seasonal demand fluctuations.

By incorporating SMA into supply chain management systems, businesses can develop predictive models that adjust logistics operations based on historical data and anticipated trends. This proactive approach enables companies to optimize inventory levels, streamline distribution processes, and enhance overall efficiency. The slime mould's predictive capabilities offer a novel way to improve the responsiveness and adaptability of supply chains in dynamic market environments.

**Case Study 5:** A food delivery service implemented the SMA to optimize its delivery routes. By continuously adapting to traffic patterns and order volumes, the service reduced its average delivery time by 20% and decreased its fuel costs by 15% (Case Study: Route Optimization Leads to Shared Savings, 2024).

**Other Application Areas**

Until now, the SMA has solved several real-world optimization problems in science and industry better than many competitive algorithms.

* The SMA has been used to optimize the Artificial Neural Network Model for Prediction of Urban Stochastic Water Demand (MDPI, 2020).
* The SMA has been employed to estimate the solar photovoltaic cell parameters (Science Direct, 2020).
* The SMA integrated with other population-based solver to overcome ISP for COVID-19 chest X-ray images (Applied Soft Computing, 2020)
* In another experiment, results show that SMA can solve some problems in optimal model parameters of solar PV panels(Sustainable Energy Technologies and Assessments, 2020).
* In a study, SMA integrated with chaos solved an SVR-based prediction approach that is presented based on the K-means clustering (IEEE Explore, 2020).

**SMA Algorithm: Advantages and Disadvantages**

|  | **Factors** |
| --- | --- |
| **Advantages** | Easy to implement, with few parameters to set |
| Superior efficiency in solving optimization issues |
| For identifying optimum values, SMA is a fierce competitor |
| Excellent convergence characteristics and cheap power production |
| High-quality of solutions |
| balance rule between exploration and exploitation |
| short computational time |
| Helpful to the balance between global search and local search |
| The SMA optimizes convergence, decision-making, and precision during foraging |
| Prevent the premature convergence |
| Getting quality outcomes faster |
| Accelerated process in finding excellent solutions |
| The varied characteristics of the population |
| **Disadvantages** | Complex issue exploitation |
| Getting stuck into local minimum regions |
| Problem magnitude increases iteration |

**Conclusion**

The **Slime Mould Algorithm (SMA)** is a game-changing strategy to optimize supply chain logistics that draws inspiration from the slime mould Physarum polycephalum's natural foraging activity. The SMA can effectively solve complicated optimization issues like vehicle routing, resource allocation, and network design by utilizing adaptive weights and a decentralized, self-organizing process.

Implementing SMA in supply chain logistics provides numerous important benefits, including cost savings, increased efficiency, adaptability, scalability, robustness, and sustainability. The algorithm's capacity to flexibly respond to real-time changes, such as traffic conditions and changing client needs, keeps supply chains resilient and efficient.

Case studies, such as enhancing urban transportation networks and dynamic traffic management, demonstrate the practical applications and benefits of SMA. These tests show that the algorithm can improve routing efficiency, minimize congestion, and boost overall supply chain performance.

Despite its advantages, SMA has some drawbacks, including the possibility of becoming stuck in local minima and increasing processing needs for bigger issue sizes. However, continued research and revisions can overcome these issues, hence improving the algorithm's capabilities.

The Slime Mould Algorithm offers a promising approach to optimizing supply chain logistics. Several types of research published in SMA per year (in a graphical form) are presented in the Figure. In 2020, there were 18 papers on SMA published. Figure shows that the percentage of schools using SMA has grown over time.

A graph with numbers and a number of papers

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Figure 7: Scope of SMA based on Published Research

By mimicking natural foraging behaviors, it provides robust solutions to complex routing problems. The algorithm's ability to dynamically adapt to changes and uncertainties makes it particularly valuable in the ever-changing landscape of supply chain logistics. Future research could focus on further refining the algorithm and exploring its application in other areas of logistics and beyond.

In conclusion, the Slime Mould Algorithm is a potential and creative technique for optimizing supply chain operations. Its natural-inspired approach delivers strong and adaptive solutions to complicated routing difficulties, making it an invaluable tool in today's ever-changing commercial context. Future study should focus on refining the algorithm and exploring its applicability in a variety of logistics and operational areas, revealing new opportunities for efficiency and effectiveness in supply chain management.

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